AN HDR EXPERIMENT AT OGACHI, JAPAN

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SUMMARY – CRIEPI has conducted a Hot Dry Rock (HDR) experiment at Ogachi in northern Japan. In this experiment, using an injection well (OGC-1) which was drilled into granodiorite to a depth of 1000 m, two separate HDR reservoirs were created by the CRSP hydraulic fracturing method. A production well *(OGC-2)* was drilled to penetrate the two HDR reservoirs to a depth of 1,100 m. Water circulation tests were conducted between the injection and production wells. In the 1995 circulation test, hot water and steam at 165 °C was produced at a water recovery rate of 25 %. In 1999 a third well (OGC-3) was drilled to increase water recovery and confirm fluid flow in the reservoirs.

1. INTRODUCTION

There are two Hot Dry Rock (HDR) projects in Japan. One is a national project operated by New Energy and Industrial Technology Development Organization (NEDO) at Hijiori in northern Japan (Matsunaga et al., 2000). The other is our Ogachi project. Locations of these sites and the concept of the Ogachi project are shown in Figure 1.

In 1989, the Central Research Institute of the Electric Power Industry (CRIEPI) started an HDR project for a clean and large electric power energy source development at Ogachi in Akita Prefecture, Japan. To establish a large power plant, technologies for developing multiple reservoirs and multiple wells is needed. In this project, two-separate HDR reservoirs were created from a water injection well (OGC-1). Water circulation tests between the injection well and a production well (OGC-2) which was drilled to penetrate the reservoir were conducted. Using the tests results, we simulated fluid flow in the reservoirs. Water recovery rates during the circulation tests at Ogachi were so small comparing with other HDR experiments.

In 1999, a third well (OGC-3) was drilled to increase the water recovery and confirm our evaluation of how water flows in the reservoirs. In this paper we describe a review of the Ogachi project and some recent results obtained from the OGC-3 well tests.

2. GEOLOGICAL SETTING AT OGACHI

The Ogachi site is situated in a mountainous region at an elevation of about 600 m. The geology of the Ogachi site consists of Cretaceous granodiorite covered with Tertiary lapilli tuff to a

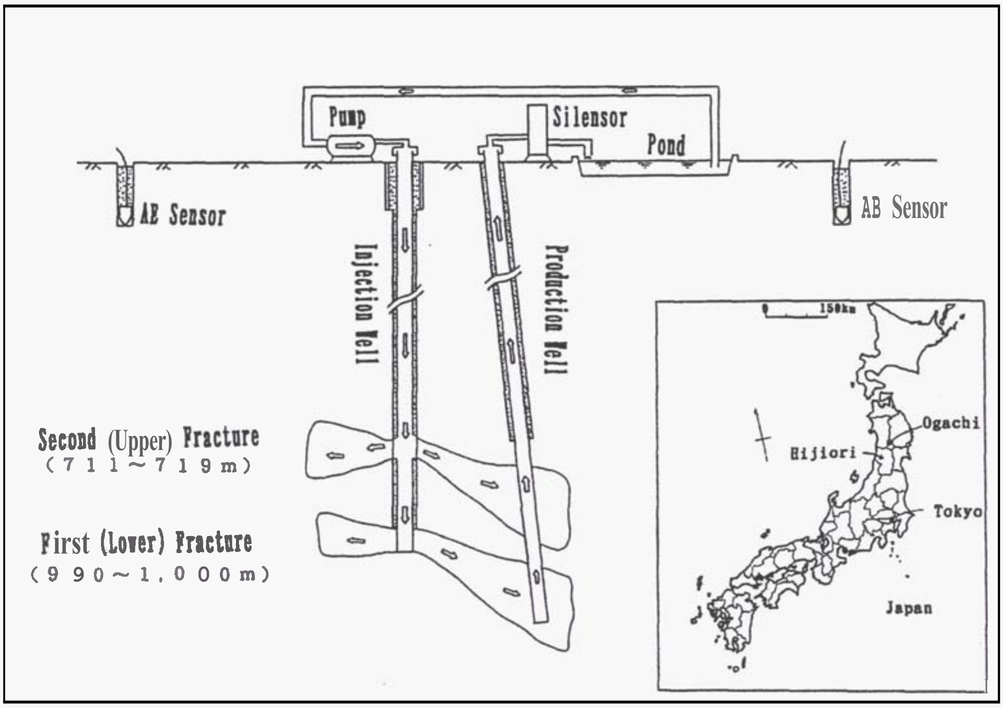

Fig. 1 Concept of the Ogachi HDR experiment

depth of 300 m from the ground surface. A number of pre-existing or natural joints exist in the granodiorite but with a comparatively low permeability.

