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Argon isotope mass fractionation to light isotope enrichment in volcanic rocks

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The basalt magma generated in the upper mantle must be in excess argon environment by the radiogenic 40Ar derived from 40K decay in the upper mantle as suggested from mantle-derived materials reported by Kaneoka and Takaoka (1980). In fact, the submarine basalts from the crest of the East Pacific rise give the older K-Ar ages up to 460 Ma (Funkhouser et al., 1968). The submarine pillow basalt lavas from Kilauea volcano, Hawaii give the extremely old K-Ar ages (43 Ma) in the quickly cooled rim part in comparison with the ages (1 Ma) in the slowly cooled core part (Dalrymple and Moore, 1968). Ryu et al. (2011) reported the quarse-grained olivine phenocrysts in the basalts from the central part of Korean Penissula were extremely older (38 Ma) than the groundmass feldspar (0.5 Ma). These results suggest the source magma had the excess argon, which has remained in the quick cooled pillow lavas and the coarse-grained olivine phenocrysts.

The island arc type magma is produced through the partial melting of mantle wedge peridotite (Tatsumi, 1986). This suggests that the magma were also in excess argon environment because the magma formed in the wedge mantle. The argon diffusion process from magma during the eruption makes more excess argon environments. However, the historical lavas have experienced the argon isotope mass fractionation to light isotope enrichment (Matsumoto et al., 1989) and the late Pleistocene volcanic rocks in Japan, New Zealand, Hawaii and China have frequently the ratios of 38Ar and 36Ar lower than the atmospheric ratio (0.187). This confirms the mass fractionation to light isotope enrichment is common in volcanic rocks.

When, where and how the mass fractionation from the atmospheric argon isotopes takes place during the magma generation and eruption process? Itaya and Nagao (1988) and Itaya et al. (1989) pointed out that the most likely location for the mass fractionation from the atmospheric argon could be in the magma reservoir in the earth crust, probably in the shallow reservoir where the magma may easily interact with the atmospheric argon transported from out of the reservoir through underground water or seawater based on Ueda and Sakai (1984) who revealed that there was a significant interaction between magma and seawater in the magma reservoir of Satsuma Iwojima volcano, south of Kyushu, Japan. We have a working hypothesis that the magma just before eruption has already the mass fractionated isotopes. Itaya and Nagao (1988) and Itaya et al. (1989) reported that the post caldera stage lava of Aso volcano has significantly different 36Ar content and the same ratio of 38Ar and 36Ar in the slowly cooled part and in the quickly cooled basement part. This shows that the mass fractionation did not take place during the degassing process in the lava flowing and the isotopic ratio in the magma reservoir did not change in the process. On the basis of this hypothesis, we propose a mixing model for the mass fractionation to light isotope enrichment. We interpret that the mass fractionation to light isotope enrichment takes place during infiltration of groundwater or seawater with the atmospheric argon isotopes into the magma reservoir with the mass fractionation law analyzed numerically (Ryu et al., 2010). When the water with mass fractionated argon isotopes interact sufficiently with the magma having the excess argon isotopes in the reservoir, the magma will have the argon isotopic ratios on the fractionation line. In this case, the mass fractionation correction is valid to get reliable ages. The insufficient interaction makes the isotopic ratios above the mass fractionation line, giving unreliable ages.

Keywords: volcanic rocks, argon, mass fractionation, light isotopes, mass fractionation correction age