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FRACTURE INVESTIGATION OF THE GRANITIC BASEMENT IN THE HDR OGACHI PROJECT, JAPAN

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ABSTRACT

Natural fractures developed in the granitic basement at the Ogachi Hot Dry Rock (HDR) experiment site were investigated in order to evaluate the reservoir characteristics. The granitic basement is located inside a Neogene caldera, in a zone where the basement is uplifted and also in a NNW-trending mylonite zone.

Natural fractures are highly developed in the Ogachi HDR reservoirs, especially in the upper one (~700 -900 m in depth). This supposedly is due to hydrothermal brecciation associated with the caldera formation. Mylonitization seems to have had little effect on the natural fracture formation. Chlorite, epidote, anhydrite and calcite veins were observed. Anhydrite veins are dominant in the lower reservoir (~900 -1100 m in depth). This explains the result that a high content of calcium and sulfate ions was detected in the returning water from the lower reservoir and indicates that the reaction between anhydrite and injected water was extensive.

Fracture orientations in both the injection and production wells were revealed by BHTV surveys. Overall, fractures with high dips are dominant throughout the reservoir. No dominant orientations were observed in the upper reservoir, whereas in the lower reservoir, fractures with a N-S trend and moderately-high W dips are dominant in the injection well and those with a NE-SW trend and high SE dips are dominant in the production well. It was assumed from AE analysis that artificially induced hydraulic fractures propagated to the east and to the NNE in the upper and lower reservoirs, respectively. From the standpoint of fracture analysis, the propagation of hydraulic fractures is largely restricted to the natural fracture system. This is because the eastward propagation in the upper reservoir coincides with relatively thick veins and andesite dikes oriented along an E-W trend. The NNE propagation of the lower reservoir coincides with the dominant natural fracture orientations in the lower reservoir.

1. INTRODUCTION

The Central Research Institute of the Electric Power Industry (CRIEPI) has been conducting a hot dry rock experiment at the Ogachi site in the northeast part of Japan since 1989. In the Ogachi experiments, two artificial reservoirs were created at ~720 m and ~1000 m depth, respectively. Our main results are that the upper and lower reservoirs extended to the east and to the NNE from the injection well (OGC-1), respectively, and during an initial circulation test involving both reservoirs, the water recovery was only 4% (Hori et al., 1995). This paper deals with the recent results of a natural fracture investigation based on core samples and BHTV logs from the production well (OGC-2). This study was conducted in order to define the reservoir characteristics. OGC-2 was drilled in 1992 to a depth of 1100 m and a final diameter of 97.8 mm.

2. GEOLOGICAL SETTING

The Ogachi HDR site is situated inside a Neogene caldera (Fig. 1). The Ogachi caldera formed between 6 and 2 Ma (Takeno, 1988; Ito, 1996) due to an intense felsic volcanic activity. The size of caldera is ~30 km long and ~20 km wide. The caldera is not so obvious topographically, but its structure can be defined from gravity data (Takeno, 1988). The basement of the Ogachi site is granodiorite. It is estimated to have been intruded at ~100 Ma (Sasada, 1985). Outcrops of the granodiorite occur mainly on the western rim of the caldera and sporadically inside the caldera. Mylonitization occurred at 100-50 Ma in a zone with a NNW trend (Sasada, 1984).

Nearly vertical block movement occurred before and during caldera formation. Presumably it ceased during the late stages of caldera formation (Fig. 2). The Ogachi site is located on a "horst", that is, an area where the top of the basement is higher than its surroundings. The vertical displacement of the blocks between the Ogachi site and the Akinomiya site to the SW is more than 1000 m (Fig. 2, 3).

