3. CONCLUDING REMARKS

Rock fracture mechanics can be used as a practical tool to design and evaluate a geothermal crack-like reservoir. The subsurface crack for HDR reservoir should be created and controlled based upon the rock fracture mechanics concept. In the summer of 86, a hydraulic fracturing field experiment was carried out within a regime of "Phase II" project, where a validation of rock fracture mechanics could be demonstrated.

The problems to be solved in the near future requiring research which are now of the greatest importance with special reference to HDR reservoir engineering are listed as follow:

(1) A research on standardization of fracture toughness test of rock by core based small specimen.
(2) Refinement of fracture mapping procedure: reasonable explanation of AE source mechanism and attenuation during the fracturing process.
(3) A fuller understanding of water-rock interaction under the geothermal environment: dissolution and scaling behavior, and their engineering application.
(4) Further development of computer simulation procedure to describe the extension of subsurface crack during the hydraulic fracturing and their control during service operation of the reservoir.

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HYDRAULIC FRACTURING EXPERIMENT AT AKINOMIYA, AKITA, JAPAN (PART 2)

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INTRODUCTION

It is indispensable for the Hot Dry Rock geothermal energy extraction system to create a man-made fracture system as a heat exchanger in hot rock. Hydraulic fracturing operations with using open-hole packers have been conducted so far to make the system. However, as the depth of the fracturing increased, the operations were often failed because of packer damaged at high temperature and high pressure (Franke et.al. 1984).

We developed a new hydraulic fracturing method (named ' casing reamer and sand plug method ') without using open-hole packers to avoid the packer problems. Casing reamer is a tool which cuts a casing pipe set in a well. Sand plug is used to prevent the injected water leaking into pre-existing fractures. The method was applied to a well of 400m depth and demonstrated to be practical.

HYDRAULIC FRACTURING OPERATIONS (See Fig.1)

A fracturing well was drilled in Tertiary lapilli tuff at Akinomiya in the south of Akita prefecture, Japan. It reached a depth of 400 m and a rock temperature of about 60℃. Casing pipes (inner diameter:78.1 mm, outer diameter:89.1 mm) were set in the well down to a depth of 390 m. 10 m at the bottom of the well was left uncased. According to the geophysical logging and the recovered core investigation P wave velocity was about 3 km/sec and natural open cracks were few around bottom of the well.

The first hydraulic fracturing was conducted by full-hole pressurizing. In this case open-hole section was only in the bottom uncased zone, so that new fractures should be created at the bottom. Water was pumped into the well with flowrate up to 143 l/min. The wellhead pressure reached a maximum of 287 kgf/cm^2.

After the first fracturing the casing pipe set in the well was cut by casing reamer from a depth of 371.5 m to a depth of 373.5 m (2 m interval). This cut zone was to be another open-hole section for second fracturing. Sand plug was emplaced below the section to prevent the injected water leaking into pre-created fractures at bottom of the well. Then water was pumped into the well. The well was pressurized full-hole again. In this case new fractures should be created at the casing cut zone. Total 81 m^3 of water was injected with flowrate up to 285 l/min and the wellhead pressure reached a maximum of 190 kgf/cm^2 in the second fracturing.

The third fracturing was conducted by the same way as the second fracturing in an attempt to make fractures from a depth of 359.7 m to a depth of 361.7 m (2 m interval). In this experiment total 85 m^3 of water was injected with flowrate up to 98l/min and the wellhead pressure reached a maximum of 193 kgf/cm^2.

FRACTURE OBSERVATION

1) Borehole TV scanning

After the first fracturing a new fracture was observed by Borehole TV scanning investigation which occured from 398.1 m to 399.1 m depth and vertical dip with N50° W strike. An average opening width of the fracture was 2～3 mm. Three fractures were observed to be occurred in the second fracturing. Strikes of these fractures were N45° E, N20° W and N60° W and the inclinations were 30° NW, 70° NE and 30° NW respectively. Average opening widths of the fractures were all almost same as that of the first fracture of 2～3 mm. Fractures by the third fracturing which might be occured were not observed because of muddy water in the well.

