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An Overview of the Ogachi HDR Project—Verification of the Reservoir Evaluation Methods Using Data from Well OGC-3

Hisatoshi Ito, Hideshi Kaieda, Koichi Suzuki, Hiroshi Suenaga, Kenzo Kiho,
Koichi Shin, Kenichiro Kusunoki, Koichi Kitano and Yoshinao Hori

Central Research Institute of Electric Power Industry (CRIEPI)
1646 Abiko, Abiko city, Chiba, 270-1194, Japan

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ABSTRACT

At the Ogachi HDR project, two initial wells (OGC-1 and-2) were drilled and several circulation tests of an upper and lower reservoir were conducted using this well pair. A new well, OGC-3, was drilled in 1999 to verify the reservoir evaluation methods established to date. In the new well, natural fracture orientations are similar to those in the initial wells, whereas in the deeper section of the well, another dominant fracture orientation was revealed. Optical fiber temperature monitoring was successfully used to detect flowing points in well OGC-3. This new well also provides additional information to characterize the stress field in the Ogachi reservoir.

Introduction

Beginning in 1989, a Hot Dry Rock (HDR) geothermal power exploitation test has been conducted at the Ogachi site, located in Akita Prefecture in northeast Japan. As shown in Figure 1, the Ogachi HDR test site is located within a Neogene caldera with uplifted granodiorite basement and a NNW-trending mylonite zone (Ito and Kitano, 2000). As shown in Figure 2 (overleaf), seismic reflection and electromagnetic survey results (Suzuki *et al.*, 2000) infer the presence of a concealed vertical fault located approximately 500 m west of the Ogachi site.

In the Ogachi experiment, a 1,000m injection well (OGC-1) and a 1,100m production well (OGC-2) were initially drilled. Two reservoirs (upper and lower) were created by hydraulic fracturing in well OGC-1; the upper reservoir extends in the east direction and the lower reservoir extends in the NNE direction (Figure 3, overleaf). Several circulation tests were performed between wells OGC-1 and OGC-2 (Kaieda *et al.*, 2000; Kitano *et al.*, 2000), as illustrated in Figure 4 (overleaf). During circulation tests, the initial water recovery was only 2%; however, water recovery increased to 24% after two changes were made to the injection/production system: 1) well OGC-2 was hydraulically stimulated; and 2) well OGC-1 was deepened by approximately 27m, thus extending the bottom-hole water injection interval (Kaieda *et al.*, 2000).

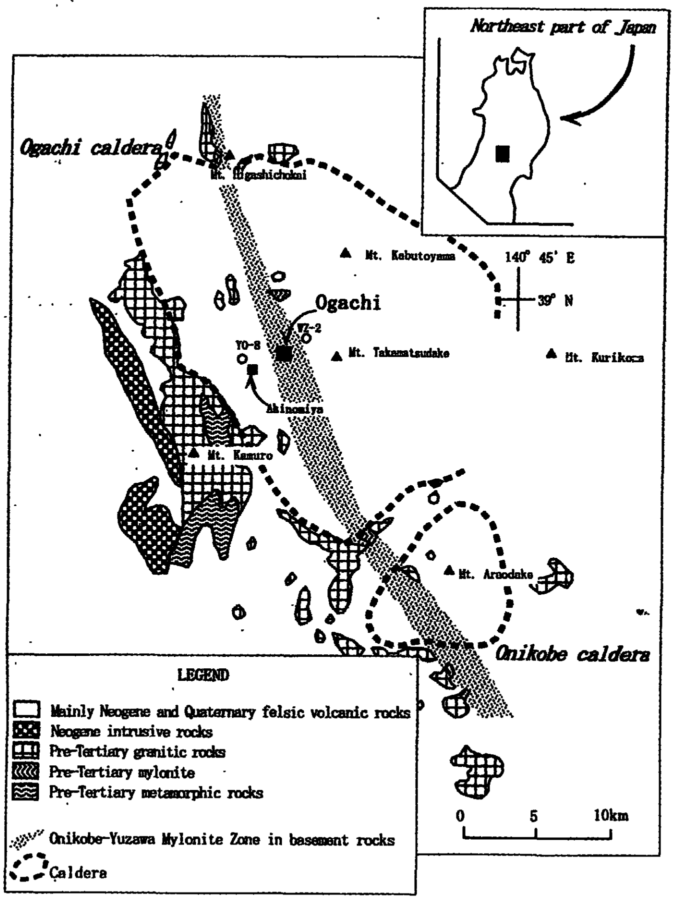


Figure 1. Locality and geology around the Ogachi HDR site (Ito and Kitano, 2000).