The Torageyama formation, which was deposited when the Ogachi caldera was formed, covers the area around the Ogachi site (Fig. 3). Quaternary volcanic products also cover the area around Mt. Yamabushidake, which is located ~3 km east of the Ogachi site. An inferred concealed fault which trends NW-SE with a steep dip is located ~500 m west of the Ogachi site (Fig. 3). It was inferred mainly from recent seismic reflection and electromagnetic data. The Torageyama formation, which is ~300 m thick, covers the basement. The elevation of the top of the basement is nearly constant around the Ogachi site, suggesting that no major faults exist nearby (Fig. 4). However, the top of the basement in well N8-AY-1, which was drilled by New Energy and Industrial Technology Development Organization (NEDO) in 1997, is ~250 m higher than that in OGC-2. During drilling, minor lost circulation of 20 l/min occurred at ~1060 m depth in OGC-2 and major lost circulation of > 100 l/min occurred at ~1300 m depth in N8-AY-1. We assume that the latter corresponds to the inferred concealed fault mentioned above (Fig. 3).

3. NATURAL FRACURE INVESTIGATION

3.1 Core survey in OGC-2

A core survey was performed from depths of 700 to 1100 m in OGC-2, which corresponds to the entire open section of the well (Fig. 5). The investigation focused on natural fractures developed in the core samples, with the help of some thin sections and XRD analyses. Overall natural fractures are intensely developed in the reservoir, and parts of the core sections exist as aggregates of “rubble” or lithic fragments. As shown in Figure 5, aggregates of rubble and dike intrusion are dominant in the upper reservoir (700 - 900 m), whereas mineral-filled veins (mostly epidote, chlorite, anhydrite) are dominant in the lower reservoir (900 - 1100 m). Druses are found commonly in the middle of the reservoir (~900 m). The open space in the druses is mainly 1-2 mm or less. Calcite is commonly found in the aggregates of rubble and also in the druses. Therefore, the upper reservoir should be permeable. Except for some small druses, natural fractures are mostly sealed by hydrothermal veinlets. However, natural fractures in the aggregates of rubble may not be sealed completely because of the existence of calcite. The fact that anhydrite veins are dominant in the lower reservoir corresponds well with geochemical data, in which a high level of calcium and sulfate ions was detected in the returning water from the lower reservoir (Kiho and Mambo, 1994). It also indicates that the reaction between anhydrite and injected water was extensive.

Hydrothermal brecciation is observed throughout the open section and is especially prominent in the upper reservoir. In thin section, mylonite breccias are embedded in finer materials of the same origin. As hydrothermal brecciation occurs in extensional stress regimes (Phillips, 1972), it should have occurred during caldera formation. The hydrothermal brecciation probably contributed to the intense natural fracture system in the reservoir.

In order to estimate the contribution of the mylonitization to the natural fracture system, the orientations of natural fractures are plotted against the mylonite foliation, whose trend is shown as approximately north (Fig. 6). Overall there is little correlation between them, although some fractures are almost parallel to the foliation (A in Fig. 6).

3.2 BHTV survey in OGC-2

In 1998, BHTV logging was performed in the range of 700 - 1075 m in OGC-2. During the logging, water was injected at the rate of 9 m^3/hour in order to keep the logging tool cooler than its maximum durable temperature of 120 °C. A total of 899 fractures was picked up. High quality data were obtained from 700 to 840 m in depth, whereas poor quality data were obtained at depths greater than 840 m because of instrument problems. Even in the low quality data, andesite dikes were clearly identified and successfully oriented because they showed clear contrast in the BHTV image. The BHTV results show that fractures with high dips are dominant throughout the reservoir (Fig. 7). No dominant orientations exist in the upper reservoir, whereas in the lower reservoir, fractures with a N-S trend and moderately-high W dips are dominant in OGC-1 and those with a NE-SW trend and high SE dips are dominant in OGC-2 (Fig. 7). The NE-SW-striking fracture set is remarkably concordant with the AE hypocenter distribution measured during stimulation of OGC-2. Therefore, it is clear that natural fractures should play an important role in the reservoir creation in OGC-2. In Figure 8, the orientation of andesite dikes in the entire section and that of thick veins at ~1060 m in depth are plotted. Andesites in the upper reservoir intruded along an E-W trend, and those in the lower reservoir intruded in along a NE-SW trend. Thick veins show the same orientation with the prominent orientation of the lower reservoir in OGC-2. Because some andesite dikes have striated faults on their boundaries and thick veins at ~1060 m contain anhydrite, both of them seem to be permeable fractures.