A three dimensional basement rock distribution map (shown in Figure 2) was obtained by compiling the results of the TDEM survey conducted in 1989, the CSAMT survey in 1996, the gravity survey in 1997 and the seismic reflection survey in 1998 (Suzuki et al., 2000). In this map, we can see a fault with steep inclination and NW-SE trends at around 500 m south-west from the Ogachi site

3. MULTIPLE RESERVOIRS

In 1990, an injection well (OGC-1) was drilled to a depth of 990 m where the rock temperature was measured at 228 °C. The well was cased from the ground surface to the bottom and re-drilled with a diameter of 76 mm to a depth of 1,000 m. The bottom 10 m was left uncased. Using this well, we created two stacked reservoirs by the Casing Reamer and Sand Plug (CRSP) hydraulic fracturing method, which was originally developed by CRIEPI (Kaieda et al., 1993).

In 1991, over 10,000 m^3 of water was injected into OGC-1 at an average injection flow rate of 41 m^3/hour and at an average well-head pressure of 19 MPa, creating an HDR reservoir at the bottom uncased (open-hole) region of the well. After the lower reservoir was created, the casing pipe was milled from 711 m to 719 m to produce an open-hole section called a window. Then, the open-hole section at the bottom was filled with sand. In 1992, an upper fracture was created at the window depth by injecting nearly 2,500 m^3 of water at an average flow rate of 30 m^3/hour and at an average well-head pressure of 22 MPa.

4. WATER CIRCULATION AND STIMULATION

In 1993, a production well (OGC-2) was drilled to a depth of 1,100 m to penetrate the upper and lower reservoirs. A first water circulation test was conducted for 22 days between OGC-1 and OGC-2 through the reservoirs in 1993. However, only a few percent of injected water was recovered in this circulation test. In 1994, OGC-2 was stimulated by hydraulic fracturing. In this stimulation, a total volume of 2,200 m^3 of water was injected at a maximum flow rate of 45 m^3/hour and at a maximum well-head pressure of 14 MPa. A second water circulation test was performed fur 5 months between OGC-1 and OGC-2 after the stimulation. In this circulation test, water recovery increased to about 10 %. In 1995 OGC-1 was re-drilled from 1,000 m to 1,027 m to extend the water injection (open-hole) region. After the re-drilling, OGC-1 was stimulated by injecting a total volume of 3,400 m^3 of water at a flow rate of 105 m^3/hour and at a well-head pressure of 10 MPa. OGC-2 was also stimulated by injecting a total volume of 4,300 m^3 of water at a fluw rate of 105 m^3 /hour and at a well-head pressure of 11 MPa. We conducted a one-month circulation test between these wells.

