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Can atmospheric noble gases be recycled back into the mantle?

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It has long been considered that the atmospheric noble gases are not recycled back into the mantle due to an effective outgassing of the dehydrating slabs. However, we have recently found that there is an unusual correlation between the amounts of He-3 (= primordial in origin) and Ar-36 (= largely of atmospheric) in a series of ultramafic rocks collected at Horoman ultramafic complex, Hokkaido. The correlation can best be explained with the occurrence of primordial and recycled noble gases in the mantle. Ultramafic xenoliths from Australia and Europe and plume-related carbonatites from Russia are the samples also showing the correlated He-3 and Ar-36. Perhaps, the possible recycling of atmospheric noble gases might have been overlooked in previous studies.

Noble gases in subducting materials are believed to be returned back to surface through arc magmatism, leaving non-radiogenic noble gas in the mantle unaffected by the global cycle. However, some recent findings of correlated Pb-Ar isotopes in oceanic basalts suggests that recycling of air-Ar into the mantle is possible [1], but ambiguity still remains as shallow level contamination can be an alternative explanation [2]. Indeed, recycling of noble gas in the mantle is generally difficult to identify because the noble gas isotopic ratios expected for a recycled component are indistinguishable from those of the present atmosphere.

We have recently reported a clearer evidence for the presence of the noble gas recycling into the mantle [3], which is based on our noble gas investigation on alpine-type peridotites from the Horoman complex. The Horoman ultramafic rocks showed the He-3/He-4 and He-4/Ar-40na(=non atmospheric) ratios quite consistent with a MORB-like mantle component. Intriguingly, He-3 contents in the samples show clear positive correlation with their Ar-36, which holds over two orders of magnitude variation in gas amounts. The observed low Ar-40/Ar-36 ratios suggest that virtually all Ar-36 in the samples can be regarded as an atmospheric component. In contrast, because of very low abundance of He-3 in the terrestrial atmosphere, all He-3 observed can be assumed as a pure mantle component. The correlation between primordial and atmospheric components cannot be explained by shallow-level atmospheric contamination. Rather, we infer that an atmospheric component is of recycled origin which had introduced into the mantle by the subducting slab when the complex was at a mantle wedge setting. Infiltration of metasomatic fluid or melt produced in the mantle wedge above the subducting slab would result in fluid inclusions being formed with noble gas signatures like those observed in the samples. This would be the first compelling evidence that some fraction of recycled atmospheric noble gases derived from the subducting slab could have been preserved in the mantle without returning to the atmosphere through arc volcanism. Moreover, provided that the accretion of island arcs plays an important role in the post-Archean continental growth, it can be speculated that the recycled atmospheric argon could have been continuously incorporated into the subcontinental lithospheric mantle. In fact, similar He-3 and Ar-36 correlation can be found in the reported data from mantle xenoliths from Australia and Europe, indicating a long-term preservation of recycled air-Ar in the subcontinental mantle. Furthermore, even the plume-related Russian carbonatites showed the correlated He-3 and Ar-36. These observations indicate that the air-derived noble gases can also be involved in the global cycle which had been operated over the history of the Earth. The issue certainly has important implications for bettering our understandings on the origin of noble gas heterogeneity observed in mantle-derived samples.

References: [1] Sarda et al., Science 283, 666-668, 1999. [2] Burnard, Science 286, 871, 1999. [3] Matsumoto et al., Earth Planet. Sci. Lett. 185, 35-47, 2001