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ACID ALTERATION AT THE SURFACE OF OTAKE GEOTHERMAL FIELD, KYUSHU, JAPAN

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SUMMARY – The alunite zone which is located at the surface and shallow depths in the production area of the Otake geothermal filed is composed mainly alunite and cristobalite. Quartz with alunite occurs only in a limited area near Well O-9 which is the only well in use since the opening the Otake power plant in 1967. The delta ^{34}S of alunite is generally high, indicating a hypogene origin of alunite.

1. INTRODUCTION

The Otake geothermal field is located on the north-western slope of Kuju Volcano, about 900 m above sea level (Figure 1) and 2 km to the north of the Hatchobaru geothermal field. The site is also 5 km to the northwest of the solfatara area of Kuju Iwo-yama where the maximum temperature of the fumarole was recorded to be 508ºC in 1960 (Mizutani et al., 1986). A geothermal power plant with a 12.5MW installed capacity has been operating there since 1967; it is the first geothermal power plant developed in a water-dominated system in Japan.

The alunite zone at Otake geothermal field has a lenticular shape with a maximum thickness of 50 to 60 m located at the top of the system (Figure 3.; Hayashi et al, 1973). This alunite zone was believed to have formed in the presence of steam-heated water (Taguchi et al., 1985), because alunite and cristobalite are the main minerals of the zone, the zonal arrangement of hydrothermal minerals, and also the location of the alunite zone about 300 m above the reservoirs (200 – 220 ºC).

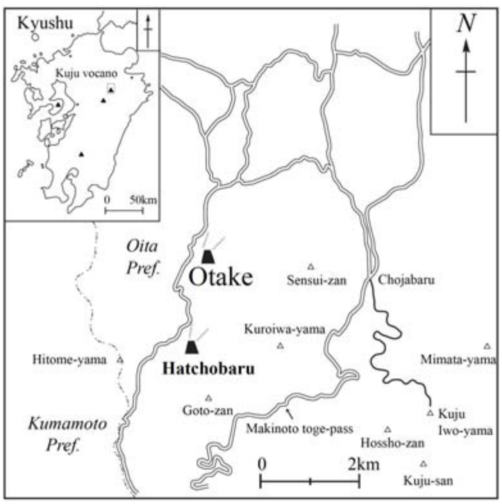

Figure 1. Location of the Otake geothermal field.

In this study, we investigated the hydrothermal mineralogy and the geochemistry of the minerals to understand the genesis of the alunite zone. The newly obtained data indicate there was a past contribution of volcanic fluid in the formation of this alunite.

2. GEOLOGICAL SETTINGS

The Hohi and Kuju volcanic rocks are the only units exposed within the Otake geothermal field (Figure 2). The former is composed mainly of pyroxene andesites with a thickness of about 1000 m, and it was deposited in the late Pliocene to early Pleistocene. The Kuju volcanic rocks are younger than 0.3Ma (Watanabe et al., 1987), and they form the domes around the field.

Northwest trending faults are dominant in the Otake and Hatchobaru geothermal fields. Many thermal manifestations such as hot springs, fumaroles, and advanced argillic alteration zones occur along the faults. Production wells are also located along the NW-trending Yokoo fault. The main reservoir when the field was first developed is located 300 to 500 m below the surface.

A small area of steaming ground called Otake Jigoku exists about 150 m to the east of the power plant, but the size and the activity of thermal manifestations are generally smaller than that of the Hatchobaru field.

The alunite zone occurs at the surface and in the uppermost level, and the zone is hosted in the Hohi volcanic rocks. With depth, the alunite zone gives way to successive zones of smectite and kaolin, zeolite and chlorite (Figure 3; Hayashi, 1973).

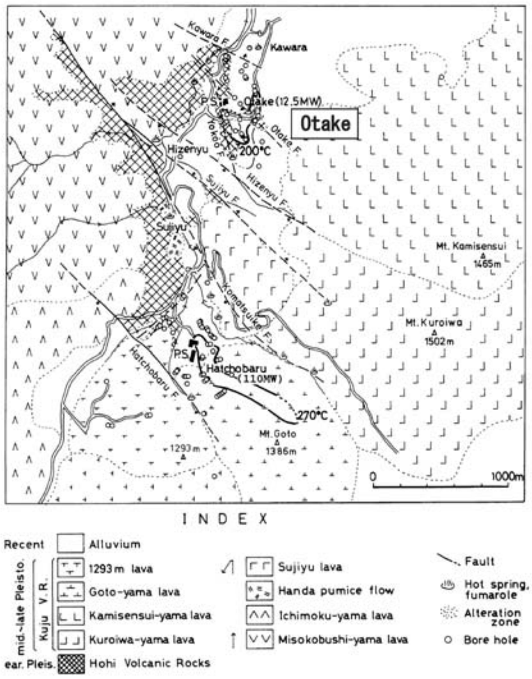

Figure 2. Geologic map of Otake geothermal field.