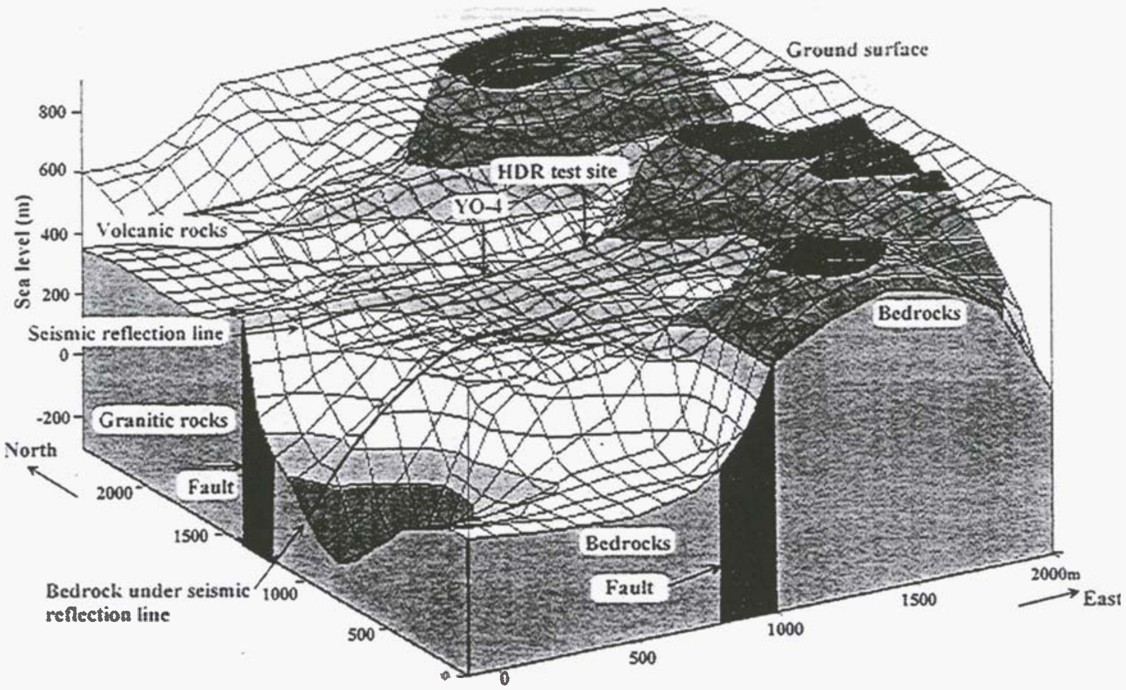

Figure 2 A schematic three dimensional structure under the Ogachi site.

During the circulation test, the injection pressure decreased to 7 MPa, about a half of that in 1994, and the water recovery from the production well increased to 25%, about twice as much as that in 1994. The water produced was 160 to 165°C. Therefore, we concluded that the extension of the bottom-hole water injection interval and the pressure stimulation of these wells were more effective in reducing the water injection pressure and improving water recovery.

In 1997, we conducted flow tests for evaluating the upper and lower reservoir more precisely. At first, we flow tested the upper reservoir by plugging off the lower reservoir with sand in OGC-1. Water was injected into OGC-1 at a well head pressure of about 20 MPa with a flow rate of about 7 m^3/hour. Though injection was continued for 7 days, the water level in OGC-2 was stable at a depth of 40-50 m below the surface 80-90 m above natural level at the end of the upper reservoir injection test. After washing out the sand from OGC-1, a water circulation test through both the upper and lower reservoirs was conducted. Water was injected into OGC-1 at a flow rate of 30 m^3/hour and at a well-head pressure of about 13 MPa for 9 days. On the second day of the test, water was produced from the well-head of OGC-2. The produced water flow rate was stable at 7m^3/hour and at a well-head pressure of 0.7 MPa.

5. RESERVOIR EVALUATION

5.1 Reservoir *Size*

Location and size of the created fractures were evaluated by the induced micro-earthquake (AE) measurement, the electric charged potential method and the electric self-potential method. According to these results (Kaieda et al., 2000), the lower reservoir was estimated to be about 200 m thick and about 500 m wide, extending 1,000 m in the NNE direction and the upper reseroir was about 200 m thick and about 400 m wide, extending 800 m in the ESE direction (see Figure 3). Both reservoirs were sufficiently wide to extract heat fkom the hot *dry* rock, although the reservoirs were oriented in different directions, with the upper one in an east-west direction and the lower one in a north-northeast-south-southwest direction..

From the results of the joint survey from core observations and the BHTV survey at OGC-1 and OGC-2, the directions of the natural joints were different for each reservoir region; that is, the lower one has a dominant direction of N-S to NE-S W and the upper one has no dominant direction (Ito and Kitano, 2000).

According to the results of the fault plane solution of AE, which were determined by using AE location and P-wave first motion distribution on the focal hemisphere, almost all AE events were caused by shear slippage and these shear planes were estimated to have a dominant direction of N-S at the lower reservoir and at the upper reservoir to have some directions of E-W, N-S and NE-SW (Kaieda et al., 2000).

