Noble gas systematics of Iceland: small scale investigation, large scale interpretation

D. Harrison
P. G. Burnard
G. Turner

Department of Earth Sciences, University of Manchester,
Manchester M13 9PL, UK

Iceland presents a unique opportunity for the study of mantle domain interactions and crustal evolution. The spatial and temporal concurrence of the Icelandic mantle plume with the North Atlantic spreading centre has produced a sub-aerial topographic high culminating in oceanic crust 9–16 km thick. Plume interaction with the North Atlantic N-MORB source is however debated and the presence of a depleted N-MORB signature in Icelandic magmatism is not universally accepted. Traditional Sr-Nd-Pb and trace element systematics offer conflicting viewpoints to this question.

Noble gas systematics of mantle derived samples are of major importance in the development of geochemical models concerning the evolution of the Earth=s atmosphere, crust and mantle. Helium isotope studies in particular have been instrumental to the development of the Alayered mantle@ models. More recently Sarda *et al.* (1988) and Honda *et al.* (1993) have refined these models by correlating neon and helium systematics and providing evidence for a solar-like origin for the primordial neon and helium budgets.

Previous noble gas studies of Iceland have concentrated on helium and argon systematics (along with volatile species) of both hydrothermal systems and volcanics associated with the neovolcanic zones. These studies have shown Iceland to be a high ^{3}He/^{4}He and high ^{40}Ar/^{36}Ar (>2000) hotspot (Kurz *et al.*, 1985 and Burnard *et al.*, 1994). The published ^{3}He/^{4}He ratios vary between 6R$_a$ and 27R$_a$.(R$_a$ = 1.38 × 10^{-6}) and show spatial provinciality. Kurz *et al.* (1985) modelled this provinciality using concentration ratios of plume/N-MORB and discounted crustal incorporation of radiogenic helium. The aims of this research are to model and quantify the noble gas systematics of the domains involved in the production of Icelandic magmatism on the Reykjanes Peninsula. This abstract will report preliminary data from an ongoing investigation. All analyses reported here are from step crushing experiments on glassy rinds from sub-glacially erupted picritic pillow basalts. In this abstract we report:

1. Neon isotope data for Iceland.
2. Noble gas parameters of the Icelandic mantle.
3. N-MORB mixing and/or crustal contamination influences on the ^{3}He/^{4}He ratios.

Results and discussions

^{20}Ne/^{22}Ne ratios vary between 9.8 and $ 13 and show a positive linear correlation with ^{21}Ne/^{22}Ne (Fig. 1). These data are interpreted as mixing between an atmospheric-like component (^{20}Ne/^{22}Ne = 9.8 and ^{21}Ne/^{22}Ne = 0.029) and a mantle component with solar-like ^{20}Ne/^{22}Ne and a ^{21}Ne/^{22}Ne $ 0.047. Neon and helium systematics are coupled. In neon isotope space the data define a gradient intermediate between arrays reported for Loihi (^{3}He/^{4}He ~ 27R$_a$) and MORB (^{3}He/^{4}He ~8R$_a$). This is consistent with similar time intergrated (U + Th)/^{22}Ne and (U + Th)/^{3}He for Iceland, Loihi and MORB.

^{40}Ar/^{36}Ar ratios vary from atmospheric-like values of ~340 to 6500 for individual crushing steps. Correlation of ^{40}Ar/^{36}Ar with ^{20}Ne/^{22}Ne allows an extrapolation of the trend to solar ^{20}Ne/^{22}Ne (Fig. 2).

In multi-isotope space the equation of the mixing plane (mixing hyperbola in Fig. 2) can be extrapolated to calculate a lower limit of ~ 7650 for the ^{40}Ar/^{36}Ar of the Icelandic mantle source. This is comparable to values reported from Loihi.

A plot of ^{3}He/^{36}Ar *vs* ^{40}Ar/^{36}Ar (not shown) forms a positive correlation trending from the ubiquitous atmospheric-like end-member upwards to a mantle point with high ^{40}Ar/^{36}Ar (6500) and high ^{3}He/^{36}Ar (~0.32). Extrapolation of this trend to the calculated mantle source ^{40}Ar/^{36}Ar of *c.* 7650 indicates a source region ^{3}He/^{36}Ar of ~ 0.36. No (or minimal) elemental fractionation of He and Ar in response to solubility controlled magmatic degassing is seen in these samples (^{40}Ar*/^{4}He ratios are between 0.3 and 0.6: similar to the calculated lower mantle accumulation production ratio). The ^{3}He/^{36}Ar of 0.36 is similar to