2) AE observation

Acoustic emission (AE) induced by hydraulic fracturing operations were monitored at six observation stations. One component(vertical) geophones with 14 Hz natural frequency were deployed in annulus of the fracturing well at depths of 40 m and 230 m. One component(vertical) geophones with 30 Hz natural frequency were deployed at depths of 60 m and 160 m in the well located 60 m northwest from the fracturing well. One component(vertical) geophone with 30 Hz natural frequency was deployed at a depth of 50 m of the well located 80 m east from the fracturing well. During the fracturing operations a three component geophone was deployed at bottom of the fracturing well.

No AE were observed during the first and third fracturings, however about 46 AE were detected before, during and after the pressure breakdown in the second fracturing and 14 of them were located as shown in Fig.2. The location distribution indicated growth of a set fracture sloping downward toward N45° W at about 45° NW inclination. It was consistent with the two fractures created in the second fracturing.

3) Permeability measurment of rock

Permeability of rock was measured before and after fracturing. The value before the fracturing was almost same for all fracturing of smaller than 10^{-7} cm/sec. After the first fracturing the value increased to 3×10^{-5}cm/sec, after the second it was 5×10^{-5} cm/sec and after the third it was 5×10^{-5} cm/sec. These results gave suggestion that new fractures were created in all fracturing operations.

4) Water recovery measurement

The amount of water returned to the surface after fracturing was measured and estimated that more than 50 % of water which had been injected was recovered in all fracturing operations This indicated that the fracture system was tightly contained.

CONCLUSIONS

In this experiment we developed a new hydraulic fracturing method. Using this method we tried to create a man-made fracture system in a well, then we succeeded to make fractures at different three depths. These three fracture occurences were observed by Borehole TV scanning and inferred by permeability measurement and AE observation.

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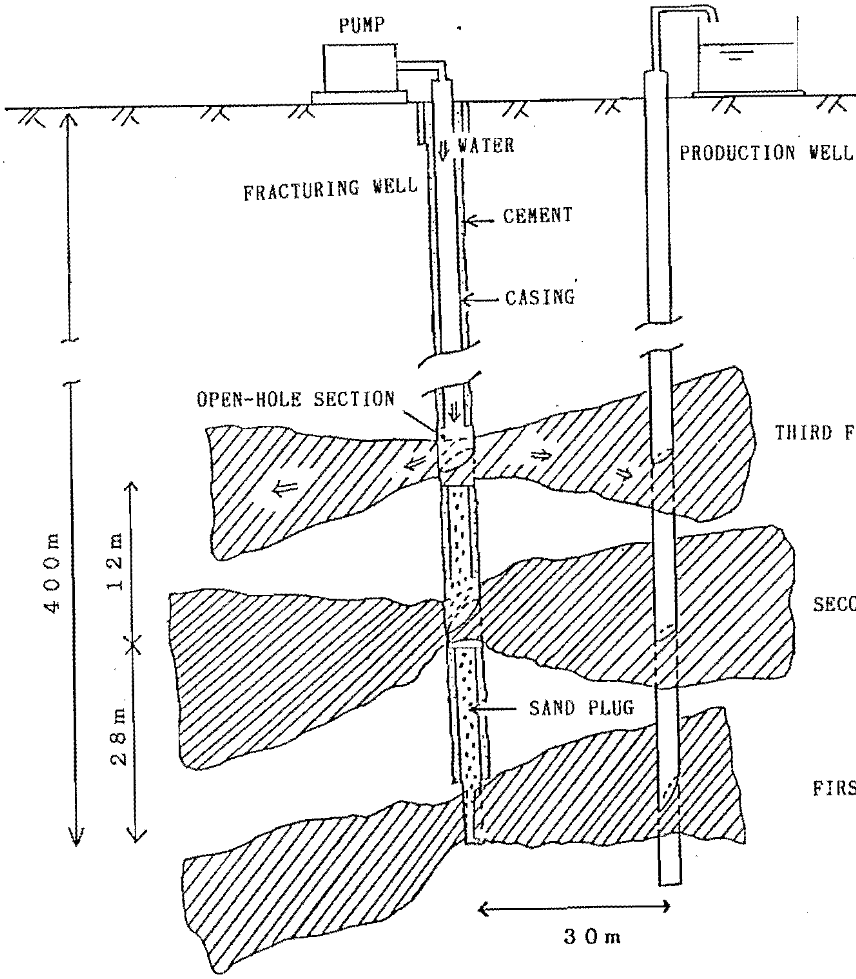

