Noble gases in the Cameroon line

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The Cameroon Line

The Cameroon line is an intraplate volcanic province straddling both oceanic and continental lithosphere. Recent lavas of the Cameroon line have radiogenic Pb, ranging up to a maximum of $^{206}Pb/^{204}Pb = 20.5$ at the continent-ocean crust boundary, similar to other HIMU lavas and indicative of source regions with high U/Pb (Halliday *et al.*, 1988). Plume impingement beneath the Gondwanan craton, immediately prior to Mesozoic rifting has been suggested as a means of generating symmetric spatial variability of Pb isotopic compositions along the volcanic chain. Another equally important aspect of the Cameroon line and other HIMU lava compositions is the distinct and uniform Sr, Nd, Hf and He isotopic compositions (Ballentine *et al.*, 1996). Excepting the lack of $^{206}Pb/^{204}Pb>21$, Cameroon line lavas are indistinguishable from other HIMU suites such as the Austral Islands and St. Helena, and are representative of HIMU source regions or processes leading to the development of HIMU compositions.

Results

Helium isotopic compositions of mafic lavas, ultramafic mantle and crustal xenoliths (in-vacuo crushing), and CO_2 spring gases are, with few exceptions, remarkably uniform along the entire Cameroon line. Neon isotopic data, from ultramafic xenoliths (in-vacuo crushing), and CO_2 spring gases deviate significantly from air and lie on an array that is coincident with or higher than the MORB array (Fig. 1), despite the same samples having helium isotopic compositions systematically more radiogenic than MORB. Assuming $^{21}Ne/^{22}Ne = 0.65$ and 6 Ra in the Cameroon source, a production ratio of $^{4}He/^{21}Ne = 10^{7}$ and solar intital ratios, the time integrated $^{3}He/^{22}Ne$ ratio is ~2.9. Argon isotopic compositions obtained by in-vacuo crushing for lava phenocrysts and xenolith phases range from atmospheric to $^{40}Ar/^{36}Ar = 4910 \pm 80$. Laser step-heating of single grains of the same materials yield ratios as high as $^{40}Ar/^{36}Ar$=16,290 ± 970.

Binary mixing

Mixing of upper mantle with recycled slab material has been proposed to explain the isotopic and trace element composition of OIB in the Austral Island chain (Chauvel *et al.*, 1992). However, binary mixing of MORB source mantle with highly radiogenic recycled material might be expected to produce a broad array of isotopic compositions tending toward production ratios for the noble gases. Such a prediction contrasts with the relative uniformity observed in data for the Cameroon line. Model calculations for closed system evolution of recycled basaltic crust over 2 Ga., followed by admixture of MORB source mantle by simple binary mixing indicate that the abundance of radiogenic gas (^{4}He, ^{21}Ne) in the recycled component is several orders of magnitude greater than can be accommodated by the isotopic constraints. The same conclusion is reached if the slab undergoes minor diffusive reequilibration.

Open system behaviour of helium and neon

Extensive diffusive exchange of helium with the

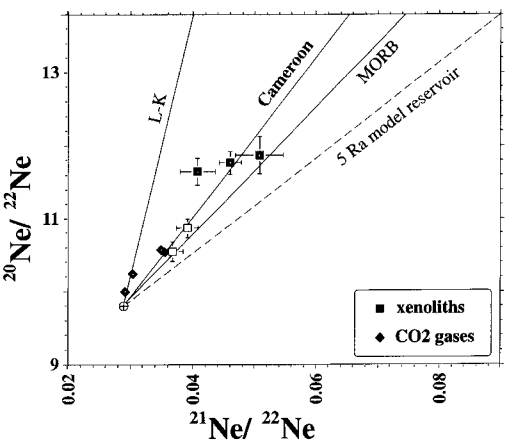

FIG. 1. Neon isotopic data from two ultramafic xenoliths and three CO_2 spring gases (with one replicate). Model 5 Ra line calculated assuming a time integrated $^{3}He/^{22}Ne = 3.8$.

ambient mantle has recently been proposed as a mechanism for generating HIMU sources with isotopic ratios of ~6.8 Ra (Hanyu and Kaneoka 1998). Their model calculations imply that recycled ocean crust must be attenuated to accommodate the length scale of diffusion. From this result they predict a length scale for the HIMU source region. Processes leading to slab attenuation are likely to produce a wide range of length scales in the mantle and when combined with variable but long storage times and variable parent element concentrations could result in a broad range of isotopic compositions, contrasting strongly with the uniformity of HIMU lavas. Additional uncertainty arises from the lack of knowledge regarding the combined pressure and temperature dependence of diffusion at high *P* and *T*.