The results of drilling, logging and testing of these two wells give rise to two primary questions of interest:

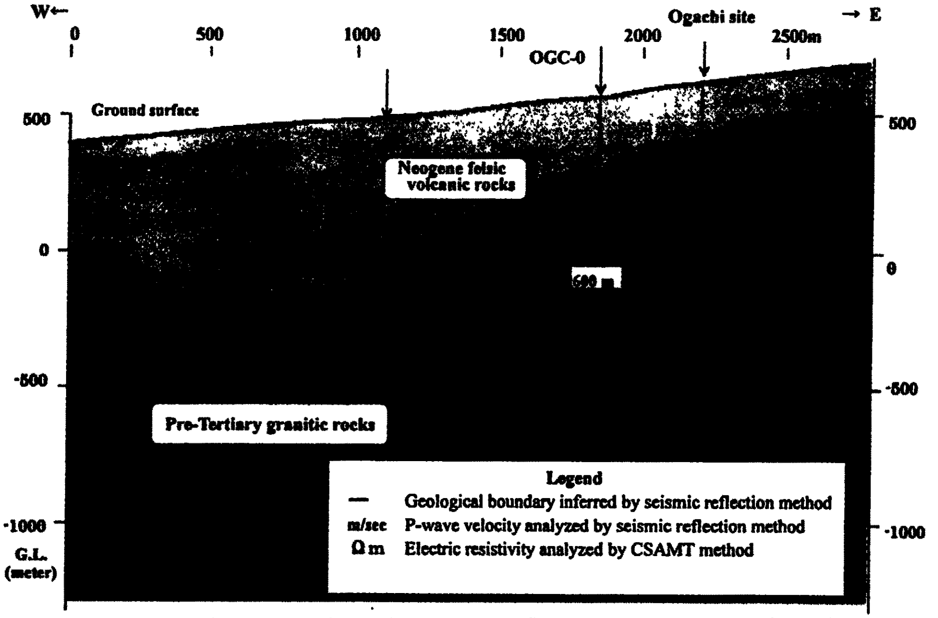


Figure 2. Geological structure inferred from seismic reflection survey (Suzuki and Kaieda, 2000).

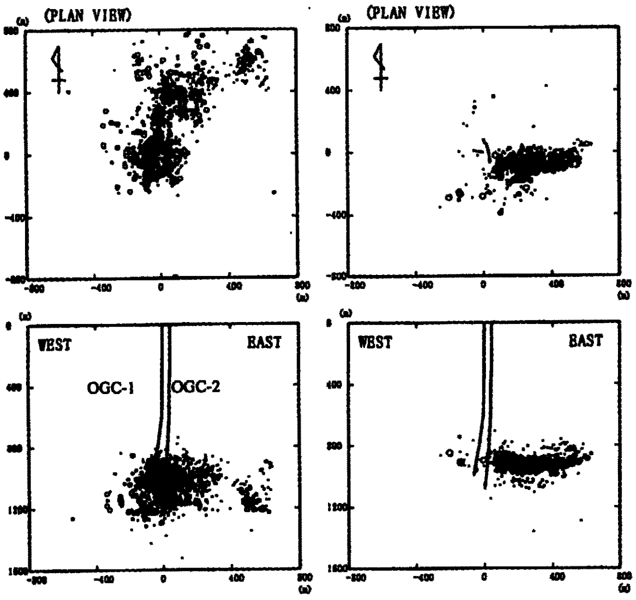


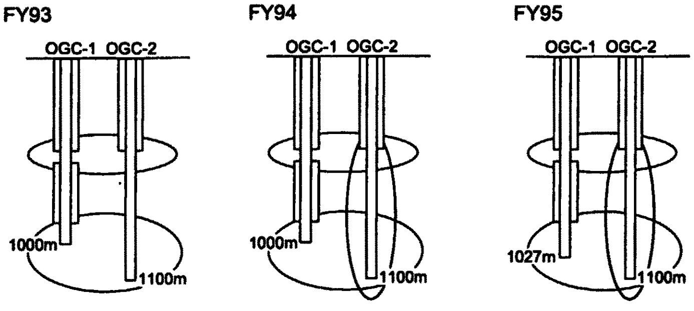
Figure 3. AE hypocenter locations.
Left top: plan view for the lower fracturing;
Left bottom: east-west cross section view for the lower fracturing;
Right top: plan view for the upper frcturing;
Right bottom: east-west cross section view for the upper fracturing (Kaieda *et. al.*, 2000).