Figure 1. Conception of this experiment.
Production well will be completed by this September,

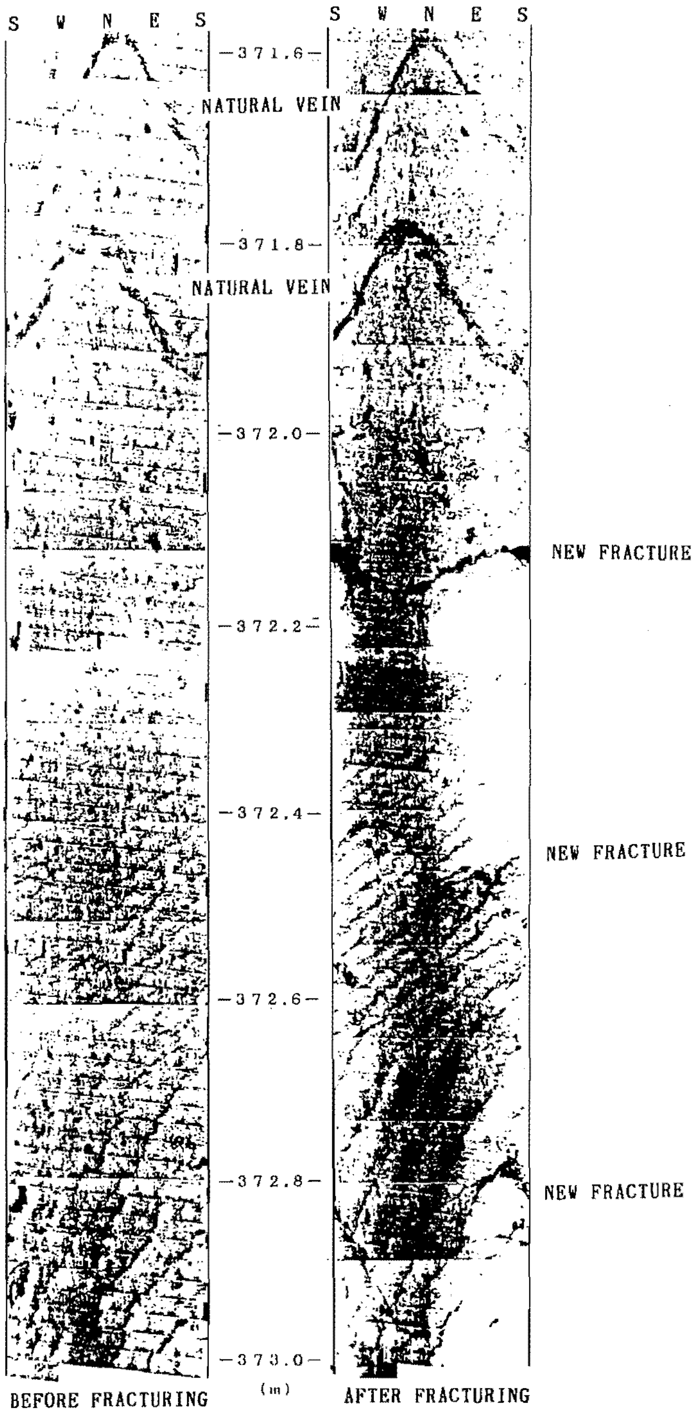

Figure 2. Fractures observed by Borehole TV scanning.
We can see three new fractures under two natural veins.
These fractures were occured during the second fracturing.