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PERMEABLE FRACTURES IN THE KAKKONDA GRANITE OF WELL WD-1B, JAPAN

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ABSTRACT

The Kakkonda Granite (Quaternary intrusion) has some feedpoints, which contribute to the steam production for the Kakkonda geothermal power plant. FMI (Schlumberger's Fullbore Formation MicroImager) log, resistivity log, gamma ray log, spinner log and temperature logs from NEDO′s well WD-1b have supplied information for determination of rock name and have revealed distributions of fractures. In the Kakkonda Granite, the fracture density analyzed from FMI log is far less than the other formations and the strike and dip of permeable fractures is partly different from that of the other formations.

INTRODUCTION

The Kakkonda geothermal field, located in northeastern Honshu, Japan (Fig. 1), has been studied by the Geological Survey of Japan (GSJ) since 1958. Japan Metals & Chemicals Co., Ltd. (JMC) investigated the system and drilled several wells to assess its potential for geothermal energy. JMC currently provides steam to power station unit 1 (50 MWe) from 1978, and Tohoku Geothermal Energy Co., Ltd. (TGE) provides steam to unit 2 (30 MWe), in production from 1996.

The project "Deep-seated Geothermal Resources Survey" has been performed by New Energy and Industry Technology Development Organization (NEDO) in order to establish a desirable direction for development of deep geothermal resources, which exist beneath the already-developed shallow reservoirs (Uchida et al.,1997). An exploration well WD-1a has been drilled in this field in 1994-1995 (Fig. 1). WD-1a is the deepest (depth; 3729m) and hottest (temperature; more than 500°C) geothermal well in Japan (e.g. Ikeuchi et al., 1998). WD-1b (depth; 2963m) has been sidetracked at 2193.5m from WD-1a in 1996-1997. By studying FMI log and other logs from WD-1b, we have been able to determine the distributions of permeable fractures in WD-1b in spite of few rock samples with drilling while total loss condition.

GEOLOGICAL SETTING

The Kakkonda geothermal field is hosted by a complex sequence of sedimentary and volcanic rocks, ranging in age from "pre-Tertiary" to Quaternary (Nakamura and Sumi, 1981; Sato, 1982; Kato and Doi, 1993; Kato et al., 1993; Doi et al., 1998). These rocks have been intruded by the 0.07-0.34 Ma Kakkonda Granite (Kanisawa et al., 1994; Doi et al., 1998). Pre-Tertiary formations consists of slate, sandstone and andesitic tuff. Miocene formations in this sequence, andesitic tuff, dacitic tuff, shale and siltstone, are divided into the Obonai, the Kunimitoge, the Takinoue-onsen and the Yamatsuda Formations in order of decreasing age. The Kakkonda Granite, which has been encountered in the geothermal field at depths below 1140-2840m, has metamorphosed formations below the Kunimitoge Formation, with extensive development of biotite, cordierite, anthophyllite, orthopyroxene, andalusite, spinel, magnetite, K-feldspar, and other metamorphic minerals (Kato and Doi, 1993; Doi et al., 1998). WD-1a and WD-1b were drilled to intersect the west part of the Kakkonda Granite, which was emplaced in a north-northwest direction (Fig. 1).

The Kakkonda hydrothermal system consists of reservoir a shallow and a deep, which are hydraulically connected but otherwise with different characteristics (Hanano and Takanohashi, 1993). The shallow part is permeable reservoir of 230-260°C and is elongate in the NW direction (Fig. 1). The deep part is less permeable reservoir of 350-360°C. The shallow reservoir is one to two orders of magnitude more permeable than the deep reservoir (Hanano, 1998).

Permeable fractures in the deep reservoir are located mainly within and at the margin of the Kakkonda Granite. Seven deep wells have encountered the Kakkonda Granite. In five wells of the seven wells, the lost circulation occurred within twenty meters of the margin of the Kakkonda Granite (Fig. 2a). A drilling while total loss condition have usually provided few rock samples and little information about new permeable fracture. In this field, however, spinner logs of these wells during injection and production test have made clear the depth of permeable fractures in the Kakkonda Granite (Figs. 2b, 2c).

