Relationship between the rate of increase in the He/CH4 ratio of volcanic gas and the number of earthquakes at Mt Hakone

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Introduction
Hakone Volcano is a caldera located in the western part of Kanagawa Prefecture, Japan. A geothermal area has developed in Owakudani valley located on the central cone of Mt Hakone. In Owakudani, tourists always approach near the eruptive crater. In order to protect tourists from eruption disasters, it is necessary to constantly monitor volcanic activity and accurately predict short-term activity. Volcanic gases (fumarolic gas) emitted from geothermal areas contain components degassed from magma (magma components: CO2, He, etc.) and also the components originating in hydrothermal system. The ratio of magma to hydrothermal components increased during the small phreatomagmatic eruption in 2015, almost synchronously with the increase in the number of earthquakes (Ohba et al., 2019). In July-August 2021, changes similar to those observed in 2015 were observed again, but the number of earthquakes was much lower. In this study, we focus on the changes of volcanic gas composition in 2021 and discuss the relationship with seismic activity.

Fumarolic gas sampling and analysis
Fumarolic gases were repeatedly collected and analyzed directly at two fumaroles (n and c) in the Owakudani geothermal area and at one fumarole (s) in the Kamiyuba geothermal area 500 m to the north. The fumarolic gases n and s were sampled and analyzed almost every month from May 2013 to January 2022. The fumarole c was generated during a small eruption in June 2015. The fumarolic gas c was collected and analyzed from January 2019 to January 2022.

Results and Discussion
The He/CH4 ratio of fumarolic gas c increased rapidly from July to August 2021, but the trend did not continue, and the ratio repeatedly decreased and increased until January 2022. The He/CH4 ratio of fumarolic gas n increased slowly from August to November 2021, and decreased from December. The CO2/H2S ratio of fumarolic gas c increased sharply from July to August 2021, and then increased slowly until October, but decreased from October to November, and then increased again until January 2022. The CO2/H2S ratio of fumarolic gas n increased slowly from October 2021 to January 2022. The CO2/H2S ratio of fumarolic gas s clearly increased from October 2021 to November, and remained high until January 2022. The SO2/H2S ratio of fumarolic gas c clearly increased from July to August 2021, but the trend did not continue. The SO2/H2S ratio of fumarolic gas c remained relatively high until January 2022.
The He/CH4 ratio of fumarolic gas n shows a cyclic increase and decrease from 2013 to the present. Four minimums were observed in the He/CH4 ratio at the following periods, February 2015, April 2017, February 2019 and May 2021. The rate of increase in the He/CH4 ratio was calculated starting from each minimum period. The rate of increase in the He/CH4 ratio after the minimum period was higher in the following order: 2021 < 2017 < 2019 < 2015. According to the JMA observation, the highest number of earthquakes per half-month after the minimum period in 2021, 2017, 2019, and 2015 was 19, 8, 142, and 1303, respectively. The number of earthquakes in the active period after the minimum is considered to be correlated with the rate of increase in He/CH4 ratio, which is an indicator that can be observed in the early stage of the active period, and is one of the methods to estimate the scale of volcanic

earthquakes in the active period.

Reference
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