In the Ogachi experiments, the upper and lower reservoirs extended to the east and NNE from OGC-1, respectively. Kondo (1994) assumed, from a survey of OGC-1, that the eastward propagation in the upper reservoir is due to the fact that thick veins are oriented in the same direction. Because andesite dikes show the same orientation (Fig. 8), they may also have contributed to the upper reservoir propagation. In the lower reservoir, it is clear that the dominant fractures are oriented along NE-SW or NNE-SSW trends, although they dip westward in OGC-1 and eastward in OGC-2 (Fig. 7). Permeable fractures, such as andesite dikes and thick veins, show NE-SW trends with SE dips in the lower reservoir in OGC-2 (Fig. 8). Therefore, it seems that the NNE propagation of the lower reservoir was strictly influenced by the natural fracture system. In conclusion, the natural fractures seem to have strongly controlled creation of the reservoir at the Ogachi site.

4. CONCLUSIONS

1) Natural fractures are highly developed in the Ogachi HDR reservoirs, especially in the upper one. This is supposedly due to hydrothermal brecciation associated with the caldera formation.

2) Anhydrite veins predominate in the lower reservoir and they reacted with injected water extensively.

3) Natural fractures with high dips are dominant throughout the reservoir and most natural fractures are oriented along NE-SW or NNE-SSW trends with steep SE dips in the lower reservoir especially around OGC-2.

4) It seems that natural fractures strongly controlled the creation of the reservoir at the Ogachi site.

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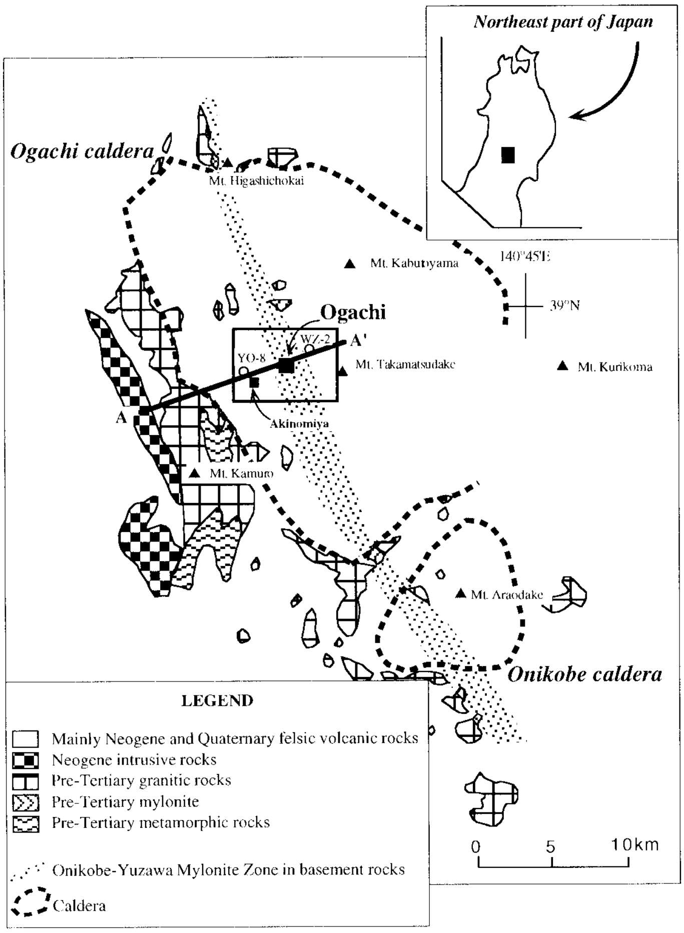

Fig. 1 Geology around the Ogachi HDR site. Modified from Sasada (1984) with the caldera positions from Takeno (1988).