LITHOLOGY AT WD-1B BY LOG DATA

Open-hole loggings, FMI log, resistivity log, natural gamma ray spectrometry log, have been done at the depth interval of 2200m to 2910m in WD-1b. WD-1b drilled the formations below 2488m depth while total loss condition. We have determined the rock name among the depth with total loss interval, 2488m to 2963m, by interpretation of these logs and rock samples collected at three depths (Fig. 3). The lithofacies of WD-1a has supplied a hint for the determination of that of WD-1b, because WD-1b was drilled near WD-1a (Fig. 1). The Obonai Formation is distributed from 2240m to 2624.67m depth, and pre-Tertiary formations is distributed from 2624.67m to 2839.48m depth. The intensity of the gamma ray changes remarkably at 2624.67m. The potassium content of the Obonai Formation, which consists of andesitic tuff, is relatively low. In contrast, that of pre-Tertiary formations, which mainly consists of slate and sandy slate, is relatively high, because slate and sandy slate are rich in muscovite and biotite. The resistivity of the Obonai Formation is also different from pre-Tertiary formations. The Kakkonda Granite is distributed from 2839.48m to 2963m depth (total depth). The resistivity of the Kakkonda Granite in WD-1a and JMC′s wells is ~1000 Ωm. In WD-1b, the resistivity is high below ~2840m depth, and the FMI image shows the clear distinction in its texture between the Kakkonda Granite and the pre-Tertiary formations at the depth of 2839.48m (Fig. 4)

FRACTURE DISTRIBUTION IN WD-1B

Interpretation of FMI log

Through detailed study of FMI logs from WD-1a, we have been able to identify seven groups of planar structures: Bedding; conductive fracture; closed fracture; fault; intrusion boundary; drilling-induced tensile fracture; and others (Kato et al.,1998). We have divided fractures in WD-1b into conductive fracture and closed fracture from FMI image. Conductive fractures correspond to thin conductive sine waves on these images (Fig. 5). Closed fractures mean the mineral veins, which was filled with highly resistive minerals (e.g. quartz, anhydrite). They appear as thin, high-resistivity sine waves.

Determination of Permeable Fractures

Temperature logs and the spinner log during injection test have been done at the depth interval of 0m to 2950m in WD-1b (Fig. 3). We used the cool drilling fluids, actually river water, during drilling because of total loss condition. The temperature log was done after 3.5 hours from finish of drilling operation. The cool drilling fluids, which invaded the fractures, keep the low temperature from thermal recovery such a short time. The permeable fractures are located at localized lows on the temperature logs. The depth of lost circulation, the temperature logs, and the spinner log have revealed permeable zones at eleven depths in WD-1b (Fig. 3).

The strike and dip of the permeable fractures at the depths of permeable zones has been determined by the interpretation of FMI image. Figure 5 shows the log data and FMI image about the permeable zone in the Kakkonda Granite. The temperature gradient of TEM, which is temperature at outside of the FMI sonde while water injection during logging, changes steeply at 2851-2851.7m depth. Moreover, the resistivity of formation around this depth is relatively low. It shows the existence of the permeable fractures in this depth. The conductive fractures within 2851-2851.7m depth have been determined permeable.

In the case of Tertiary and pre-Tertiary formations, the log data does not show just permeable fractures, because the data have little distinction in permeability of fractures. In this case, the permeable fracture has been determined by the apparent width of the conductive part on the FMI image. If the conductive fracture located within the permeable zone has over 5 cm, the fracture is permeable.

Fractures from FMI Interpretation

Figures 6 and 7 show the orientation of conductive fractures and closed fractures interpreted from the FMI log. The fracture density of spot core (pre-Tertiary formation) from core observation is 89 fractures par 10m (frac/10m). The fracture density from FMI interpretation is underestimated by reason of the difference of resolution for the fracture detection. The fracture of the core is identified to a thickness of 0.1 mm. However, FMI log cannot detect fractures less than 5 mm wide (Schlumberger′s FMI interpretation manual).

In the Obonai Formation, a lot of conductive fractures strike N0°E to N50°E and dip 10-45° SE, and some of them strike N10°W to N50°W and dip 10-45°NE, and some of them strike N20 °E to N80°E and dip 60-90°NW. The fracture density of the Obonai Formation is mainly 40-80 frac/10m, 52 frac/10m on an average, except the depth interval in poor data (Fig. 6).

In the pre-Tertiary formations, a lot of conductive fractures strike N10°E to N90°E and dip 5-45°SE. These fractures are characteristic of low dip angle. The conductive fractures dipping high angle strike NW and NE. The fracture density is 20-40 frac/10m, 28 frac/10m on an average, and is different between sandy slate and slate. The sandy slate has a lot of fractures in comparison with the slate (Fig. 6).

In the Kakkonda Granite, the conductive fractures strike mainly NE and dip 20-50°SE. The conductive fractures dipping high angle strike ENE. The fracture density is mostly less than 10 frac/10m, but the fracture density at the margin of the Kakkonda Granite is 24 frac/10m. It correspond with the occurrence of the lost circulation at the other wells in the Kakkonda geothermal field (Fig. 2).

