HOMOGENIZATION TEMPERATURES OF FLUID INCLUSIONS VERSUS BOREHOLE TEMPERATURES

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Fluid inclusions in minerals have generally put several thermal episodes on record. Homogenization temperatures (Th) of fluid inclusions trapped at the latest thermal event may indicate the present temperatures of underground geologic formations when the pressure correction is negligible (Taguchi, 1982; Sasada, 1988a). On the other hand, the final temperature recovery of boreholes can be estimated from the observed transient behavior using a Horner plot, if there is no circulation of fluid within the borehole, and if the depth where the recovery is observed is not a zone of circulation loss (Grant et al., 1982). The borehole temperatures measured very long time after drilling also correspond to the final temperature recovery, if the thermal situations mentioned above are assumed (NEDO, 1987).

Trapping temperatures (Tt) and reequilibration temperatures of fluid inclusions may correspond to those of geothermal events on cooling or warming processes. These fluid inclusion temperatures are determined from Th measured. When boiling fluid is trapped in primary fluid inclusions during the precipitation of hydrothermal minerals, Th of the inclusions which trapped only the liquid phase indicate Tt without any pressure correction. However, some pressure correction must be applied to determine Tt for the non-boiling fluid away from the boiling point curve for water. When fluid inclusions are produced in shallow geothermal systems, the hydrostatic pressure correction is reasonable for determination of Tt. The relationship between Th and Tt for secondary inclusions formed during healing of fractures in minerals is similar to that for primaries. However, Th of secondary inclusions which trapped the liquid phase during the necking down, which is essential to fracture healing processes, may be more or less different from Tt for boiling fluid.

The reequilibration of fluid inclusions with volume expansion often occurs on warming processes. Stretching is one of the reequilibration processes of fluid inclusions, especially in soft minerals, e.g. calcite and fluorite. Fluid inclusions may stretch when the internal pressure exceeds a certain finit limit by overheating beyond Th (Bodnar and Bethke, 1984).

Fluid inclusions in hydrothermal minerals from geothermal drill holes were generally trapped under the temperature conditions at previous times, and some of the inclusions may have been trapped under the same physicochemical conditions as present ones. The Tt of the latter may correspond to the final temperature recovery estimated from the systematic measurements of borehole temperatures or the borehole temperatures measured very long time after drilling. The change of physicochemical conditions in geothermal reserviors or that in hot dry rocks makes differnce between the Tt of fluid inclusions trapped at previous times and present temperatures of geologic formations. Temperature differences significantly observed between the Th of fluid inclusions and the borehole temperatures measured with very long standing times or the the final temperature recovery estimated may be caused by temperature decreases after trapping of inclusions with complete filling of hydrothermal minerals in fractures, or with transition from hot water dominated system to vapor dominated system (Sasada, 1987).

On the contrary, the present formation temperatures in warming geothermal reservoirs or in warming hot dry rocks, where stretching of fluid inclusions may have occurred, may be higher than the Th of fluid inclusions trapped at previous times. If the pressure corrected Th of the fluid inclusions in hydrothermal minerals are lower than the borehole temperatures measured very long time after drilling, or the final temperature recovery at the depth where no thermal disturbance is observed, the temperature of geologic formations may have increased there (Sasada, 1988b). The reequilibration of fluid inclusions in detrital grains of sedimentary rocks, phenocrysts of volcanic rocks, and constituent minerals of plutonic rocks might also show thermal events before the precipitation of hydrothermal minerals (Burruss and Hollister, 1979; Sasada, 1988b).

In conclusion, when Th of fluid inclusions and the final temperature recovery are known, the thermal history of underground geologic formations in geothermal fields can be accurately delineated.

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HYDROTHERMAL ALTERATION AND GEOTHERMAL STRUCTURE IN THE TAKIGAMI GEOTHERMAL AREA, KYUSHU, JAPAN

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1 Introduction

The Takigami area is located in the north-eastern part of the Hohi geothermal field which is one of the most active geothermal field in Japan. Many hot springs and alteration halos are distributed in the Hohi geothermal field, but the Takigami area is characterized by no surface geothermal manifestation. Since 1974, more than 20 exploration wells have been drilled in this area. The highest measured temperature in these wells was 252 ℃.

Drill core and cutting samples in these wells were studied by X-ray diffraction to clarify the nature of hydrothemal alteration. The purpose of this report is to describe the distribution of alteration minerals and to discuss the geothermal structure related to alteration zoning.

2 Geology

One of the geologic cross sections of the Takigami area is shown in Fig.1. Quaternary volcanic rocks thickly overlie on the Tertiary basement of Usa formation and are divided into four formations, Takigami formation, Ajibaru formation, Kusu formation and Noine-dake volcanic rocks in ascending order. Usa formation is mainly composed of andesite lavas and pyroclastic rocks which are characterized by propyritization. Quaternary volcanic rocks are composed of andestic and dacitic volcanic products, partly intercalated with lake sediments.