1) Why do the fractures in the upper and lower reservoirs have different orientations?

2) Why are there excessive water losses in the system?

To answer these questions, the stress field and the characteristics of the natural fracture system have been studied extensively; results are summarized by Ito and Kitano (2000) and Shin *et al.* (2000a). The extension of the reservoir was explained fairly well by dominant natural fracture orientations and stress field. A numerical model of the field (using the simulation code GEOTH3D) was developed to help predict the behavior of underground water flow, after being calibrated by matching the results of a 1-month circulation test conducted in 1995; results are presented in Suenaga *et al.* (2000).

In 1999, a new well (OGC-3) was drilled to 1,300 m to verify these previous conclusions about the characteristics of the Ogachi reservoir. Following well completion, various geophysical logs were run. An optical fiber temperature monitoring with FMI (Formation MicroImager from Schlumberger) and UBI (Ultrasonic Borehole Imager from Schlumberger) detected several flowing fractures in well OGC-3. The FMI and UBI logs were also analyzed to reliably evaluate the stress field.



FY	Experiment	Injection			Production		
		Flow Rate	Wellhead Pressure	Total Water Volume	Flow Rate	Temperature	Recovery
		l/min	MPa	1000m³	l/min	Max:°C	%
93	22 days Circulation	750 1200	17 19	21	12 30	109	2
94	5 months Circulation	500 750	13 16	140	50 65	155	10
95	1 month Circulation	500 750	7 9	24	125 150	170	24

Figure 4. Main results of circulation tests at the Ogachi HDR test site.

Drilling of Well OGC-3

The OGC-3 well was drilled almost vertically to a depth of approximately 400m and then with an inclination of approximately 17° toward the NNW. At its total measured depth of 1,303m, the maximum measured temperature was approximately 250°C. Well OGC-3 was drilled through a microseismic (AE) cloud and an expected fracture zone identified from well OGC-2. The bottomhole location of well OGC-3 is approximately 200m south of well OGC-1 and the bottomhole location of well OGC-2 is approximately 80m northeast of well OGC-1 (Figure 5). At least three zones of major lost circulation were encountered in well OGC-3 below a measured depth of approximately 1,100m (Figure 6).

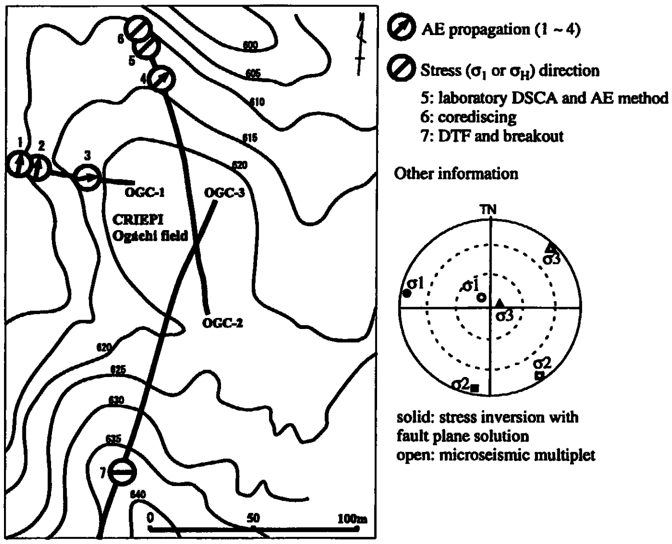


Figure 5. Stress field at the Ogachi site (modified from Shin *et. al.*, 2000).

Immediately after the completion of drilling, geophysical logs were run throughout the entire open-hole section of well OGC-3 (from 700m to TD). As shown in Figure 6, the locations of major lost circulation and dike intrusion can be identified using the density, porosity, natural gamma ray and caliper logs.