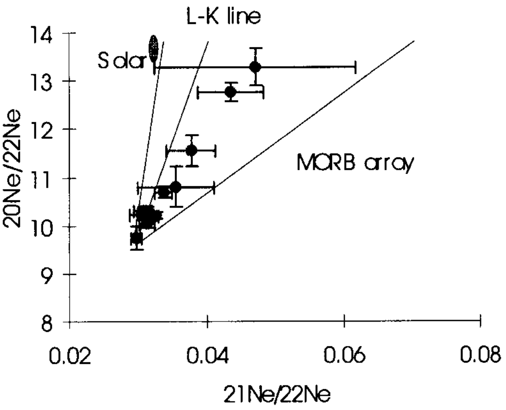

FIG. 1. $^{21}Ne/^{22}Ne$ *vs* $^{20}Ne/^{22}Ne$.

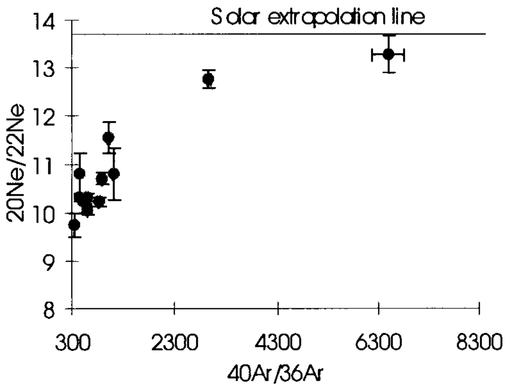

FIG. 2. $^{40}Ar/^{36}Ar$ *vs* $^{20}Ne/^{22}Ne$.

the value suggested by Valbracht *et al.* (1997) of 0.5 to 1.5 for the Loihi source but when compared to the solar value of *c.* 11 clearly suggests that the ^{36}Ar of the Icelandic mantle source is not solar in origin.

Further extrapolations to solar mantle values for $^{20}Ne/^{22}Ne$ give a mantle source $^{3}He/^{22}Ne$ of ~2.3 for this dataset. The is comparable to the calculated solar value of ~3.6. However published $^{3}He/^{22}Ne$ ratios for MORB and indeed Loihi range from 7 to 11. This discrepancy suggests an inconsistency with steady state models.

In a plot of $^{4}He/^{3}He$ *vs* $^{21}Ne/^{22}Ne$ extrap ($^{21}Ne/^{22}Ne$ extrap = data extrapolated to a solar value in order to discount atmospheric-like contamination; plot not shown) the Icelandic data (the high $^{3}He/^{4}He$ ratios of ~$17R_a$) falls onto a mixing line between a Loihi-like source and N-MORB. This mixing relationship has previously been described for southern hemisphere plume influenced volcanics (Moriera *et al.*, 1995).

Taking into consideration the geographical proximity of the samples analysed (a single fissure system) there exists a disparity in the measured $^{3}He/^{4}He$ ratios. The southern part of the fissure is characterised by $^{3}He/^{4}He$ ratios ~ $13R_a$ whereas the northern samples (some 6–7 km away) have $^{3}He/^{4}He$ ratios ~ $17R_a$. This disparity has been previously recognised in individual Icelandic samples between incorporated olivine xenocryst phases and their host glasses and ascribed to ingrowth of radiogenic helium within the olivines during crustal residence (Burnard *et al.*, 1994). Results from this study highlight a variation in the $^{3}He/^{4}He$ ratios along a fissure between glass phases. A heterogeneous mantle source (with varying N-MORB/plume concentration ratios) is not required to explain these data. Taking into account the neon-helium coupling described in Fig. 1 it is evident that a high (U + Th)/^{3}He contaminant is affecting the helium systematics over a small geographical range.

All $^{129}Xe/^{132}Xe$ ratios are atmospheric-like.

This abstract highlights and offers initial interpretations of an ongoing research project.

References

Burnard, P.G., Stuart, F.M. and Turner, G. (1994) *J. Geophys. Res.*, **99**, 17709–15.

Honda, M., McDougall, I., Patterson, D.B., Doulgeris, A. and Clague, D.A. (1993) *Geochim. Cosmochim. Acta.*, **57**, 859–74.

Kurz, M.D., Meyer, P.S. and Sigurdsson, H. (1985) *Earth Planet Sci. Lett.*, **74**, 291–305.

Moreira, M., Staudacher, T., Sarda, P., Schilling, J.G. and Allègre, C.J. (1995) *Earth Planet Sci. Lett.*, **133**, 367–77.

Sarda, P. Staudacher, T. and Allègre, C.J. (1988) *Earth Planet Sci. Lett.*, **91**, 73–88.

Valbracht, P.J., Staudacher, T., Malahoff, A. and Allègre, C.J. (1997) *Earth Planet Sci. Lett.*, **150**, 399–411.