The basement of Usa formation is depressed over 1000m by N-S trending Noine fault from east to west. Takigami formation very thickly overlies on the basement in the western depressed area and becomes abruptly thinner to the east (Fig.1). Ajibaru formation and above two formations have no large displacement by Noine fault, suggesting that the major part of the faulting terminated before the deposition of Ajibaru formation (0.7 Ma).

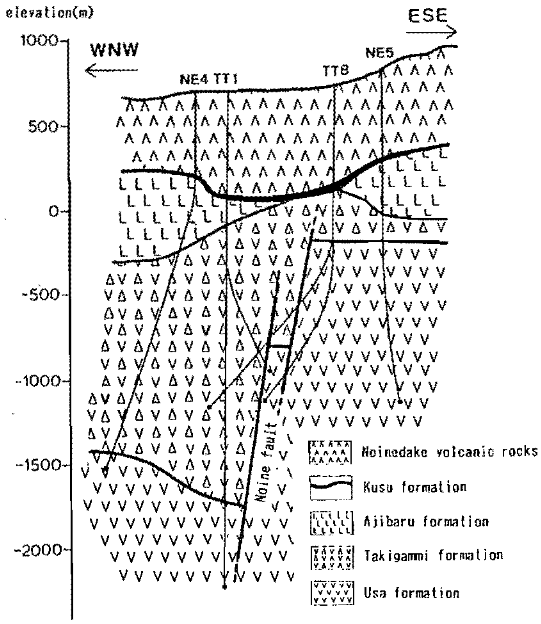

Fig.1 Geologic cross section of the Takigami area

3 Hydrothermal alteration

Based on the classification of UTADA(1980), hydrothemal alteration zones in the Takigami area are classified into two types, acidic and intermediate alteration zone.

Acidic alteration zone

Alteration minerals in acidic alteration zone are considered to be formed from the solution with high hydrogen ion activity. Characteristic minerals of this zone consist of kaolinite, dickite, alunite, and pyrophyllite. Large amounts of anhydrite also occur. Major part of acidic alteration zones are widely distributed in the western part of Takigami formation and have special wide ditribution along Noine fault (Fig.2).

Major part of acidic alteration zones are inferred to be a fossil hydrothermal system, because the Takigami geothermal waters are all of neutral sodium chloride type. Probably, these alteration zones were formed closely related to the faulting of Noine fault.

Intermediate alteration zone

Characteristic minerals of intermediate alteration zone consist of montmorillonite, sericite/montmorillonite, chlorite/montmorillonite, sericite and chlorite, which are cosidered to be formed from the solution that has intermediate ratio of alkali and alkaline earth ion to hydrogen ion activity. Based on the distribution of these minerals, intermediate alteration zones are divided into the following three zones in descending order (Fig.3).

(1) Montmorillonite zone

Montmorillonite zone is widely distributed 300-740m below the surface with a thickness of 220-790m. The boundary of this zone roughly reflects the temperature contours. Quaternary volcanic rocks overlying on the montmorillonite zone are relatively fresh and no alteration minerals are detected by X-ray diffraction analyses except the minor appearance of halloysite.

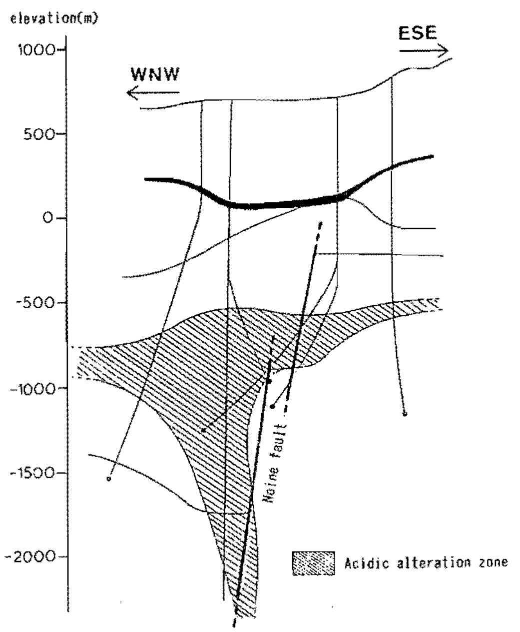

Fig.2 Disribution of acidic alteration zone

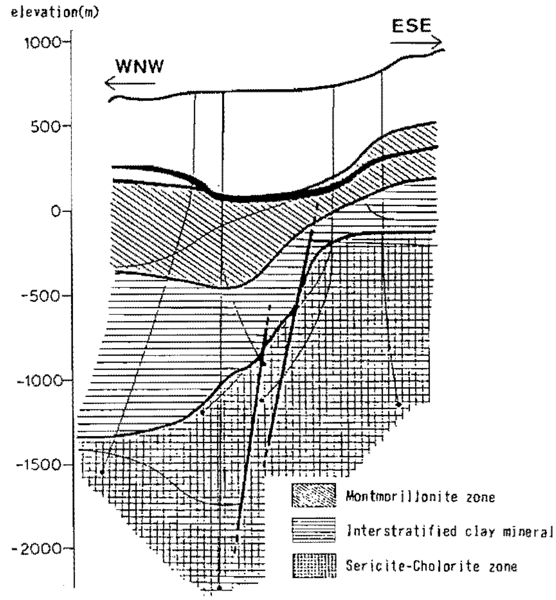

Fig.3 Distribution of montmorillonite, interstratified clay mineral and sericite-chlorite zone.

