Helium isotope variations along mid-ocean ridges: mantle heterogeneity and melt generation effects

D.W. Graham

College of Oceanic & Atmospheric Sciences, Oregon State University, Corvallis, OR 97331 USA

Introduction

Mid-ocean ridge basalts (MORB) are characterized by $^3He/^4He$ ratios between 6–9 R_A (R_A is the atmospheric ratio of 1.39×10^{-6}). This study compares helium isotope ratios for MORB from a variety of ridges around the world, but focuses primarily on two areas which have been studied in detail; the East Pacific Rise from 5–16°N, and two ridge segments at 26°S and 33°S on the Mid-Atlantic Ridge. Systematic relationships exist in these areas between helium and other isotope systems such as strontium and lead. Also, an inverse correlation exists between spreading rate and the variance of He isotopes for most ridges away from the influence of high ^3He hotspots such as Iceland and Easter.

East Pacific Rise

Variations of $^3He/^4He$ along the East Pacific Rise fall in a narrow range of 7.6–8.8 R_A. Rare alkali basalts erupted on or close to the ridge have lower ratios than associated tholeiites. In contrast, lavas from the Lamont Seamounts at ~10°N have systematically higher $^3He/^4He$ ratios than the adjacent ridge. Helium isotope characteristics do not change across the Clipperton transform, similar to Sr and Pb isotopes. However, north of the overlapping spreading center at 11°45'N many of the basalt glasses are E-MORB and display enrichment in lithophile elements such as the light rare earths. A change in isotope characteristics occurs in this region, with more radiogenic (lower) $^3He/^4He$ ratios to the north.

Collectively, there is an overall trend of decreasing $^3He/^4He$ with increasing Ti_8 for East Pacific lavas. The lowest $^3He/^4He$ ratios and highest values of Ti_8 are found in the rare alkali basalts, and in some E-MORB to the north of 11°45'N. The highest values of $^3He/^4He$ and lowest values of Ti_8 are found in the *LREE*-depleted Lamont Seamount basalts and in some N-MORB from south of 11°45'N. In a general way, partial melting of mantle peridotite which contains variable amounts of pyroxenite (Prinzhoffer *et al.*, 1989) explains these observations. U and Th in peridotite are primarily located in clinopyroxene, and consequently this is where a substantial portion of radiogenic He in the upper mantle is produced. Variations in TiO_2 of parental MORB magmas (Ti_8) are most plausibly attributed to partitioning between clinopyroxene and melt during partial melting; parental magmas that contain more of a pyroxenite component will be enriched in ^4He, *LREE* and TiO_2. Part of the $^3He/^4He$ variations in the East Pacific therefore appear to be related to melting of pyroxenite-rich zones in the underlying mantle.

South Atlantic

Much of the range in ^4He isotopes previously observed along the Mid-Atlantic Ridge between 2–47°S (Graham *et al.*, 1992) also occurs over a distance of less than 300 km at 33°S. The $^3He/^4He$-$^{206}Pb/^{204}Pb$ negative covariation for the 33°S region is remarkable, with a correlation coefficient of 0.95 (Hanan *et al.*, 1992). The 26°S data set shows a similar, but more restricted He-Pb alignment, but with some slightly higher $^3He/^4He$ ratios near the midpoint of the $^{206}Pb/^{204}Pb$ range. Those MORB samples from 26°S which lie above the He-Pb trend are from areas near fracture zones and ridge axis discontinuities, where the magmas are generated deeper and at lower degrees of partial melting (Batiza *et al.*, 1988). These samples with slightly higher $^3He/^4He$ ratios also have the same Pb isotope compositions as several off-axis seamounts (Castillo and Batiza, 1989). The seamount glasses from this region actually have $^3He/^4He$ ratios ranging up to 11 R_A, significantly higher than typical MORB values. This is the first known occurrence of such elevated $^3He/^4He$ ratios in the South Atlantic north of 47°S. $^3He/^4He$ is also positively correlated with $^{87}Sr/^{86}Sr$ in this suite of seamount glasses ($r^2 = 0.99$). The high $^3He/^4He$ ratios (9–11 R_A, n=6) are found at seamounts from both sides of the ridge, but are absent from the present-day ridge axis. These results are consistent with formation of these seamounts at or near the ridge, in association with rift propagation and temporal evolution of the Moore discontinuity (Carbotte *et al.*, 1991).

Helium isotope variability in MORB

Variability in $^3He/^4He$ (represented by the population standard deviation) along spreading centers increases with decreasing spreading rate, once the effects of contamination by nearby high $^3He/^4He$ hotspots are taken into account. Similar observations have previously been made for Sr isotopes (Batiza, 1984; Holness and Richter, 1989). The increased variability is most readily discernible for spreading rates below 70 mm/year. The presently available data set ($\sim$390 analyses) allows only a first order attempt at investigating the possible trends; for example, the studied regions have been treated equally regardless of their length. A complete interpretation is further complicated by the possibility that the observed relationships between isotopic variability and spreading rate are not simply zero age phenomena; samples from the neovolcanic zones of faster spreading ridges naturally encompass shorter timescales. Nevertheless, the data indicate the worldwide presence of helium isotope heterogeneities in the upper mantle.

The upper mantle source of MORB is isotopically variable, sometimes locally on a scale comparable to the scale of magma generation. Enriched materials are also globally dispersed in the upper mantle, but in varying proportions beneath the respective ocean basins, as evidenced by Pb isotope systematics in MORB. Where these heterogeneities are more radiogenic in He and Sr isotopes, they may have their origin as reinjected crustal or lithospheric materials, which were isolated outside the upper mantle convective flow for long time periods (>1 Ga). Enriched heterogeneities may be more readily sampled by volcanism at slow spreading ridges either because magma production rates are lower, or because mixing and homogenization within magma chambers is less extensive. For example, small, near-axis seamounts from the East Pacific (Graham *et al.*, 1988) and South Atlantic show diverse He and Sr-Nd-Pb isotope compositions, even adjacent to ridges where the isotopic variance is low. Alternatively, regional patterns in the isotopic variability of the upper mantle are linked to the history of subduction around the respective ocean basins. Slower spreading ridges (or younger ocean basins) may sample upper mantle regions which contain an intrinsically higher abundance of recycled 'blobs'; faster spreading ridges (or older ocean basins) sample upper mantle regions where these blobs have been effectively mined by volcanism, because the convecting upper mantle beneath these ridges is more distant from the sites of recycled input.

References

Batiza, R. (1984) *Nature*, **309**, 440.

Batiza, R., Melson, W. G. and O'Hearn, T. (1988) *Nature*, **335**, 428.

Carbotte, S. M., Welch, S. M. and Macdonald, K. C. (1991) *Mar. Geophys. Res.*, **13**, 51.

Castillo, P. and Batiza, R. (1989) *Nature*, **342**, 262.

Graham, D. W., Zindler, A., Kurz, M. D., Jenkins, W. J., Batiza, R. and Staudigel, H. (1988) *Contrib. Mineral. Petrol.*, **99**, 446.

Graham, D. W., Jenkins, W. J., Schilling, J.-G., Thompson, G., Kurz, M. D. and Humphris, S. E. (1992) *Earth Planet. Sci. Lett.*, **110**, 133.

Hanan, B. B., Graham, D. W., Michael, P. J. and Schilling, J.-G. (1992) *EOS*, **73**, 582.

Holness, M. B. and Richter, F. M. (1989) *J. Geol.*, **97**, 247.

Prinzhoffer, A., Lewin, E. and Allègre, C. J. (1989) *Earth Planet. Sci. Lett.*, **92**, 189.