The maximum principal stress direction from a core disking method, the most reliable method among several kinds of stress orientation methods performed at the Ogachi site, showed NE-SW horizontally (Shin, 2000). The values of the maximum and the minimum horizontal stress are 30 MPa and 22 MPa, respectively. It was thought that the growth directions of both the upper and the lower reservoirs were able to be explained under this stress direction with no contradiction.

5.2 Water Flow in the Reservoir

We have developed a computer simulation code (GEOTH3D) to indicate the production flow volume and to help predict the behavior of underground water flow visually. To apply GEOTH3D to the Ogachi reservoir simulation, a permeability distribution model in and around the reservoirs was constructed. Flow tests for permeability measurements under controlled pressure at each well and between OGC-1 and OGC-2 were conducted before and after fracturing. Summarizing these results, the permeability of the rock before fracturing was 10^{-15} to 10^{-16} m^2, and after fracturing it was 10^{-13} to 10^{-14} m^2. It was thought that the former showed initial rock permeability around the reservoirs, and the latter showed well-developed fractured rock permeability in the reservoirs. The AE data were used to define the distribution of fracturs and the permeability in and around the reservoirs. This approach allowed us to predict the behaviour of the underground fluid flow. We have examined the accuracy of GEOTH3D by comparing it with field data that had been acquired for a 30-day water circulation test in 1995. It was found that the results derived from the computational model were well-correlated to those measured in the field tests (Suenaga et al., 2000).

5.3 Hydraulic Characteristics of the Reservoirs between OGC-1 and OGC-2

The feed points in OGC-2 were recognized at 730 m to 750 m depth and 960 m to 1,070 m depth by PTS logging in 1994; the top interval is situated in the upper reservoir and the bottom interval is situated in the lower reservoir. We estimated that 15 % of the production came from the upper reservoir and that 85 % of the production came from the lower reservoir.

From the results of a tracer test in the 1994 circulation test, the response curve of the tracer density showed a bi-modal curve. The modal volumes of the upper and the lower reservoirs were estimated to be about 10 m^3 and about 250

