Noble gas isotope composition of fumaroles and hydrothermal gases around Kusatsu-Shirane volcano

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Mount Kusatsu-Shirane, an active stratovolcano consisting of three pyroclastic cones (from north to south, Mt. Shirane, Mt. Ainomine, and Mt. Motoshirane) erupted on 23 January 2018 at Mt. Motoshirane. This eruption was a phreatic eruption, which often occur without magma movement. Therefore, there is no or very small precursor geophysical signals. In contrast, the chemical and isotopic compositions of volcanic gases can change reflecting pressure rise of a gas reservoir which caused the phreatic eruption. Especially, helium isotope ratio ($^3He/^4He$) is regarded as a useful tracer for the volcanic activity, because it exhibits unique values corresponding to the origin (e.g., 7-8 Ra in the mantle and < 0.1 Ra in the curst, where 1 Ra denotes atmospheric $^3He/^4He$ ratio of 1.4×10^{-6} [1]). Some studies have reported pre-eruptive $^3He/^4He$ anomalies, suggesting the increase of supply of the magmatic helium into the hydrothermal system preceding eruption [2,3].

We report the noble gas (He, Ne, Ar) isotopes of fumaroles and hot-spring gases collected from 9 sites around Kusatsu-Shirane volcano during 2014 and 2018. The measured $^3He/^4He$ ratios were corrected for atmospheric contamination based on $^4He/^{20}Ne$ ratios. The air-corrected $^3He/^4He$ ratio of Sesshogawara fumarole, located on 2 km east of the 2018 phreatic vent, had been constant at 7.0-7.5 Ra during 2014 and 24 January 2018, and dropped to 6.5 Ra on 13 February 2018. The $^3He/^4He$ ratio increased to 7.6 Ra on 21 May 2018 and has been constant at about 7.5 Ra. The $^3He/^4$ He ratios of bubbling gases of Kusatsu-Yubatake hot spring, which located on 5 km east of the 2018 phreatic vent, had been constant at 6.5-6.9 Ra during 2014 and 12 February 2018, decreased to 6.0 Ra on 3 June 2018, and then increased to 7.5 Ra on 6 August 2018. The $^3He/^4$ He ratios of Hoshimata fumarole, which located on 3 km west of the 2018 phreatic vent, increased from 6.2 Ra to 7.3 Ra during 2 March 2018 and 19 June 2018. The trends observed in these sites seem to be associated with the 2018 eruption with different time lags, which may reflect the migration distance from the 2018 phreatic vent to the sites.

In Kusatsu-Shirane area, two hydrothermal reservoirs, one of which is located beneath Yugama crater of Mt. Shirane and the other is located beneath Mt. Motoshirane (between Ainomine and Mt. Motoshirane), have been proposed [4]. The $^3He/^4He$ ratios (7.2-8.1 Ra) of Kitagawa fumaroles on the northern flank of Mt. Shirane near the Yugama crater, may reflect the values of the gases derived from the hydrothermal reservoir beneath Mt. Shirane. On the other hand, the lower $^3He/^4He$ ratios observed in Sesshogawara, Kusatsu-Yubatake and Hoshimata after the eruption may result from another contribution from a reservoir having lower $^3He/^4He$ ratios (less than 6.5 Ra), which could be attributed to the hydrothermal reservoir beneath Mt. Motoshirane. The reservoir beneath Mt. Motoshirane may be enriched in radiogenic ^4He derived from the crust, because Mt. Motoshirane has not erupted for last 1500 years [5].

It has been proposed that the 2018 eruption was caused by sealing of gas pathway from magma to the hydrothermal reservoir beneath Mt. Shirane [4]. This would result in decrease of supply of magmatic gas with high $^3He/^4He$ ratio to Sesshogawara, Kusatsu-Yubatake, and Hoshimata. Therefore, the low $^3He/^4He$

ratios observed in these sites after the 2018 eruption may reflect relative increase of the contribution of gas supplied from the Mt. Motoshirane hydrothermal reservoir. In contrast, the high and relatively constant $^{3}He/^{4}He$ ratios at all of the sites since August 2018 suggest that the gas from the reservoir beneath Mt. Shirane is dominant. Ohba et al. [4] proposed that supply of magmatic gas to the Mt. Motoshirane reservoir increased before the eruption as a result of the sealing of gas pathway from magma to the Mt. Shirane reservoir, and that it caused high fluid pressure of the reservoir and subsequent phreatic eruption at Mt. Motoshirane. This implies that $^{3}He/^{4}He$ ratio of the Mt. Motoshirane reservoir also increased from a lower value to a higher value less than 6.5 Ra before the eruption. Although further study is necessary to constrain $^{3}He/^{4}He$ ratios of the reservoirs, the remarkable temporal $^{3}He/^{4}He$ variation after the eruption can be accounted for by the change in mixing ratio of the gases from the two reservoirs.

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