The number of conductive fractures and closed fractures is different at every formations. The fracture density in the Kakkonda Granite is far less than that in the Obonai Formation and the pre-Tertiary formations (Fig. 6). This discrepancy also has been known in observation of spot cores in well WD-1a (Kato et al., 1998). The distribution of the fractures within the Kakkonda Granite is partly different from that of the Obonai Formation and the pre-Tertiary formations. The fractures striking NNE and dipping at a high angle (more than 60°), and the fractures dipping at a low angle (less than 20°) have not been formed in the Kakkonda Granite (Fig. 7). The difference in the fracture density and distribution between the Kakkonda Granite and the other formations may reflect the young age of the Kakkonda Granite as well as its unique physical properties.

Permeable Fractures in WD-1b

The permeable fractures in the Obonai Formation strike N20°E to N35°E and dip 26-42 °SE, and strike N84°W and dip 15°SE (Fig. 7). The permeable fracture dipping at a high angle strikes N19°E and dips 79°NW. These have widths of 5-20 cm in conductive part on FMI image. In pre-Tertiary formations, the permeable fractures dip at a high angle (more than 54°). These strike N8°E to N21°E and dip 70-82°NW, and strike N44°W and dip 54°SW, and have widths of 5-25 cm in conductive part on FMI image. The distribution of permeable fractures is not correspond with highly distribution of the conductive fracture.

In the Kakkonda Granite, most of the permeable fractures dip easterly (Fig. 7). These strike mainly NE and dip 28-89°SE, and have widths of 0.5-10 cm (mostly 0.5-5 cm) in conductive part on FMI image. Although the number of the fractures is less than the pre-Tertiary formations, permeable zone in the Kakkonda Granite is more than that in the pre-Tertiary formations. It suggests that a number of permeable fracture is independent of a fracture density.

CONCLUSIONS

The lost circulation depth, temperature log, spinner log, and FMI log has revealed the permeable fractures in well WD-1b. The fracture density within the Kakkonda Granite is far less than the other formations. The strike and dip of fractures within the Kakkonda Granite is partly different from that within the other formations.

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Fig. 1. Generalized geology of the Kakkonda geothermal field showing well locations (modified from Kato et al., 1998). 1: Permeable zone in the shallow reservoir, 2: dacite intrusion, 3: anticlinal axis, 4: synclinal axis, 5: fault (ornaments on downthrown block), 6: contour of the top of the Kakkonda Granite (relative to sea level), 7: drill pad, 8: power plants.

Fig. 2. Distances between the margin of the Kakkonda Granite and the permeable fracture in deep wells in the Kakkonda geothermal field. Distance; vertical distance from the margin of the Kakkonda Granite. Host rocks; Pre-Tertiary and Tertiary formations. (a) Number of lost-circulation points. (b) Number of injection points by injection test. (c) Number of feedpoints by production test.

Fig. 4. The FMI image around the top of the Kakkonda Granite in well WD-1b. The Kakkonda Granite has been intruded up to 2839.48m depth shown by broken lines. FMI; Schlumberger’s Fullbore Formation MicroImager. Arrow shows a permeable fracture. Bright color indicates high resistivity, dark color indicates low resistivity in the image. RES; Resistivity, GR; Gamma ray.

Fig. 5. Resistivity, gamma ray, temperature data and FMI image in the Kakkonda Granite from well WD-1b. Arrow shows permeable fractures in 2850-2852m. TEM; Temperature while water injection.

Fig. 3. Casing, geologic column, lost-circulation (L/C) point and log data in well WD-1b. Rock name has been known by resistivity and gamma ray log, and temperature and spinner log make clear the depth of permeable fractures. The spinner log was done while water injection. *1; Rocks collected by junk sub. 1; Andesitic tuff, 2; Siliceous tuff, 3; Dacitic tuff, 4; Slate, 5; Sandy slate, 6; Biotite hornblende tonalite, 7; No rock sample. K; Kunimitoge Formation, O; Obonai Formation, P; Pre-Tertiary, G; Kakkonda Granite.

Fig. 6. Interpretation of results from FMI log in well WD-1b. Legend of lithology is same as in Fig. 3. (a) Dip azimuth of conductive fractures and closed fractures. (b) Dip angle of conductive fractures and closed fractures. (c) Number of conductive fractures and closed fractures per 10 meters. *1; FMI image data is poor by bad borehole wall condition in the depth interval of 2286m to 2303m. *2; Fracture density from spot core. (d) Depth of permeable fracture.

Figure 7. p-pole diagrams of fractures from FMI interpretation at the permeable fracture depths in well WD-1b. Equal-area, lower-hemisphere projection. All fractures, 1(square): conductive fracture, 2(triangle): closed fracture. Permeable fracture, 1(open circle): apparent width of low resistivity is from 5 mm to 10 cm, 2(solid circle): apparent width of low resistivity is over 10 cm.

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