PERGAMON

GEOTHERMICS

Geothermics 28 (1999) 627–636

Development of hot dry rock technology at the Hijiori test site

Michio Kuriyagawa[a,*], Norio Tenma[b]

[a]National Institute for Resources and Environment, AIST, MITI, 16-3 Onogawa, Tsukuba, Ibaraki, 305, Japan

[b]New Energy and Industrial Technology Development Organization, Sunshine 60, 3-1-1 Higashi-Ikebukuro, Toshima-ku, Tokyo, Japan

Received 14 November 1998; accepted 17 March 1999

Abstract

Since 1985, the New Energy and Industrial Technology Development Organization (NEDO) has conducted a Hot Dry Rock project at the Hijiori test site, Yamagata prefecture. The objective of this project is to develop and test technologies such as borehole logging, hydraulic fracturing, fracture mapping and reservoir evaluation, which are essential for the development of a Hot Dry Rock power generation system. In 1991, heat was successfully extracted from a shallow reservoir at a depth of 1800 m for three months using one injection well (SKG-2) and three production wells (HDR-1, HDR-2 and HDR-3). About 80% of the injected water was recovered from these production wells. The thermal output of hot water and steam reached about 8 MW. Since 1992, a deep reservoir at a depth of 2200 m has been developed. In 1995 and 1996, heat extraction tests were conducted using one injection well (HDR-1) and two production wells (HDR-2 and HDR-3). A long-term circulation test, lasting about two years, is planned to evaluate the reservoir, starting in 2000.

Keywords: Hot dry rock; HDR; Reservoir; Hijiori; Japan

* Corresponding author. Fax: +81-298-58-8117.
E-mail address: kuri@nire.go.jp (M. Kuriyagawa)

PII: S0375-6505(99)00033-4

1. Introduction

At Hijiori, there is a caldera which was formed about 10,000 years ago (Fig.1). The diameter of the caldera is about 2 km. The Ministry of International Trade and Industry (MITI) and private sector companies conducted a survey to explore a natural geothermal reservoir around the caldera. Although the temperature of the rock was high enough, there was no evidence of a natural reservoir in the rock. MITI decided to carry out an HDR field test at the Hijiori caldera in 1984. The top of the basement rock, granodiorite, is located at about 1500 m depth. The 1800 m deep well SKG-2, which is located at the southern edge of the caldera, had a bottomhole temperature of 254°C. Two reservoirs were created, a shallow reservoir at the depth of 1800 m, and a deep reservoir at 2200 m. The results of the short term heat extraction tests from these reservoirs (Kuriyagawa et al., 1996) are described in this paper.

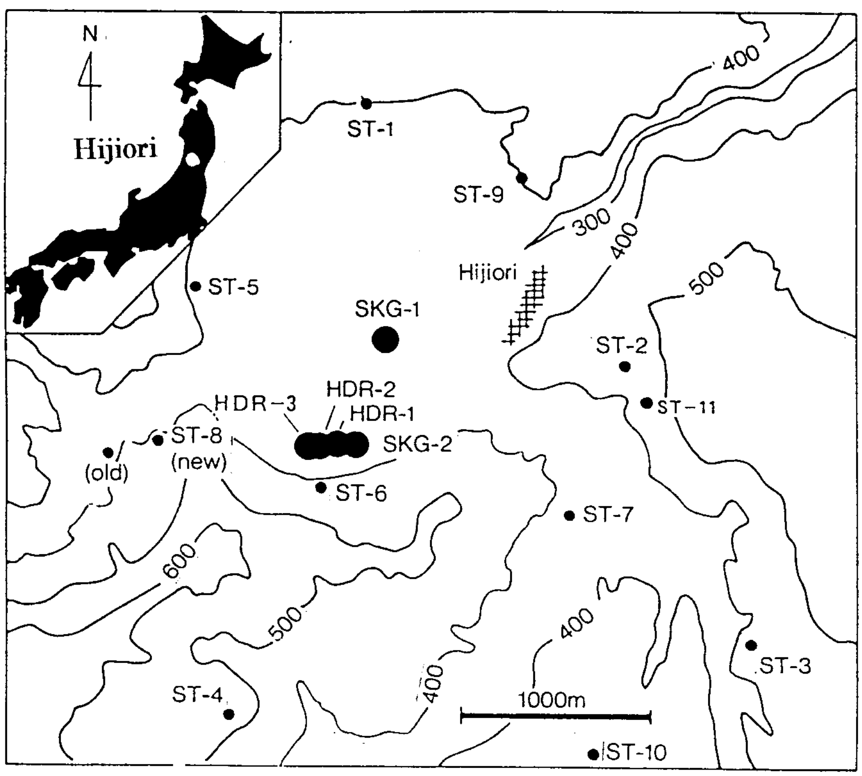

Fig. 1. Hijiori HDR site.

