

GEOTHERMAL RESOURCES IN THE TAKIGAMI GEOTHERMAL AREA, KYUSHU, JAPAN

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ABSTRACT •

There is no surface manifestation in the Takigami geothermal area. Deep wells drilled in the area have been making clear the geothermal system underneath. They show that geothermal system at Takigami is classified into three different layering units and that N-S trending fault, named Noine fault, separates the area into two parts; the western and the eastern. This paper describes the layered structure, fault-fracture system developed over the area, and hydrothermal alteration, based upon the subsurface information from drilled wells.

INTRODUCTION

Idemitsu Geothermal CO., LTD.(IGC), founded in 1979, has started nationwide exploration of the geothermal resources and has made much progress in the Takigami area, which is located in the southwest part of Oita prefecture, Kyushu island (Fig.1).

The area is in the northeastern part of Hohi geothermal region, which is known to have many geothermal manifestations such as hot springs and fumaroles. However, Takigami area is exceptionally characterized by the absence of surface manifestation. IGC has carried out various kinds of survey in and around the area to clarify the geothermal system and to estimate the geothermal potential in the past 9 years. In addition to these field surveys, more than 20 wells have been drilled. They are used to evaluate the capability to generate electricity, based upon the long term discharge and injection tests, including 3-dimensional model matching with downhole pressure monitoring.

GEOLOGICAL SETTING

This area is located in the Beppu-Shimabara Graven, which traverses middle Kyushu from east to west. The late Pleistocene volcanos are seen inside the Graven.

Lithology in the area can be classified mainly into three geological formation units from the results of drilled wells. The following is a brief description about three formation units.

Late Pleistocene volcanic products are the first unit, which is mainly andesitic volcanic products. Further this unit can be classified into three formations; Noine-dake volcanic rocks (0.4-0.7Ma), Kusu formation, and Ajibaru formation (0.7Ma).

The second unit is early Pleistocene volcanic rocks. It is named Takigami formation. This is also composed of three

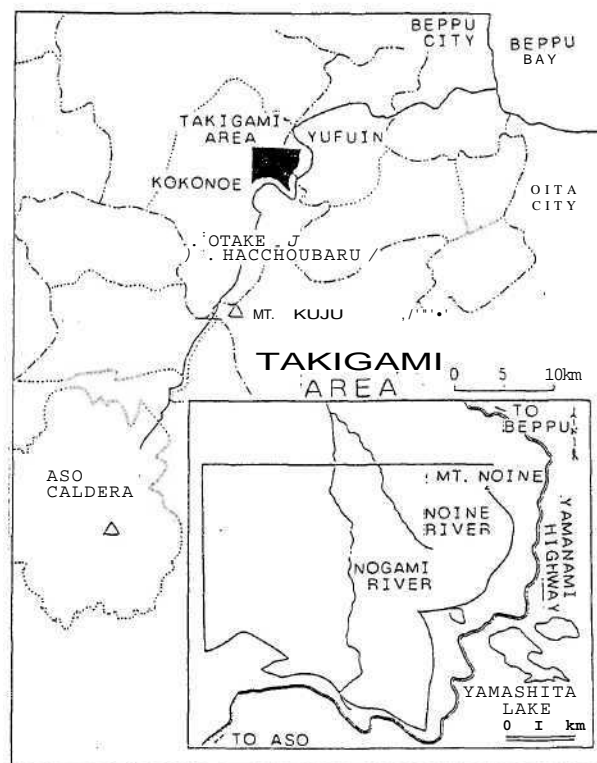


Fig.1. Location map of the Takigami area.

parts. Upper part is dacitic, middle is andesitic, and lower is again dacitic. This formation has a maximum thickness of 1,200 m in the center Takigami and is extremely thin in the eastern.

The third unit is Tertiary rocks, which is named Usa groups. It is made up of entirely altered andesitic lava and pyroclastic rocks with propylitization.

Pre-Tertiary basement rock is not confirmed yet, though many deep wells has been drilled in Takigami.