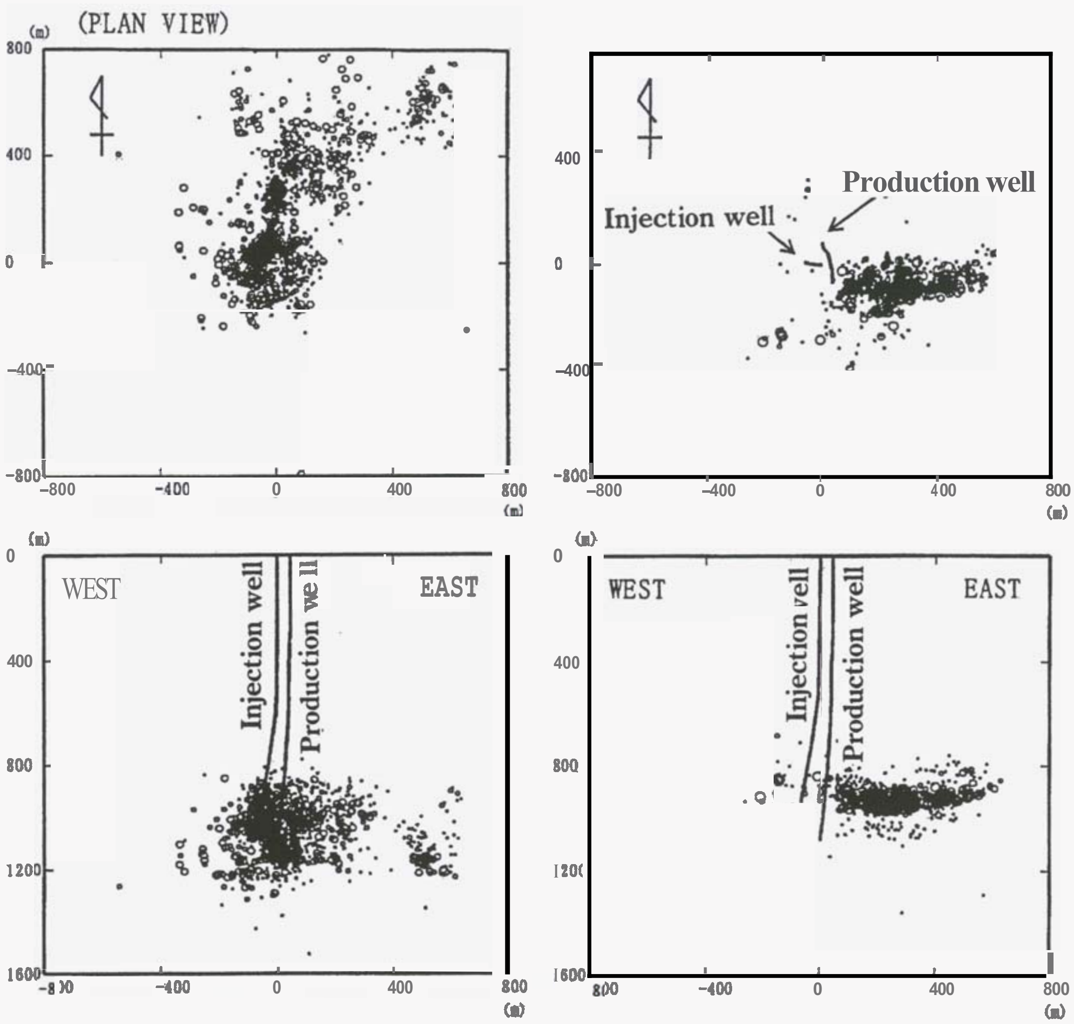

Figure 3 AE hypocenter locations. The left top : plan view for the lower fracturing, the left bottom : east-west cross section view for the lower fracturing, the right top : plan view for the upper fracturing, the right bottom : east-west cross section view for the upper fracturing.

m^3 respectively. The results of a tracer test during the **1995** circulation test showed a nearly single-peak curve and the modal volume was estimated **135** m^3 **(Kiho, 2000).** This means that the hydraulic characteristics of the reservoirs were changed by the stimulation at **OGC-2** and the addition of the open-hole at the bottom of **OGC-1** after the **1994** circulation **test** and the enhanced connection between the wells.

6. THE THIRD WELL

In **1999,** a third well **(OGC-3)** was drilled into an AE cloud and an expected fracture zone. The well had a diameter of **220** mm to a depth of **1,303m** where the rock temperature was around **250°C.** The well-head was located **25** m east of **OGC-1** and inclined **to** the south. The bottom of the well was located about 200 m **SSW** from **OGC-1** (see Figure **4).** The well was cased from the surface to **704** m and the bottom **599** m was left uncased. During this drilling, lost circulations of drilling mud occurred at depths of **950** m and **1,150** m.

The water level in **OGC-1** well varied corresponding to the circulation losses of **OGC-3** drilling; it increased 17 meters with the mud loss **1,150** m. After well completion, well loggings were conducted. Formation Micro Imager **(FMI)** and Ultra-sonic Borehole Imager (UBI) surveys showed clear **open** fractures at these circulation loss depths. Water communication **tests** between **OGC-1** and **OGC-3** were conducted in 2000. In these tests, the optical fiber thermometer was installed in **OGC-3.** Water was injected into OGC-3 for cooling at first. After stopping the injection into **OGC-3,** water was injected into **OGC-1** and some water flowed into **OGC-3.** The water level of **OGC-3** increased with corresponding **to** the water injection into **OGC-1.** The temperature distribution in **OGC-3,** observed by an optical fiber thermometer every **10** minutes, is shown in Figure **5.** There are some clear temperature anomalies, which are likely water flow zones. These anomalies are consistent with the estimation of the fracture zone **from** the AE hypocenter location distribution.