FMI & UBI Logs

FMI and UBI logs were run throughout the open-hole interval in well OGC-3. High quality data were obtained and the natural fracture characteristics were analyzed. It was revealed that natural fracture orientations in the OGC-3 are similar to those observed in wells OGC-1 and OGC-2. However, in the deeper part of well OGC-3 (below a measured depth of approximately 1,100m), there is another dominant fracture orientation. In this deeper part of the Ogachi reservoir, the fractures have a NE trend and dip gently toward the NW (see Figure 3 in Ito and Okabe, 2001). Considering the stress field at Ogachi, fractures with this orientation are expected to be permeable (Ito and Okabe, 2001).

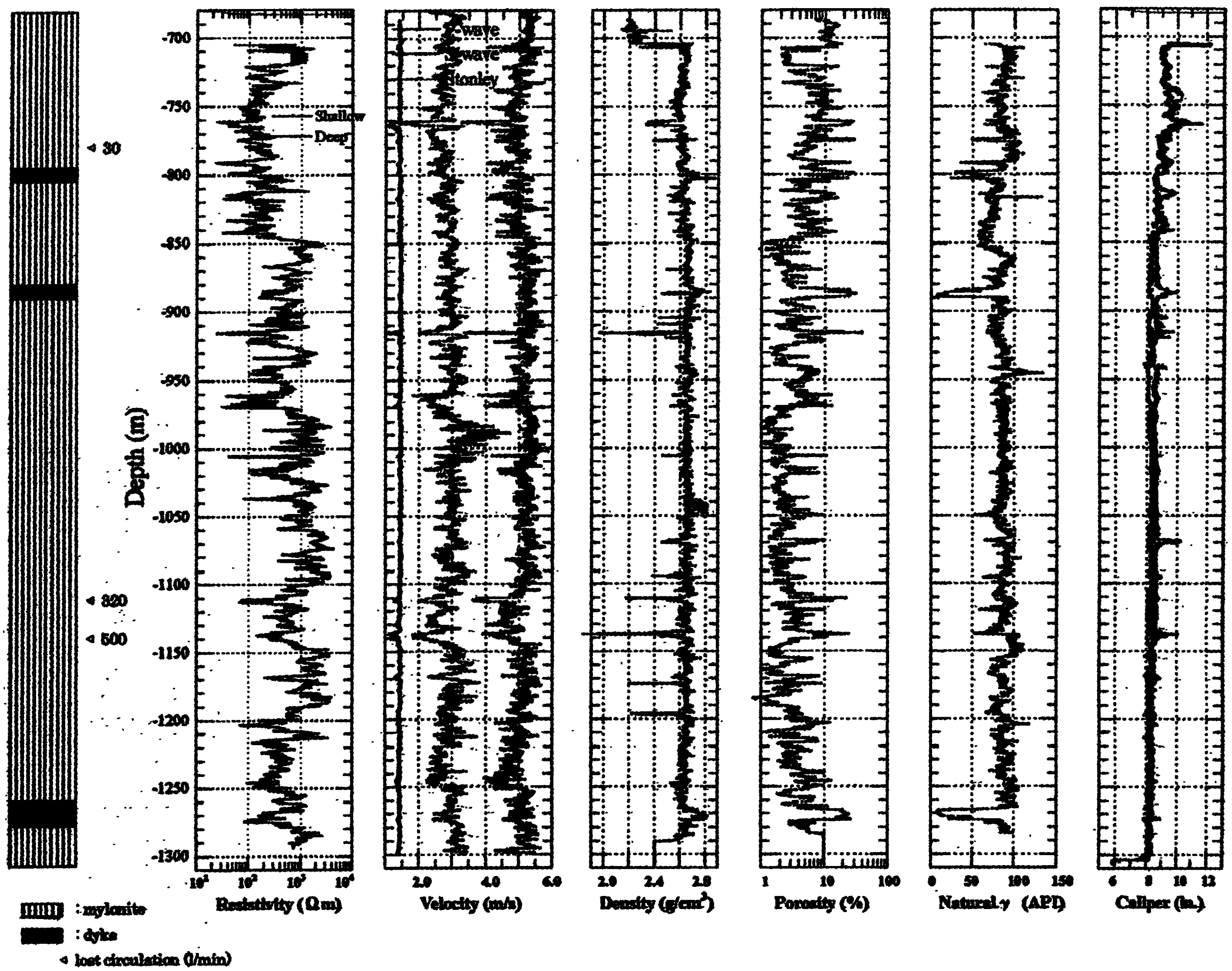


Figure 6. Geophysical logs at OGC-3 of Ogachi HDR site.