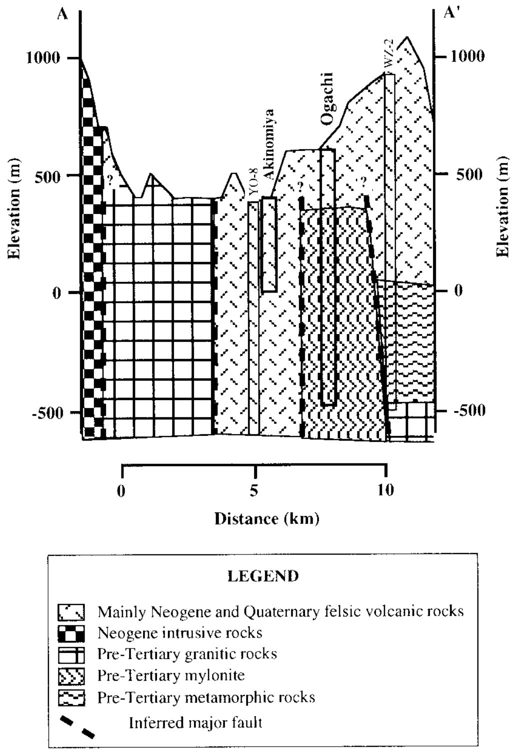

Fig. 2 Cross section of A-A' in Fig. 1

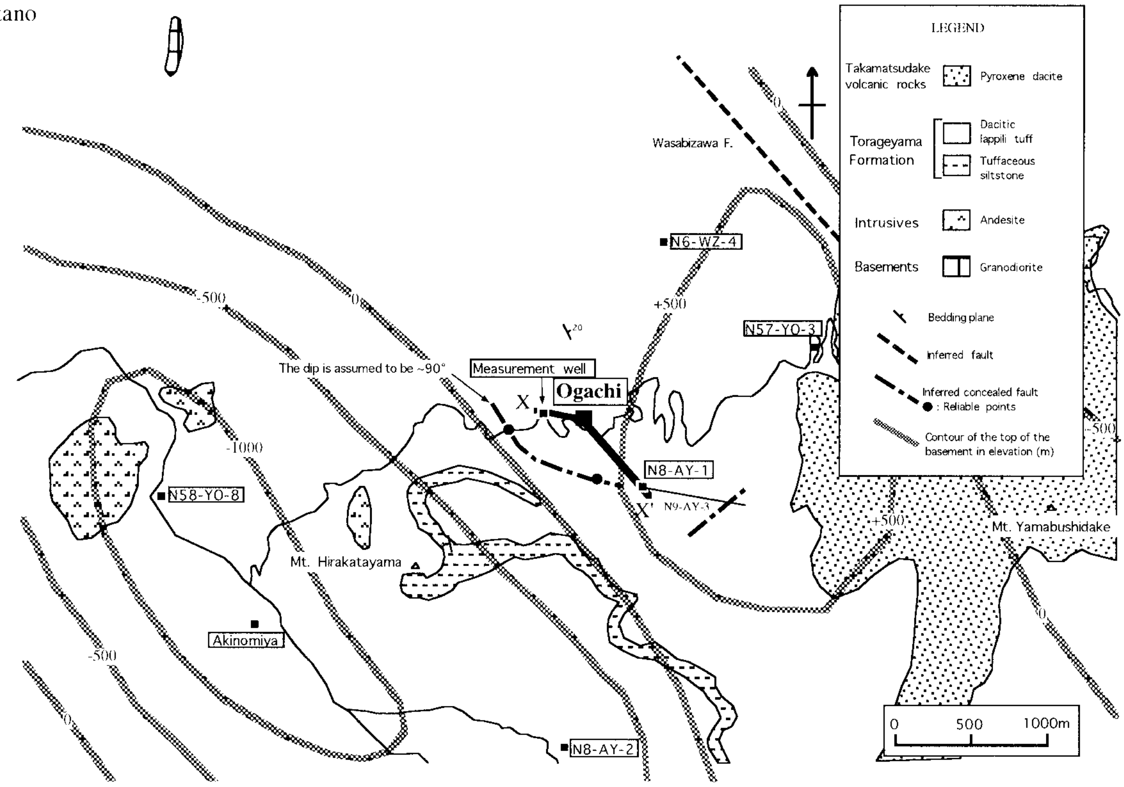

Fig. 3 Detailed geology around the Ogachi HDR site. The area corresponds to the inset of Fig. 1.

