

# Fumarole and hot spring activities after the 2015 eruption of Hakone Volcano and their relationships with the seismicity and crustal deformation

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A very small phreatic eruption occurred at Hakone volcano in 2015. Before the eruption, in Owakudani, where the eruption center formed, there has been no significant fumarole activity; however, more than 20 craters and fumaroles formed associated with the eruption and they still remain active. We have routinely measured the steam temperatures emitted from the fumaroles and analyzed chemical composition of hot spring and surface waters every two weeks since we were permitted to enter the eruption center. In this presentation, we show the temporal changes and its relationship with the seismic activity and crustal deformation.

## 1. Steam temperature of fumaroles

Among the more than 20 fumaroles, we have measured 10 fumaroles that are significant and accessible (Mannen et al., 2019). We have only two stable fumaroles named 15-12 (since May 1, 2017) and 16-1 (since January 11, 2018) for routine measurement.

The temperature of 15-12 was higher than 150 °C before August 2017. However, the temperature lowered gradually up to 120 °C until the late 2018. The temperature of 16-1 was approximately 140 °C when we started measurement. However, the steam temperature also lowered gradually and marked 130 °C in the late 2018.

On the other hand, fumaroles named 15-1 and 15-14B continuously emit high temperature steams and higher than 150 °C even in the late 2018 without significant decline although steam vents of these fumaroles are unstable and migrate frequently. We suppose that the steam temperature and emission are on decline since detection of high temperature steam is getting difficult and extinction of fumarolic activity is common recently. The highest temperature ever recorded was 162.0 °C from 15-1 observed on August 23, 2017.

## 2. Chemical composition of hot springs and surface waters

In Owakudani area, we routinely correct and analyze waters from 13 sources including natural springs, stream water and artificial hot springs, which is made by mixing of steam emitted from steam well and water (Kikugawa et al., 2019). The stream water, watershed of which includes the eruption center, shows high Cl content associated with the 2015 volcanic unrest ( $\text{Cl}/\text{SO}_4 > 1.0$ ; Mannen et al. 2018). The Cl concentration lowered to the background level ( $\text{Cl}/\text{SO}_4 \sim 0.2$ ) until early 2017; however, increased slightly from November 2017 to January 2018 ( $\text{Cl}/\text{SO}_4 \sim 0.3$ ). The artificial hot springs from No. 52 steam well also showed significant rise of electric conductivity and Cl content and decline of pH.

Our measurement of volcanic gas from underfloor of a building in Owakudani shows continuous decline of  $\text{CO}_2/\text{H}_2\text{S}$  ratio after the eruption. The decline rate seemed to lower in 2017; however, it was not clear. On the other hand, Daita et al. (2018) reported that  $\text{CO}_2/\text{H}_2\text{S}$  ratio of volcanic gas from Kamiyu, north of Owakudani showed rise from around June 2017.

### 3. Seismicity and crustal deformation in 2017

In Hakone volcano, earthquake swarm, deep low frequency earthquakes and increase of baseline length across the volcano have observed before increase of geothermal activity (Harada et al. 2018; Mannen et al. 2018). After the 2015 eruption, there has been no earthquake swarm; however, there were slight increase of seismicity from the late April to the early May in 2017 beneath Mt. Kintoki (Yukutake et al. 2018). Before the earthquake swarm, in the mid-April, deep low frequency earthquakes (DLF) was found active by matched filter method (Yukutake, 2017). The baseline length across Hakone volcano started to increase from the early May in 2017 and ended in the late November of the year with total stretch of 12 mm (the total stretch during the 2015 eruption and unrest was 21 mm). In the period, there is no significant change in steam temperature. Increase of hydrothermal activity was implied by the changes in chemical compositions of artificial hot spring water and surface water in the late April and in November respectively.

The observed trend of the weak change in 2017 are similar to that of the volcanic unrests in 2013 and 2015. We thus suppose that there was a small increase of volcanic activity in 2017. Comparing to the changes in 2013 and 2015, seismicity and stretch rate of the baseline in 2017 are notably lower. Daita et al (2018) also pointed out that the increase in CO<sub>2</sub>/H<sub>2</sub>S ratio in 2017 was significantly lower than that observed in 2013 and 2015. Such differences observed in 2017 may imply that the magma-hydrothermal system of Hakone volcano has altered by the 2015 eruption (Daita et al, 2018).

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