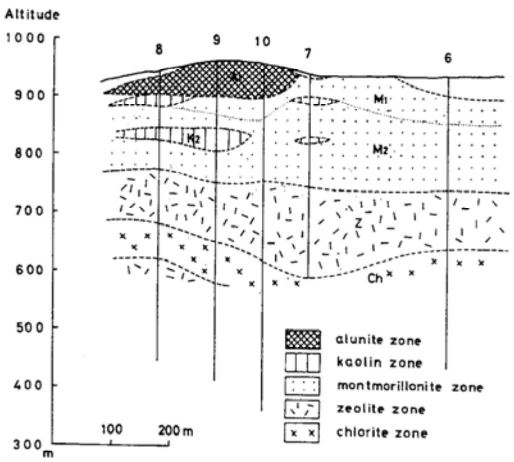

Figure 3. Distribution of hydrothermal alteration zones at the Otake geothermal field (Hayashi, 1973).

Discharged fluids are the neutral to alkaline pH, chloride type; pH = 8.15-8.4, Na = 805 – 1,098 mg/l, and Cl = 1,219-1,753 mg/l (Koga, 1970). The water chemistry suggests reservoir temperatures of 195 to 215ºC. No evidence of deeply derived acid waters exists.

Fluid inclusion microthermometry indicated a reservoir (200 to 220 ºC) had a mushroom structure and a small upflow zone dipping steeply to the south (Taguchi et al.,1985). The alunite zone occurs at the surface above this upflow zone.

Production wells and reinjection wells are located in both the southern and the northern parts (Figure 4). Among the production wells, only Well O-9 has been utilized since the opening of the power plant in 1967. Eastern (O-7, O10) and north-western (O-8, O-14, and O-1) production wells have decreased in output, and the current production wells are arranged in a NW direction, along the Yokoo fault (Figure 4).

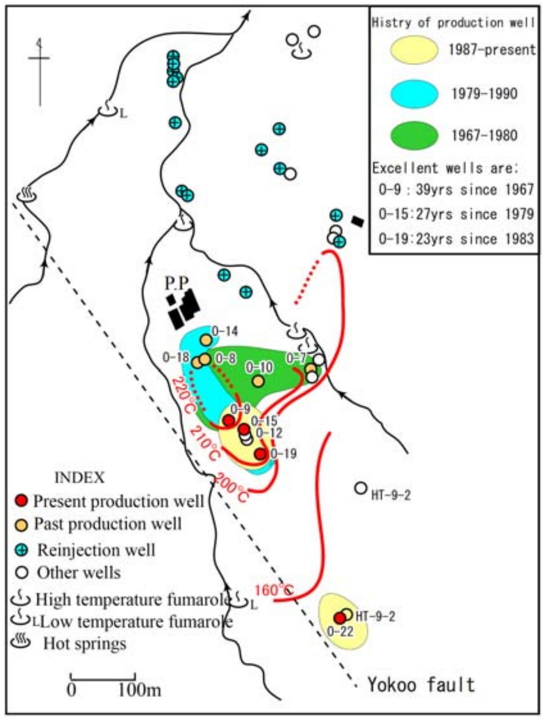

Figure 4. Well location and history of production wells. Distribution of reservoir temperature estimated from fluid inclusions (Taguchi et al., 1985) is also shown.

3. ACID ALTERATION

We collected more than 200 altered rock samples from the surface and drill cores and cuttings of Wells O-8, O-9, O-12, O-14, O=15, O-16, O-18, O-19, O-22, HT-9-1, and HT-9-2 to determine hydrothermal alteration minerals by XRD.

3.1 Alteration zones

According to the minerals paragenesis, we identified three alteration zones as shown in Figure 5, alunite zone, kaolin zone and smectite zone.