Neon data from the Cameroon line place additional constraints on a diffusive equilibration model. Because the atomic volume of Ne is approximately twice that of helium, Ne diffusivity is lower than that of helium. If diffusive exchange of He is effective enough to bring the isotopic ratio of the recycled material to 5 Ra, the reequilibrated Ne isotopic composition would likely be more radiogenic than the MORB array, schematically represented by the 5 Ra model line in the figure. Also, as a result of the slower diffusion of Ne, the $^{3}He/^{22}Ne$ ratio would be high in the recycled material relative to the ambient mantle. This is the opposite of what is inferred for the Cameroon line source region.

MORB source isolation

Closed-system evolution of an isolated portion of MORB-source upper mantle provides another mechanism to produce the observed He and Ne isotopic compositions of the Cameroon line samples. The model calculations assume MORB-like initial isotopic compositions of 8 Ra and $^{21}Ne/^{22}Ne = 0.07$. Model parameters ($^{238}U/^{3}He$, $^{3}He/^{22}Ne$, and isolation time) were adjusted to achieve the compositions seen in the Cameroon data, i.e. MORB-like Ne ($^{21}Ne/^{22}Ne<0.08$) with radiogenic He at 6 and 5 Ra. Model results indicate that the data can only be reproduced with $^{3}He/^{22}Ne$ ratios less than 3.4 (6Ra) and 1.9 (5Ra). These estimated $^{3}He/^{22}Ne$ ratios are significantly lower than the lowest MORB estimates from Moreira *et al.* (1998) based on popping rock data. Evaluation of the time scale of radiogenic ingrowth for helium indicates a minimum $^{238}U/^{3}He$ of ~50 to achieve a decrease from 8 to 5 Ra over 1 Gy [$^{238}U/^{3}He$ of ~100 for 0.1 Gy]. This estimate of $^{238}U/^{3}He$ is several orders of magnitude lower than estimates for the upper mantle (O=Nions and Tolstikhin 1994), suggesting that the time scale of isolation is shorter than 10^{8} yrs. or that the source region of the Cameroon line is gas rich relative to MORB source mantle. The latter model is consistent with the model of Mesozoic plume impingement (Halliday *et al.*, 1988).

A closed system model for isolated MORB source mantle can account for the noble gas isotopic compositions within geologically reasonable time spans, but appears to require noble gas fractionation (helium depletion?). Linkage of the HIMU noble gas isotopic compositions to the MORB source region (via the pathway of short term isolation) is appealing given the fact that both reservoirs are isotopically uniform. However, the extremely radiogenic Pb in HIMU cannot easily be explained by short term (i.e. age of the lithosphere) isolation of MORB source mantle and must involve other reservoirs.

The argument against open system behaviour of the noble gases relies on the overall homogeneity of the observed HIMU isotopic compositions. Given our preliminary modelling, it appears to be difficult to achieve a realistic balance of processes that lead to a globally uniform HIMU reservoir. Long term preferential diffusive exchange on the order of kilometers within the mantle (Hanyu and Kaneoka 1998) would predict severe decoupling of the noble gas and lithophile trace element isotopic compositions. Although in some cases the lithophile isotopes appear to be poorly coupled to the noble gas isotopes, in many cases they are strongly correlated and long term differences in the geochemical behaviour of noble gases versus lithophile elements are unlikely. Nevertheless, given the problem of reconciling diffusive noble gas exchange with observed compositions, slab recycling cannot be easily accommodated by the HIMU noble gas isotopic data.

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