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Terrestrial Noble Gases-A Unique Indicator for the Chemical Structure and Evolution of the Earth

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Noble gases are chemically inert and behave as incompatible and volatile elements during magmatic processes. They include lighter (He, Ne) to heavier (Ar, Kr, Xe) elements, and have higher diffusivity compared to the other elements. Especially He has the highest one except for hydrogen. Noble gases have both radiogenic (^{4}He, ^{40}Ar, ^{129}Xe) including nucleogenic (*e.g.,* ^{21}Ne) and fissiogenic (*e.g.,* ^{136}Xe) and stable isotopes. By utilizing such characteristics, noble gases can give us unique information which cannot always be drawn from isotopes of solid elements.

Noble gases are degassed easily from a magma at a shallow depth. Hence, to get information on magmatic signatures, pillow glasses and mantle-derived xenoliths were mostly used initially for MORBs and lithospheric mantle materials. For subaerial volcanic rocks, however, it is necessary to get different phases which should be equilibrated with a magma. Olivine and/or pyroxene phenocrysts have been found to be useful for this purpose and they have been successfully used to demonstrate the difference of noble gas signatures between MORBs and OIBs.

MORBs show the relatively uniform ^{3}He/^{4}He of around 8Ra (1Ra: the ^{3}He/^{4}He of the atmosphere, 1.4×10^{-6}) with the high ^{40}Ar/^{36}Ar up to about 40,000. They also show the ^{129}Xe/^{130}Xe of up to around 8 (the ^{129}Xe/^{130}Xe of the atmosphere, 6.48). In the ^{20}Ne/^{22}Ne-^{21}Ne/^{22}Ne diagram, MORBs show a mixing trend between a magmatic component and the atmospheric one. On the other hand, typical OIBs show the ^{3}He/^{4}He higher than those of MORBs, though some OIBs show lower values. The ^{40}Ar/^{36}Ar of OIBs is systematically lower than those of MORBs. The ^{129}Xe/^{130}Xe of some Loihi and Iceland samples have been found to be higher than the atmopsheric value, but its highest value is lower than that of MORBs. In the ^{20}Ne/^{22}Ne-^{21}Ne/^{22}Ne diagram, OIBs show a steeper mixing trend between a magmatic component and the atmospheric value than those of MORBs at each site. Based on such noble gas signatures and the most depleted nature of the MORB source inferred, it has been considered that the OIB magma source retains more primordial noble gases than the MORB source. This implies that the OIB source is less degassed than the MORB source and the former is probably located in the deeper part compared to the latter. Such a model is compatible with the solid isotope data and supports the plume model of lower mantle origin. It should be noted, however, that only noble gas isotopes can designate the existence of relatively primitive parts in the mantle.

Recent seismic tomography suggests a possibility of slab penetration into the lower mantle. To explain it by a whole mantle convection model, inferred existence of the primitive mantle is a matter of troublesome issue. Hence, there have been trials to explain the occurrence of the high ^{3}He/^{4}He in OIBs by different models under various assumptions. They include the occurrence of the high ^{3}He/U due to remaining of ancient gases with no parent nuclides (U,Th) in the mantle, contribution of the depleted phase as a magma source without degassing, addition of ^{3}He from the core or incorporation of cosmogenic ^{3}He into the mantle through subducted slabs. If we consider physico-chemical properties of He (*e.g.,* fast mobility, low solubility in the metal, the low abundance in a depleted phase, *etc.*), however, none of such proposed hypotheses seem to succeed in explaining the observed data satisfactorily. It should be noted further that it is not only He but also all the other noble gas isotopes which support the less degassed state of the OIB magma source. It has been argued that OIBs do not contain larger amounts of He compared to MORBs (He paradox). In rocks or minerals, however, apparent concentrations of noble gases are controlled by many factors through magmatic processes. Hence, unless each magmatic process is evaluated properly for analyzed samples, it is insignificant to compare the apparent concentration of noble gases in samples statistically to infer the concentration in magma sources. In this respect, sample selection is quite important to get significant noble gas signatures by considering its geological and petrological circumstances.

In addition, most ^{40}Ar in the atmosphere has been explained by degassing of about a half of radiogenic ^{40}Ar accumulated in the Earth's interior for 4.5 b.y. Since He has higher mobility than Ar, this implies that the primordial He should be located in parts where radiogenic ^{40}Ar is retained. The deeper part in the lower mantle is the most likely part as the reservoir. Furthermore, the occurrence of excess ^{129}Xe in both the MORB and OIB magma sources suggests that the primordial components had not totally mixed with the atmospheric components and between each source since several hundreds of million years after the formation of the Earth. If the magma source of kimberlites is related to that of the plume source as inferred from the solid isotope data, kimberlites are expected to show similar noble gas signatures to those of Hawaii and Iceland samples. Our preliminary results for some kimberlites from Greenland support such a conjecture, indicating the definitely higher ^{3}He/^{4}He compared to the MORB values.