GEOTHERMAL SYSTEM

LAYERED STRUCTURE

Basically geothermal system at Takigami is likely to be made up of three different layering units from view points of hydrothermal structure.

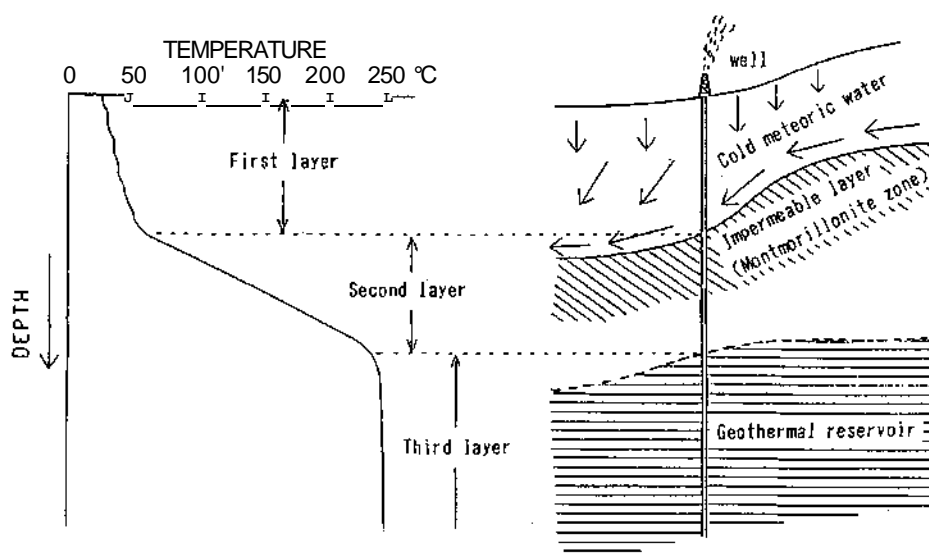


Fig.2. Generalized temperature profile in the wells and layered structure.

The first layer is the zone in which cold meteoric water can circulate and is stored. This is the reason why the temperature is lower than 50°C and also its gradient is very low. That is, the first layer is isothermal zone with low temperature. This zone is geologically corresponding to Quaternary uncompact fresh volcanic products. In electrical logging, it shows original resistive value (30-500 Ohm-m) of rocks, because it doesn't suffer from hydrothermal alteration.

The second layer is impermeable basically. This prevents cold meteoric water from flowing downward and functions as "cap-rock" against the geothermal reservoir underneath the second layer. By this nature of things, temperature profile in the layer shows the pattern of conductive heat flow. That is, thermal gradient is high and constant in the second layer. Impermeable nature of the second layer is due to clay minerals related to the hydrothermal alteration. In fact, the second layer strongly suffers from hydrothermal alteration. And then these minerals make the layer conductive (1-10 Ohm-m) also.

The third layer is equal to geothermal reservoir at Takigami. Both high temperature of $160\text{--}210^{\circ}\text{C}$ and semi-isothermal profile are the third layer's characteristics. Those are the results that geothermal hot water circulates inside the layer by convection. Geologically the third layer is mainly made up of the Tertiary brittle andesite lavas. This layer's rocks also suffer from hydrothermal alteration. But it shows relatively resistive value (10-300 Ohm-m) on logging charts.

Conceptual model of layered structure is shown in Fig. 2.

FAULT-FRACTURE SYSTEM

Lineament study and geological well-to-well correlation clarified several fault-fracture system, which developed over the area and dominated in the three orientations; N-S, NW-SE, and E-W.

N-S trending fault between the eastern and the western part of Takigami area, is certified geologically by the results of

drilled wells. It is named Noine fault. Its strike is from NW-SE to N-S direction and it is dipping westward. Vertical displacement of the fault is drastic and estimated to be more than 1000 meters from Usa Groups' stratigraphic correlation. And also Noine fault is supposed to be accompanied with anomalous basin-like structure on the west side of central part. This basin-like structure gradually becomes almost flat in the western part of the area.