The alunite zone occurs mainly in two areas; one is in the production area and is elongated in the NW direction (central alunite zone), and the other is about 200 m to the northwest of the production

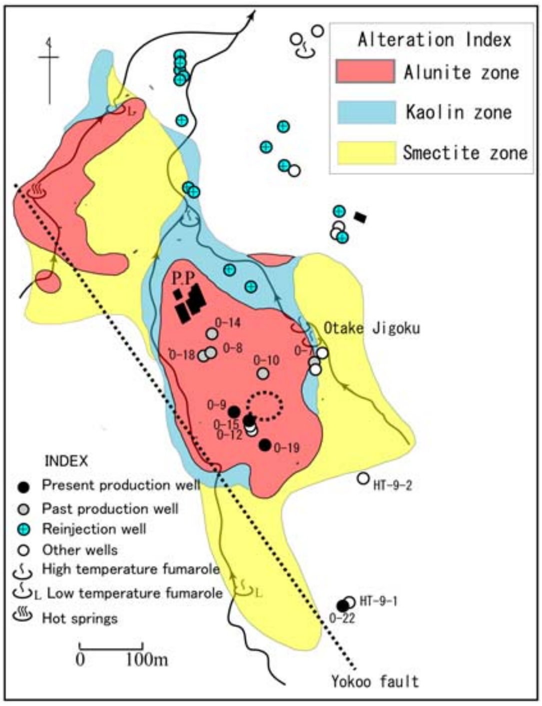

Figure 5 Distribution of alteration zones at the Otake geothermal field. Alunite occurs with quartz in the dotted circle area in the Central alunite zone (see text).

area along the river valley (NW alunite zone). The latter is located at a lower elevation than the central alunite zone.

Common minerals of the central alunite zone are alunite and cristobalite, attended by small amounts of quartz, kaolinite and anatase. Natroalunite and minamiite occur on the margin of the zone. Quartz is the main silica mineral in the NW alunite zone indicating a higher formation temperature than the central alunite zone. This is possibly due to the erosion level, and the deep exposure in the NW alunite zone. However, in the vicinity of Well O-9 in the central alunite zone, quartz appears with alunite. In general, alunite from the central zone is characterised by tabular habit and small crystals (10 µm). Locally (Sp:S050612-10), alunite is coarsely crystalline and up to 100 µm across. Moreover, aluminium phosphate sulphate minerals (APS) were identified by EPMA in the alunite zone from a small limited area.

The kaolin zone surrounds the alunite zone, and the main minerals are kaolinite and cristobalite, with quartz substituting at deeper level. The kaolin zone is thin at the surface and also in the subsurface as shown in a cross-section of Figure 7.

3.2 Sulfur isotopic analysis of alunite

Four alunite samples from surface exposures and twelve samples from wells were analysed for $\delta^{34}S$. The results are shown in Figures 6 and 7. Alunite samples from the surface have relatively homogeneous $\delta^{34}S$ values of 21.4 to 23.7‰. On the contrary, alunites from wells have a wide range of $\delta^{34}S$ from 1.6 to 23.1 ‰. The lowest value of 1.6 ‰ was obtained from 18 m depth in Well O-14, and the next lowest value of 10.4 ‰ was from 36 m depth in Well O-10. These wells are located near the margin of the production area, which is closer to the presently active steaming ground.

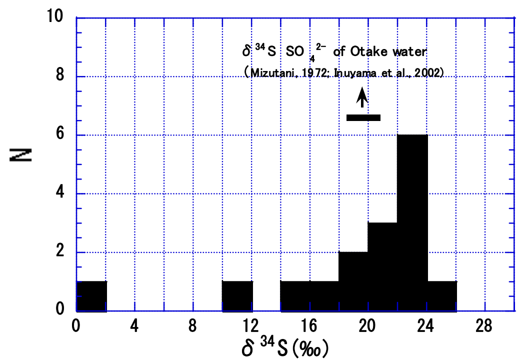

Figure 6. Histogram of $\delta^{34}S$ of alunite from Otake.

