Helium isotope ratios at Kusatsu-Shirane volcano

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At Kusatsu-Shirane, an active stratovolcano consisting of three pyroclastic cones (Mt. Shirane, Mt. Ainomine, and Mt. Motoshirane), a phreatic eruption occurred on 23 January 2018 at Mt. Motoshirane. Phreatic eruptions often occur without magma movement, thus are accompanied by no or very small precursor geophysical signals. In contrast, chemical and isotopic compositions of volcanic gases are expected to change reflecting pressure rise of a gas reservoir which causes a phreatic eruption. Helium isotope ratio (^{3}He/^{4}He) has a great potential as a tracer of volcanic activity, because it exhibits unique values corresponding to the origin (e.g., ca. 8 Ra in the mantle and < 0.1 Ra in the curst, where 1 Ra denotes atmospheric ^{3}He/^{4}He). Some studies reported pre-eruptive ^{3}He/^{4}He anomalies, suggesting the increase of supply of the magmatic helium into the hydrothermal system preceding eruption [1-3].

We report ^{3}He/^{4}He of fumaroles and hot/cold spring gases collected from 11 sites at Kusatsu-Shirane volcano during 2014 and 2019. The measured ^{3}He/^{4}He were corrected for atmospheric contamination based on ^{4}He/^{20}Ne. ^{3}He/^{4}He drops down to 6.0-6.5 Ra after the 2018 eruption and subsequent recovery to higher values were observed at Sesshogawara fumarole and Kusatsu-Yubatake hot spring. Although there are no data before the 2018 eruption, ^{3}He/^{4}He increases were observed at Hoshimata fumarole and Anajugoku cold spring after the eruption. Since then, ^{3}He/^{4}He of the four sites have been constant at high levels (7.0-7.6 Ra). The temporal ^{3}He/^{4}He variations seem to be associated with the 2018 eruption with different time lags, which may reflect the migration distance of fluids from the volcanic center.

Based on magnetotelluric investigation, Matsunaga et al. [4] suggested the presence of hydrothermal reservoir at depths of 1-3 km broadly extending from beneath Mt. Shirane to Mt. Motoshirane, which supplies fluids to the shallow hydrothermal systems. The constant and high ^{3}He/^{4}He (7.2-8.1 Ra) during the study period of Kitagawa fumaroles on the northern flank of Mt. Shirane near the Yugama crater may reflect the value of the hydrothermal reservoir.

On the other hand, the ^{3}He/^{4}He drops at the four sites after the eruption requires another reservoir having low ^{3}He/^{4}He value. The ^{3}He/^{4}He of fumaroles, hot and cold springs decrease with distance from the volcano. Some of the springs relatively far from the volcano indicate involvement of fossil salt water in groundwater flow system [5], which would exhibit low ^{3}He/^{4}He value due to accumulation of crustal helium. Therefore, the ^{3}He/^{4}He decrease with distance from the volcano can be accounted for by an increase of contribution of crustal helium derived from old groundwater to the magmatic helium with migration distance of the fluid from the hydrothermal reservoir to the sampling site.

Ohba et al. [6] showed that the Kitagawa, Sesshogawara, and Hoshimata fumaroles are derived from distinct, small hydrothermal reservoirs which share the same magmatic fluid. It has been proposed that the 2018 eruption was caused by sealing of magmatic gas pathway to the shallow hydrothermal reservoir which supplies gas to the Kitagawa fumarole [7]. If such sealing would have similarly occurred for Sesshogawara, Kusatsu-Yubatake, Hoshimata, and Anajigoku reservoirs, it would also result in decreases of supply of magmatic gas from the deep hydrothermal reservoir, which were observed as the ^{3}He/^{4}He drops.

Although further study is necessary to constrain the high- and low-$^3He/^4He$ reservoirs, the remarkable temporal $^3He/^4He$ variations associated with the 2018 eruption implies $^3He/^4He$ tells us the state of hydrothermal reservoir potentially causing a phreatic eruption.

References

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