Noine fault is important on thinking about Takigami geothermal system. It is the boundary, which makes various differences between the western and the eastern.

In the eastern part, reservoir appears shallow in depth. The depth of reservoir top is from -600 m to 0 m in elevation. The temperature of reservoir fluid ranges from 160°C to 210°C . It shows high permeability (30-100 T/H/KSC).

In the western part, the reservoir is deeper than the eastern. The depth is from -1,500 m to -600 m. The temperature is high and ranges from 230°C to 260°C . But it shows relatively low permeability (1-15 T/H/KSC).

There's a possibility of another N-S trending fault in the west vicinity of Takigami, inferred from gravity etc. But it is not found yet.

E-W directional faults is not recognized from the geological correlation, because those are thought to have too small vertical displacement to notice. But borehole televiewer (BHTV), which is recently developed and often used, clearly imaged fractures within borehole. According to those images of boreholes, many fracture are observed in the interval at and near the points of "lost circulation" and dominated in the orientation mentioned above.

Above mentioned structure is shown in Fig.3 and Fig.4. And Fig.5 shows the permeability distribution encountered by the wells, with Injectivity Index (I.I.).

Promising permeable points for production or injection are found close to the fault-fracture system mentioned above.

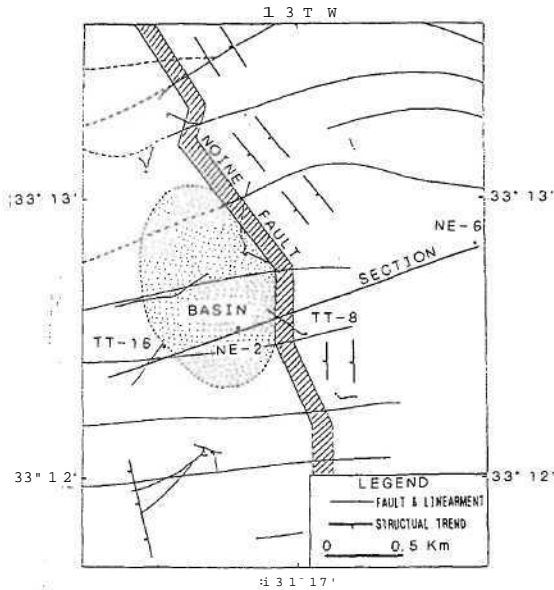


Fig. 3. Conceptual map of geological structure obtained from the correlation of Usa groups.

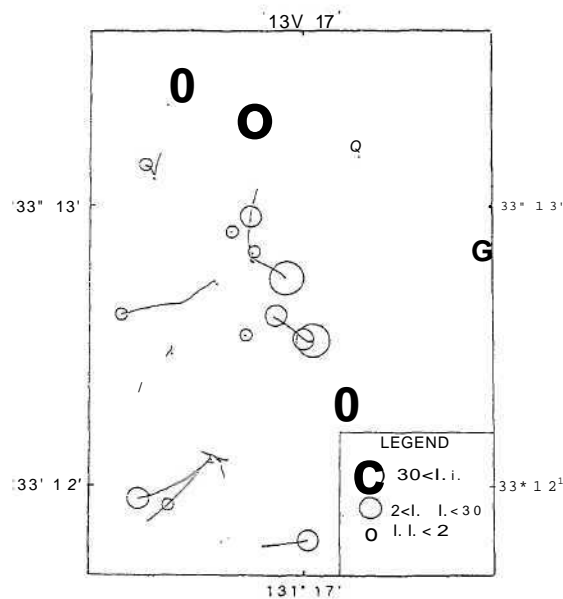


Fig. 5. Permeability distribution map showing injectivity index (I.I.) encountered with the wells. I.I. is obtained from the injection test in each well.