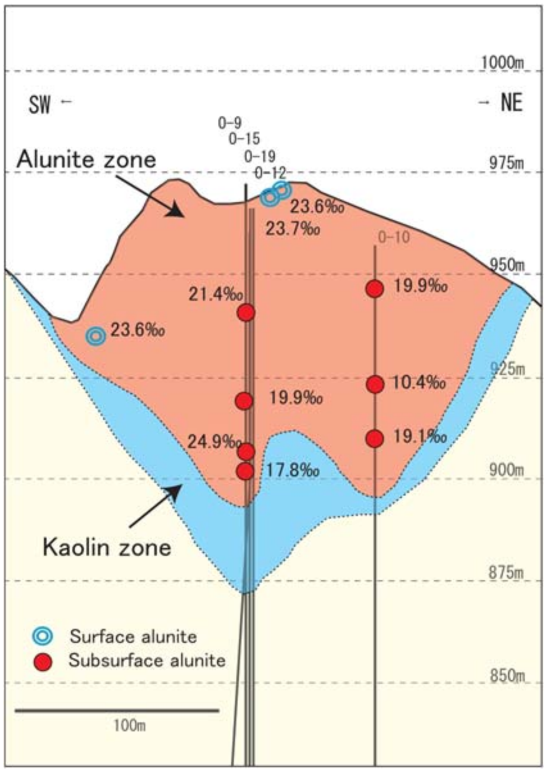

Figure 7 Sulfur isotope of surface and subsurface alunite plotted on a NE-SW section across the central alunite zone in Otake.

3. DISCUSSION

The sulfur isotope values ($\delta^{34}S$) of alunite from the central alunite zone have a wide range of $\delta^{34}S$ values from 1.6 to 23.1 ‰. This range is almost similar to that of Hatchobaru (0 to 24 ‰; Kiyosaki et al., 2003). At the Hatchobaru geothermal field, the $\delta^{34}S$ of alunite from steaming ground ranges from 0.6 to 2.7‰, but some sample give 11 ‰ (Taguchi et al., 2003). Moreover, $\delta^{34}S$ of alunite from the drill cores and cuttings increases with depth and is about 20 ‰ at the depths deeper than ~300 m. Taking into account the results of alteration mineralogy, these facts were interpreted to indicate the former presence of a magmatic gas discharges in the Hatchobaru geothermal field.

The $\delta^{34}S$ of surface alunite samples from Otake shows high values as 21.4 to 23.7 ‰. This means that the alunite has no relation with steam heated acid sulfate waters that currently dominate the activity at Otake Jigoku. However, some alunite samples from Wells O-14 and 10 show low $\delta^{34}S$ values of 1.6 ‰ and 10.4‰, respectively. These lower values indicate that the alunite was affected by steam heated water.

The $\delta^{34}S$ values of SO_4^{2-} of modern Otake hot waters from 4 wells are homogeneous, ranging from 18.5 to 18.7 ‰ (Mizutani, 1972), slightly lower than the $\delta^{34}S$ values of alunite from the surface. The pH of these hot waters ranges 8.15 to 8.4 (Koga, 1970). Such geochemical characteristics of the present deep waters at Otake suggests they are genetically unrelated to the alunite formation.

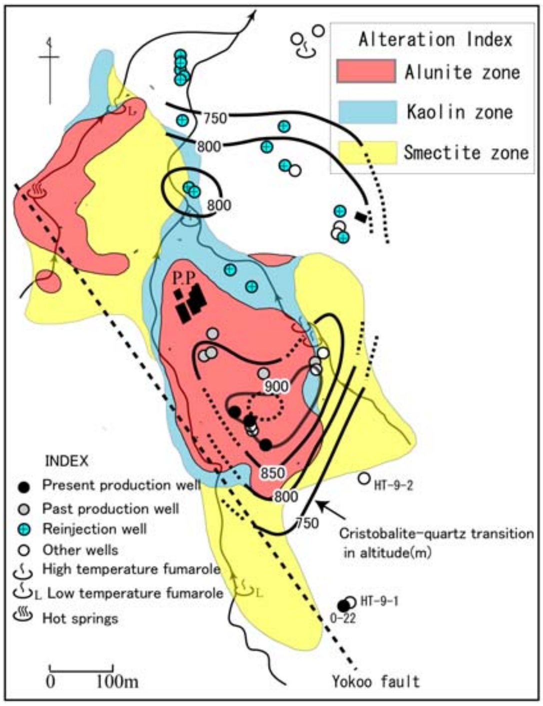

Figure 8. Elevation contours of the cristobalite – quartz transition in the alunite alteration zone.

As shown Figure 8, the cristobalite-quartz transition level shallows near Well O-9, where the central alunite zone reaches maximum thickness. The coarse alunite crystal size near Well O-9 is and the occurrence of quartz along with the sulfur isotope data suggest that magmatic fluids once discharged perhaps in an early stage of the Otake geothermal system. But the conduit size appears to have been small, because thick development of acid alteration zone did not develop like that at Hatchobaru.

Well O-9 has been used continuously for production since the commissioning of the Otake geothermal power plant in 1967. Perhaps its location, coinciding with the centre of past ascending acid fluid, is important. Ancient hypogene acid fluid conduits are probably occupied by the modern upflow zone of deeply circulated near neutral pH waters at Otake.

4. ACKNOWLEDGEMENTS

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