A hydrothermal system of Kusatsu-Shirane volcano inferred from Cl concentrations and stable isotope ratios of Yugama crater lake water

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Kusastu-Shirane volcano exhibits geothermal features such as hot springs that have almost the same SO_4^{2-}/Cl^- ratio of water. These hot springs are derived from common parental fluid (Pf) which is produced by a mixing of magmatic high temperature volcanic gas and local meteoric water. The Pf is diluted by hot waters containing low concentration sulfate as waters flow under the ground surface (Yamamoto et al., 1997; Hirabayashi, 1999). A relation between Cl^- concentrations and stable isotope ratios of water requires an existence of vapor-liquid reservoir. The liquid phase of the reservoir is highly condensed in Cl^- produced by a boiling of the Pf. The vapor-liquid reservoir supplies hot water to Kagusa and Jyofu hot springs, located near the top of Kusatsu-Shirane volcano (Ohba et al., 2000).

Shirane pyroclastic cone, located at the summit of Kusatsu-Shirane volcano, has three crater lakes. The largest crater lake, locally called Yugama, has over 0.5 million m^3 of water with a temperature between 0 and 30 degree Celsius which is 10 degree Celsius higher than an ambient temperature. Phreatic eruptions have repeatedly occurred around the cone during the last 130 years. During the recent calm periods, subaqueous fumaroles of Yugama crater lake continue to supply hot water containing high concentration of H^+, Cl^- and SO_4^{2-} to lake. Stable isotope ratios of lake water have values that are larger than that of the local meteoric water due to additions of magmatic fluids from the lake bottom.

We can easily collect lake water on the lake shore in order to monitor changes in concentrations of lake water. However, we cannot directly evaluate chemical features of fluid emitting from subaqueous fumaroles, because lake water experiences somewhat complex processes including isotropic fractionations during evaporation, condensation, seepage through the lake bottom and meteoric input.

In this study we have developed a numerical model which takes factors associated with variations of Cl^- and stable isotope ratios into account. Applying the model to observation data including water level, temperature, Cl^- concentrations and stable isotope ratios of hydrogen and oxygen, we estimate mass flux, enthalpy, Cl^- concentration and stable isotope ratios of water emitting from the lake bottom. During a calm period in 2012 - 2013, a relation between Cl^- concentrations and stable isotope ratios of water indicates that the hydrothermal reservoir beneath Yugama crater lake is a mixture of magmatic high temperature volcanic gas and the local meteoric waters.

Intense micro earthquake swarms and ground deformations occurred around Shirane pyroclastic cone in 2014, which are accompanied by changes in water temperature, Cl^- concentration and stable isotope ratios. Our model reveals an increase in supply of magmatic high temperature volcanic gas to the hydrothermal reservoir located beneath Yugama crater lake. However, the relation between Cl^- concentrations and stable isotope ratios of water cannot be explained by a mixing. We believe that enhanced boilings have occurred in the reservoir leading fractionations of stable isotope ratios.

In order to reveal the locality of the hydrothermal reservoir, which is an origin of water of Yugama crater

lake, hypocenters of micro earthquakes are precisely relocated by the DD technique. We identify two groups of hypocenters on the basis of its depth and time sequences. Attenuations of seismic waves indicate that the reservoir locates between the shallow and the deep groups of hypocenters, corresponding to an altitude of around 900 m a.s.l. The depth is consistent with the altitude of undersurface of an impermeable layer suggested by MT surveys (Ogawa, in prep.).

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