HYDROTHERMAL ALTERATION

The cores and cutting samples from the wells were studied by X-ray diffraction to clarify the nature of hydrothermal alteration. Based on the classification of Utada (1980), hydrothermal alteration zones at Takigami 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. Kaolinite, dickite, alunite, and pyrophyllite are characteristic minerals of this zone. Large amounts of anhydrite also

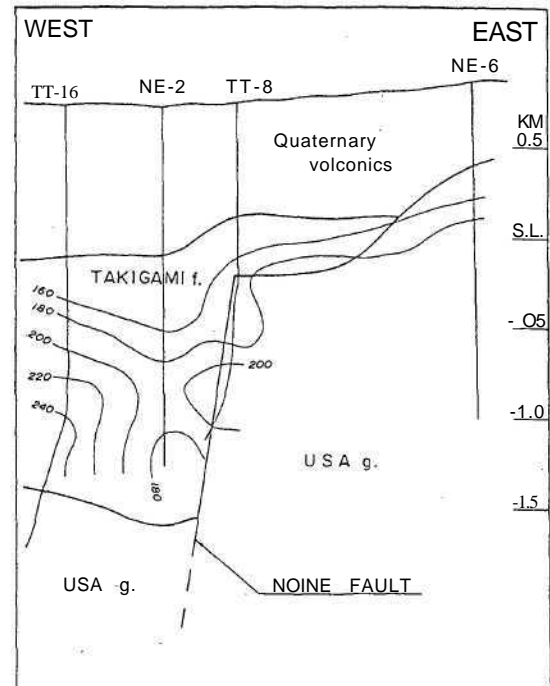


Fig. 4. Schematic E-W cross section of the structure. Location of the section is shown in Fig. 3.

occur in this zone. Major part of acidic alteration zones are widely distributed in the western part of Takigami formation and have special wide distribution along Noine fault (Fig. 6).

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. They are considered 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. 7).

(a) Montmorillonite zone

Montmorillonite zone is widely distributed 300-740 m below the surface with a thickness of 220-790 m. 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.

(b) Interstratified clay mineral zone

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

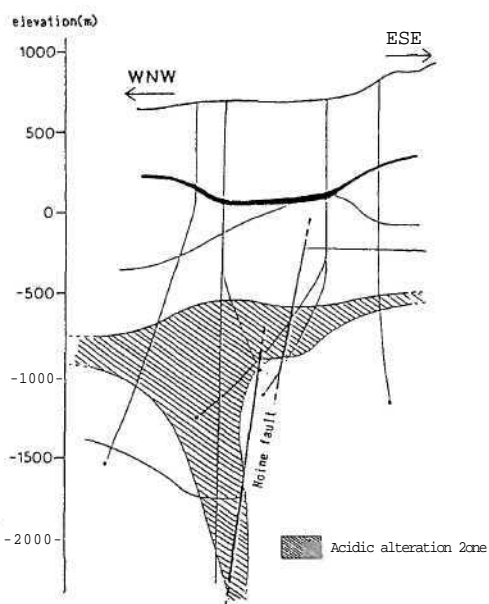


Fig. 6. Distribution of acidic alteration zone in WNW-ESE cross section.

montmorillonite layer in sericite-montmorillonite decreases gradually with increasing depth.

(c) Sericite and chlorite zone

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

RELATION BETWEEN THE PERMEABILITY AND THE ALTERATION

Quaternary volcanic rocks in the first layer are relatively fresh and porous. These unaltered permeable rocks permit down flowing of cold meteoric water. The base of the first layer coincides with the top of montmorillonite appearance. It is well known fact that montmorillonite has a property of swelling by soaking in water. It means that the montmorillonite plays the role to plug up the permeable pore in the rocks with itself and to form an impermeable layer by self-sealing. So it prevents cold meteoric water from penetrating to the deeper.

The third layer consists of the deeper part of interstratified clay mineral zone and the sericite and chlorite zone, where montmorillonite in sericite-montmorillonite is very small in quantity. The small content of montmorillonite is one of the reason to have the third layer permeable.

Acidic alteration zones are also distributed in the third layer. There is no large lost-circulation inside the acidic alteration zone in the wells. Acidic alteration zones show less permeability because the acidic alternated rocks are silicified and the fractures are filled with large amounts of anhydrite.