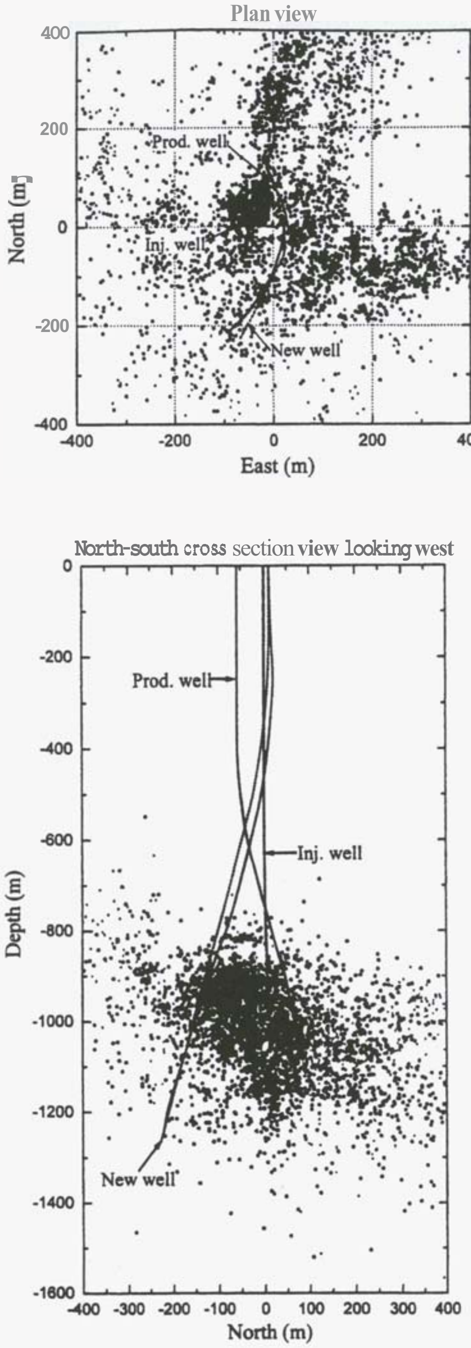

Figure 4 OGC-3 (New well) drilling trajectory and all AE hypocenter locations. The upper is plan view and the lower is an east-west cross section looking north.

7. CONCLUSIONS

(1) In the Ogachi HDR Project, an injection well (OGC-1) was drilled to a depth of 1000 m, and two separate HDR reservoirs were created by hydraulic fracturing. Then, a production well (OGC-2) was drilled through the two fkactured reservoirs to a depth of 1,100 m. Between 1993 and 1997, four circulation tests we performed between the injection and production wells. The 30-day circulation test in 1995 resulted in the production of water and steam at a temperature of 165 degree C, with a fluid recovery rate reaching 25% of the injection rate.

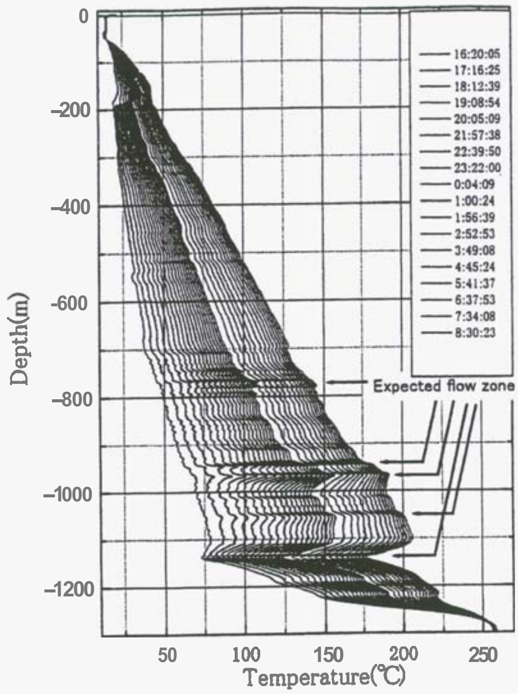

Figure 5 OGC-3 temperature change during water injection into OGC-1.

(2) Each of the HDR reservoirs, based on the distribution of AE locations, contains enough fractured volume for significant heat extraction. However, the directions of fracture propagation of these two separate reservoirs differ, with the directions probably being strongly influenced by natural joints in the host rocks.

(3) In 1999, a third well (OGC-3) was drilled through the reservoirs. The water communication tests between OGC-1 and OGC-3 showed a clear flow zone in OGC-3. OGC-3 will be used as a second production well for the future and CRIEPI will demonstrate the viability of geothermal heat extraction through multiple HDR reservoirs with multiple wells.

8. REFERENCES

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