(2) Interstratified clay mineral zone

Montmorillonite disappears at depths greater than 740-1440m and sericite/montmorillonite is predominant in this zone. Chlorite/montmorillonite is also present in shallower part of the zone. The percentage of montmorillonite layer in sericite/montmorillonite decreases gradually with increasing depth.

(3) Sericite - chlorite zone

Sericite-chlorite zone is characterized by disapearance of montmorillonite layer in sericite/montmorillonite and predominant appearance of sericite-chlorite mineral assemblage. A small amount of epidote is present sporadically. The distribution of the sericite-chlorite zone is roughly concordant with those of Usa formation, suggesting that the alteration type of this zone is correspond to the Tertiary propyritization of Usa formation.

4 Geothermal structure

The Takigami geothermal structure is divided into three layers based on the temperature profiles observed in the wells (Fig.4), which is in descending order as follows;

(1) The first layer : Temperature in this zone is below 50℃ and temperature profile shows low temperature gradient because of the cold meteoric water flows.

(2) The second layer : Temperature profile in this layer shows high temperature gradient and the temperature gradually rises with conductive temperature gradient. There are no water circultion in this layer.

(3) The third layer : Temperature profiles in this layer is almost isothermal with high temperature (160-260℃), which shows the convection of hot water in the geothermal reservoir.

5 Relation between the permeability distribution and the hydrothermal alteration

Quaternary volcanic rocks in the first layer are relatively fresh and porous. These unaltered permeable rocks permit downward movement of cold meteoric water. The lower limit of the first layer coinsides with the upper surface of the montmorillonite zone, which shows that the montmorillonite zone plays the role of an impermeable layer by self-sealing and prevents cold meteoric water from penetrating to the deeper zones (Fig.4). It means no surface manifestation on the Takigami area.

The third layer consists of the deeper part of interstratified clay mineral zone and sericite-chlorite zone, where the content of montmorillonite in serocite/montmorillonite is very low. The low content of expandable and plastic montmorillonite layer contributes to the high permeability in this layer.

Acidic alteration zones are also distributed in the third layer. There are no large lost circulation zone in the wells inside the acidic alteration zone. Acidic alteration zone shows low permeability because the acidic altered rocks are silicified and the fractures are filled with large amounts of anhydrite.

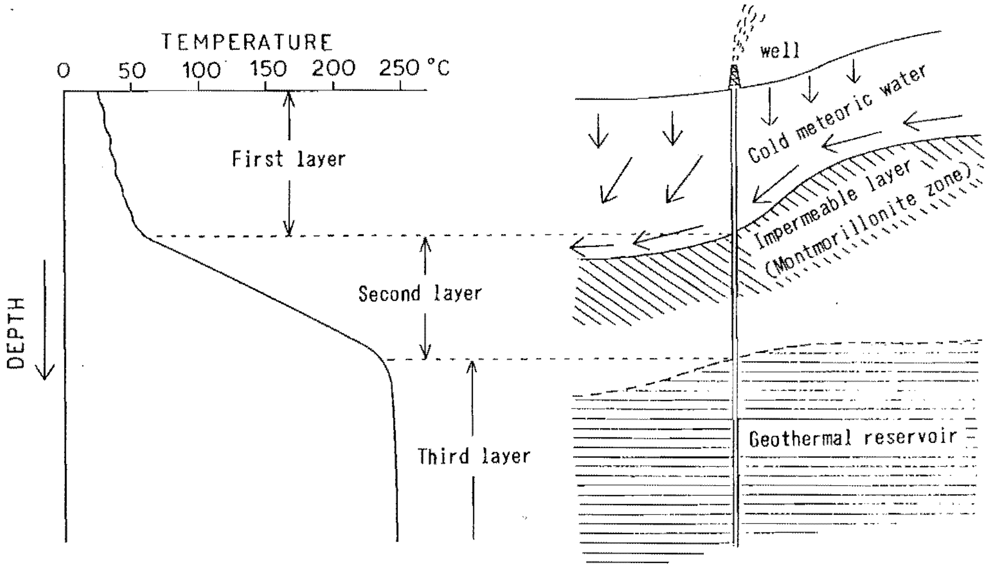

Fig.4 Generalized temperature profile in the wells and geothermal structure

6 Conclusion

1) Montmorillonite zone which is widely distributed 300-740m below the surface forms a thick impermeable layer by self-sealing and prevents the subsurface cold meteoric water from penetrating to the deeper zones. In other words, the reason of no geothermal manifestation at the Takigami area is existence of that impermeable layer. The permeable geothermal resorvoir exists below the montmorillonite zone.
2) Acidic alteration zones in the geothermal reservoir show low permeability. High permeable zones are expected outside the acidic alteration zone.

The detailed investigation of the hydrothermal alteration in the Takigami geothermal area is necessary to explore the high permeable production or injection zone.

Reference

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