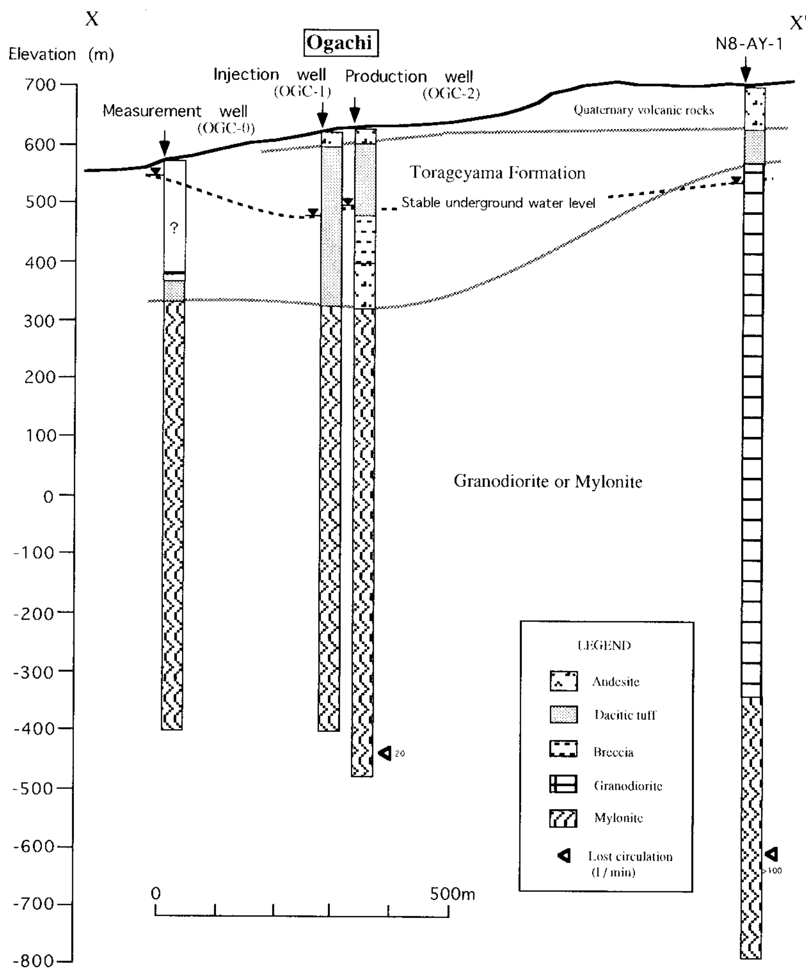

Fig. 4 Cross section of X - X' in Fig. 3.

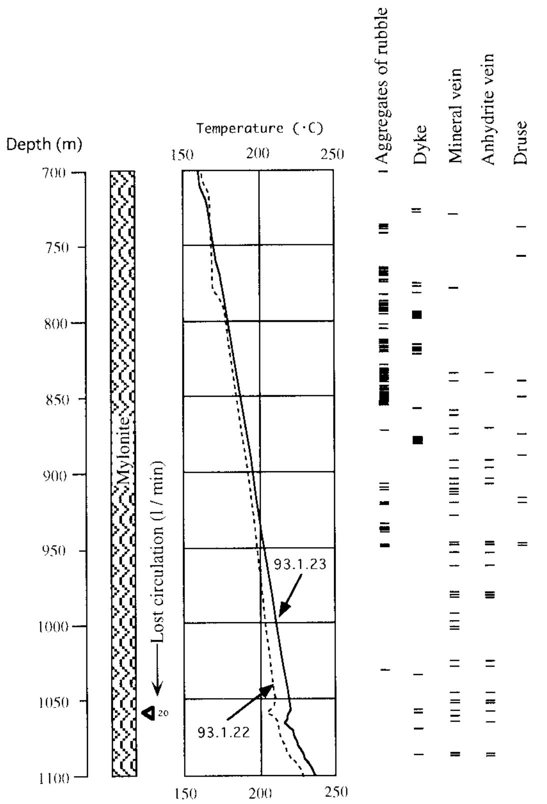

Fig. 5 Core analyses of the production well (OGC-2). Mineral vein, anhydrite ($CaSO_4$) vein with >5 mm thick are picked up.

