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 (³He/⁴He) 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 crust, where 1 Ra denotes atmospheric ³He/⁴He). Some studies reported pre-eruptive ³He/⁴He anomalies, suggesting the increase of supply of the magmatic helium into the hydrothermal system preceding eruption [1-3].

We report ³He/⁴He of fumaroles and hot/cold spring gases collected from 11 sites at Kusatsu-Shirane volcano during 2014 and 2019. The measured ³He/⁴He were corrected for atmospheric contamination based on ⁴He/²⁰Ne. ³He/⁴He 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, ³He/⁴He increases were observed at Hoshimata fumarole and Anajugoku cold spring after the eruption. Since then, ³He/⁴He of the four sites have been constant at high levels (7.0-7.6 Ra). The temporal ³He/⁴He 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 ³He/⁴He (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 ³He/⁴He drops at the four sites after the eruption requires another reservoir having low ³He/⁴He value. The ³He/⁴He 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 ³He/⁴He value due to accumulation of crustal helium. Therefore, the ³He/⁴He 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 ³He/⁴He drops.
Although further study is necessary to constrain the high- and low-\(^{3}\)He/\(^{4}\)He reservoirs, the remarkable temporal \(^{3}\)He/\(^{4}\)He variations associated with the 2018 eruption implies \(^{3}\)He/\(^{4}\)He tells us the state of hydrothermal reservoir potentially causing a phreatic eruption.

References

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