Remote temperature sensing of volcanic fumaroles using hydrogen isotopes of excess molecular hydrogen in plumes

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The temperature of fumarolic gases provides important information about the magmatic/hydrothermal systems under the volcanoes. Direct measurements on fumaroles, however, are often neither practical nor safe in most of the active volcanoes. Remote sensing using infra-red (IR) wavelengths of surface temperatures offers an alternative to direct measurement since the early 1960s. The IR remote sensing, however, have several problems when applied to determine the outlet temperature of volcanic fumaroles.

In high-temperature volcanic fumaroles (>400℃), the isotopic composition (δD value) of molecular hydrogen (H_2) reaches equilibrium with that of the fumarolic H_2O under the outlet temperature so that the δD value of fumarolic H_2 is a function of fumarolic temperature. Combining this temperature-dependent variation in δD value of fumarolic H_2 with our high-sensitivity mass spectrometric technique which enable us to deduce the δD value of fumarolic H_2 from trace H_2 in the volcanic plume, we can determine the temperature at volcanic fumaroles remotely. To ascertain that we can estimate the δD value of fumarolic H_2 from those in a volcanic plume, we estimated the values in three fumaroles with outlet temperatures of 630℃ (Tarumae), 203℃ (Kuju), and 107℃ (E-san). For this we measured the concentration and δD value of H_2 in each volcanic plume, along with those determined directly at each fumarole and found a linear relationship between the depletion in the δD values of H_2 in each volcanic plume, with the reciprocal of H_2 concentration. Furthermore, the estimated endmember δD value for each H_2-enriched component (–260±30‰vs. VSMOW in Tarumae, –509±23‰in Kuju, and –437±14‰in E-san) coincided well with those observed at each fumarole (–247.0±0.6‰in Tarumae, –527.7±10.1‰in Kuju, and –432.1±2.5‰in E-san). Moreover, the calculated isotopic temperatures at the fumaroles agreed to within 20℃ with the observed outlet temperature at Tarumae and Kuju. We concluded that the δD value of the fumarolic H_2 was quenched within the volcanic plume. This enabled us to remotely estimate these in the fumarole, and thus the outlet temperature of fumaroles, at least for those having the outlet temperatures more than 400℃. The remote temperature sensing using hydrogen isotopes (HIReTS) developed in this study is widely applicable to many volcanic systems.