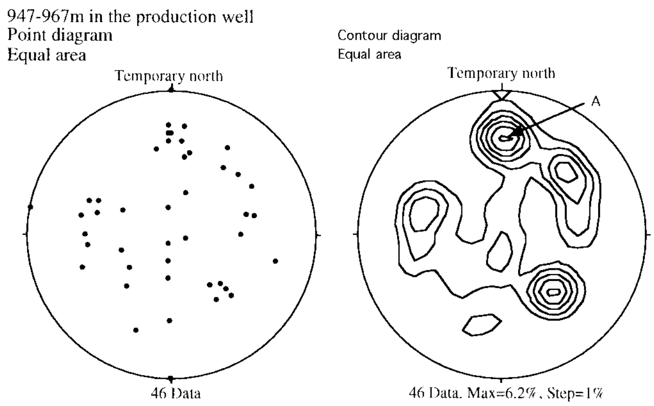

Fig. 6 Correlation between mylonite foliation (shown as temporary north) and natural fractures.

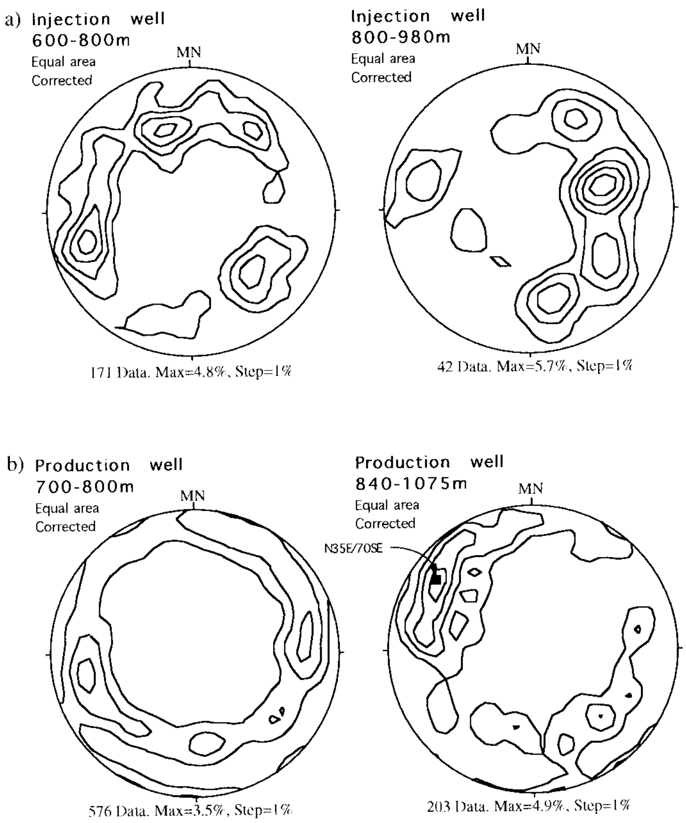

Fig. 7 Orientation of natural fractures revealed by BHTV survey. a) Injection well (OGC-1). Modified from Kondo (1994). b) Production well (OGC-2).

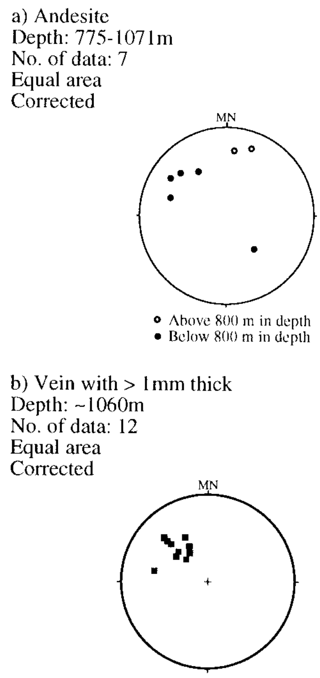

Fig. 8 Orientation of some natural fractures in the production well (OGC-2) revealed by BHTV survey.