Optical Fiber Temperature Monitoring

As summarized in Figure 7, tests were conducted in 2000 to evaluate the degree of hydraulic communication between wells OGC-1 and OGC-3. The first activity in these tests was to inject water into well OGC-3 to cool the well prior to installing an optical fiber thermometer. After stopping the injection into well OGC-3, water was injected into OGC-1 while monitoring temperatures every 10 minutes in well OCG-3. The temperature data clearly show water inflow in well OGC-3 at a measured depth of 960 m; the corresponding fractures were identified on the FMI and UBI logs (Ito and Okabe, 2001).

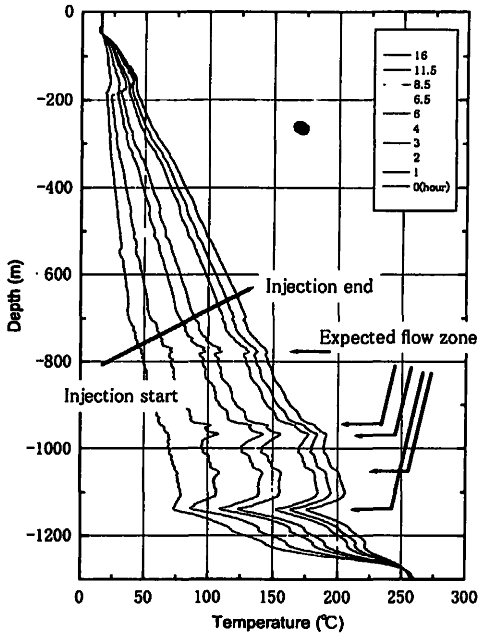


Figure 7. OGC-3 temperature change during water injection into OGC-1 (Suenaga *et. al.*, 2001).

Stress at the Ogachi site

DTFs (Drilling-induced Tensile Fractures) and borehole breakouts, which are useful to determine the stress field, were clearly detected in the FMI and UBI logs in well OGC-3. The analyses of DTFs and the borehole breakouts show that the maximum horizontal stress is oriented in approximately E-W in the entire open section of well OGC-3 (Ito and Okabe, 2001). A three-dimensional analysis of the stress field was also undertaken using DTF data. A reverse fault type stress is deduced (see Figure 5 in Ito and Okabe, 2001), which is consistent with that from the stress inversion method with fault plane solutions of AE (Figure 5). The maximum horizontal stress direction obtained from a measured depth of 1,000 m in well OGC-2 is NE-SW, while that obtained from 700-1,300 m in well OGC-3 is E-W. The former stress field and the dominant NE-NNE-trending natural fractures in the lower reservoir around the OGC-2 (see Figure 3 in Ito and Okabe, 2001) are consistent with the observed northeastward propagation of AE events during the lower reservoir stimulation in well OGC-1 and the stimulation test in well OGC-2.

Conclusions and Future Works

A new well, OGC-3, was drilled at Ogachi to verify previously determined reservoir characteristics. Logging in this new well yielded high quality data for evaluation of fracture directions and stress field orientations. The orientations of natural fractures above a measured depth of 1,100 m in well OGC-3 were comparable with results from earlier wells, which supports the idea that the natural fracture system strongly constrained the AE propagation; however, below 1,100 m, another dominant fracture orientation (NE trend with low NW dip) was found. Fluid inflow points were detected using optical fiber temperature monitoring. FMI and UBI identified the flowing fractures and also yielded a reliable stress field.

In the next Ogachi experiment, the hydraulic properties of the lost circulation / fluid inflow zones in well OGC-3 will be carefully examined by PTS logs and optical fiber temperature monitoring after stimulation of well OGC-3. After completing the hydraulic characterization of well OGC-3, a circulation test will be conducted with injection in well OGC-1 and production from both OGC-2 and OGC-3. In these tests, water recovery will be improved and the answer why excessive water losses happen will be obtained.

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