Helium and argon poor magmas from the undegassed mantle

A. Jambon — Laboratoire Magie, Université P. et M. Curie (Paris 6) 75252 Paris Cedex 05, France

P. Gillet — Institut Universitaire de France, Laboratoire de Sciences de la Terre, ENS LYON, 46 allée d'Italie, 69364 Lyon cedex 07, France

E. Chamorro
N. Coltice — Laboratoire de Sciences de la Terre, ENS LYON, 46 allée d'Italie, 69364 Lyon cedex 07, France

The helium paradox

Isotopic signatures of He and Ne in basalt glasses and phenocrysts require that the OIB source has retained a fair amount of primordial gases whereas the MORB source is extensively outgassed according to its mostly radiogenic composition. Unexpectedly, all basalt glasses recovered from oceanic islands (seamounts) exhibit low noble-gas contents when compared to MORB glasses erupted at similar depths. This feature cannot be explained by extensive late outgassing specific to OIB according to a number of evidences. ^{3}He/^{4}He *vs* ^{87}Sr/^{86}Sr plots for instance, confirm that OIB primary magmas contain less helium than MORB (Kurz *et al.* 1982), the extent of late magma degassing being irrelevant in that case. The ^{4}He/^{40}Ar ratio of OIB glasses (about 5 ± 3) is close to the radiogenic production ratio in the mantle (about 2), while degassing strongly fractionates the two elements as observed in MORB glasses. The observation that samples derived from a presumably gas rich source contain only small amounts of gas compared to the degassed source derived MORB, is referred to as the He paradox.

Depth of melting and He isotopes in Hawaii

Basalt glasses from Hawaii (Loihi, Kilauea, Mauna Loa, Hualalai, Haleakala) are particularly well documented. Because of its location far away from any spreading center this island offers the best opportunity to characterize the differences in rare gas content and isotopic ratios between the two types of basalts.

Correlations between ^{4}He or ^{40}Ar abundances, ^{4}He/^{40}Ar and ^{4}He/^{3}He isotopic ratios are observed which demonstrate that late outgassing effects do not overprint the signature of the source. The changing nature of the magmatic source is documented by a regular evolution in space for Loihi, Kilauea, Mauna Loa and a time-evolution for Mauna Loa. In all diagramms, the observed trend is clearly resolved from the MORB field even though He isotope ratios overlap with the MORB range.

From the correlation of He isotopes with Fe_8 (an index of the average pressure of melting; Klein and Langmuir, 1987) we infer that the undegassed component (high ^{3}He/^{4}He) is, on the average, melted at greater depth. It becomes progressively mixed at shallow depth with a depleted mantle component containing MORB type noble gases.

Variable compatibility with depth

The He paradox and all the above correlations can be understood if the solid/melt partition coefficients of noble-gases decrease with increasing pressure. This inference is supported by recent argon solubility measurements in melts at high pressure (up to 10 GPa) which show that argon solubility decreases dramatically in melts when the pressure exceeds 5 GPa (Chamorro-Perez *et al.*, 1998). According to the solubility model, a similar effect is expected for helium. Since at high pressure melts become more closely packed than silicate crystals, noble gases are expected to become less incompatible and even compatible at high pressure. As a result, melts generated at great depth will contain small amounts of noble gases. The observation that the mean melting pressure for OIB is significantly higher than for MORB supports this inference.

Geodynamical implications

The melting residue of OIB remains in the upper mantle and becomes ultimately mixed with it. As it carries a significant amount of primordial gases it may be the ultimate source of primordial noble gases in the extensively degassed upper mantle. In this case, the transfer of primordial noble gases from the undegassed mantle to the MORB source will not be a boundary layer process (e.g. specific transfer of noble gases through a boundary layer by diffusion). Decoupling of radiogenic noble gases from other radiogenic isotopes in oceanic basalts is in agreement with the model. We negate the existence of two kinds of hot spots (with primordial and radiogenic noble gases), all probably originating from a deep undegassed mantle. Radiogenic helium signatures are derived from significant interaction with a degassed lithosphere and/or the crust enriched in U and Th.

References

Chamorro-Perez, E., Gillet, P., Jambon, A. McMillan, P. and Badro J. (1998) *Nature*, in press.

Klein, E.M. and Langmuir, C.H., (1987) *J. Geophys. Res.*, **92**, 8089–115.

Kurz, M.D., Jenkins, W.J. and Hart, S.R.(1982) *Nature*, **297**, 43–7.