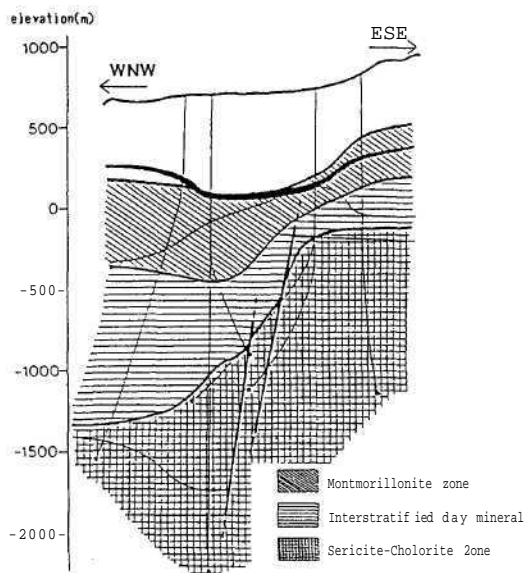


Fig. 7. Distribution of montmorillonite, interstratified clay mineral and the sericite and chlorite zone in WNW-ESE cross section.

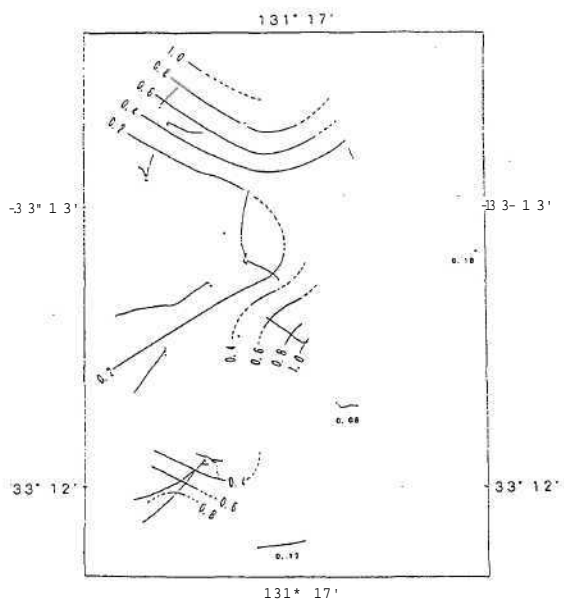


Fig. 8. Ratio map of Zeolite minerals. Ratio is a fractional number of summation of zeolite mineral appearance intervals, divided by drilling length of alteration zone.

Zeolite group such as laumontite and wairakite occurs in the zone with temperature 150-200°C and more than 200°C respectively. These zeolite minerals are abundant at and near the points of lost-circulation in many wells, which is thought to have much thing to do with promising permeable path of geothermal fluid.

On the other hand, zeolite group doesn't occur in the acidic alteration zones in Takigami. These facts suggest that the acidic alteration was made in the past with an other geothermal activity and was out of relation to the present geothermal fluid of neutral sodium chloride type.

CONCLUSION

(1) Geothermal system at Takigami is mainly classified into three layers, which has the following features.

The first layer is composed of unaltered Quaternary volcanic products. Temperature in this layer is below 50 °C, because of circulation of the cold meteoric water.

The second layer strongly suffers from alteration and becomes impermeable. It is due to clay minerals related to the hydrothermal alteration. Temperature profile in the second layer shows the pattern of conductive heat flow.

The third layer is corresponding to geothermal reservoir at Takigami. Both high temperature and semi-isothermal profile are the third layer's characteristics.

(2) Promising permeable points for production or injection are found to be closely related to the fault-fracture system developed over the area. They dominated in three orientation; N-S, NW-SE, and E-W. Especially, N-S trending fault, Noine fault, separates the area into two parts; the western and the eastern.

(3) Prospective zone, which is rich in fracture, can be indicated by Zeolite mineral distribution such as laumontite and wairakite.

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