2. Circulation tests in shallow reservoir

In 1986, the shallow reservoir was created by hydraulic stimulation at the bottom of SKG-2. Water was injected at flow rates of 33–100 kg/s. The pumping pressure reached about 16 MPa at the maximum flow rate. The amount of injected water was 1080 m^3. During the stimulation, fractures were mapped by detecting acoustic emission (AE) using AE sensors located at a depth of 500 m in SKG-1 and at the surface stations ST-1–ST-11, which are shown in Fig.1. HDR-1 was drilled in 1987 to a depth of 2206 m to intersect the reservoir south of SKG-2 and to keep its distance from the injection well at about 40 m. The openhole section of HDR-1 is from 1500 m to the bottom. The heat extraction tests were performed to estimate the characteristics of the shallow reservoir using two wells (SKG-2 and HDR-1) for 16 days in 1988 (Exp.8805). In the first 10 days, the flow rate was kept at 8 kg/s and thereafter increased to 17 kg/s. A total of 13,600 m^3 of water was injected and 33% of this was recovered from HDR-1. It was found that the connection between the two wells through the fractures was poor. The results of AE fracture mapping showed that the fracture seemed to extend mainly towards the west-southwest. A second production well, HDR-2, was drilled west-southwest of SKG-2 at a depth of 1800 m (Fig. 2). In 1989, a one-month

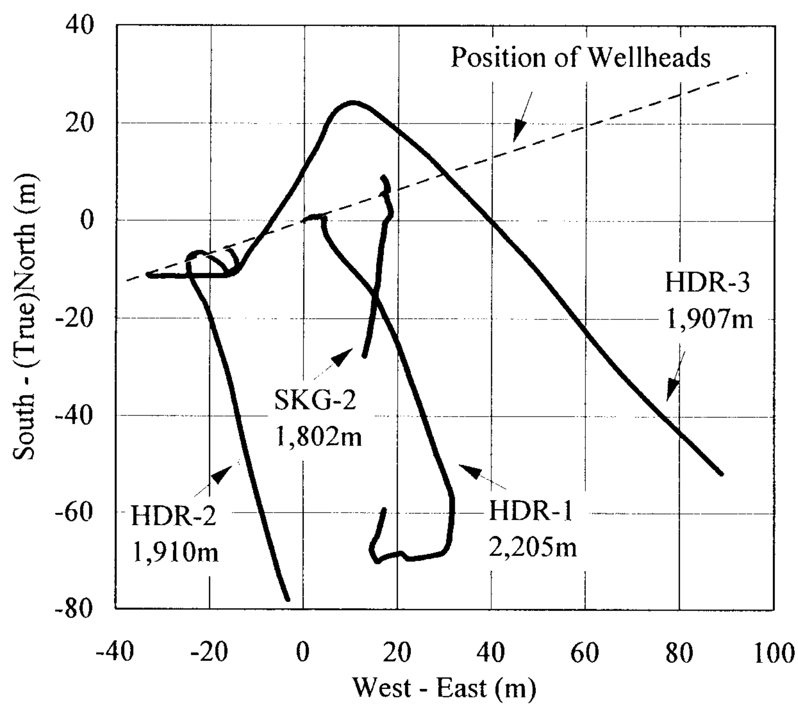

Fig. 2. Trajectory of wells at Hijiori in 1991.

circulation test (Exp.8902) was conducted by injecting water in SKG-2 and producing hot water and steam from HDR-1 and HDR-2. The injection flow rate was kept at 17 kg/s. Pumping pressure was 6 MPa initially and decreased to 4.5 MPa. The wellhead pressures of the production wells were kept at 1–2 MPa to prevent boiling. The production flow rate from HDR-1 was 1.5–1.6 kg/s and 4.2–

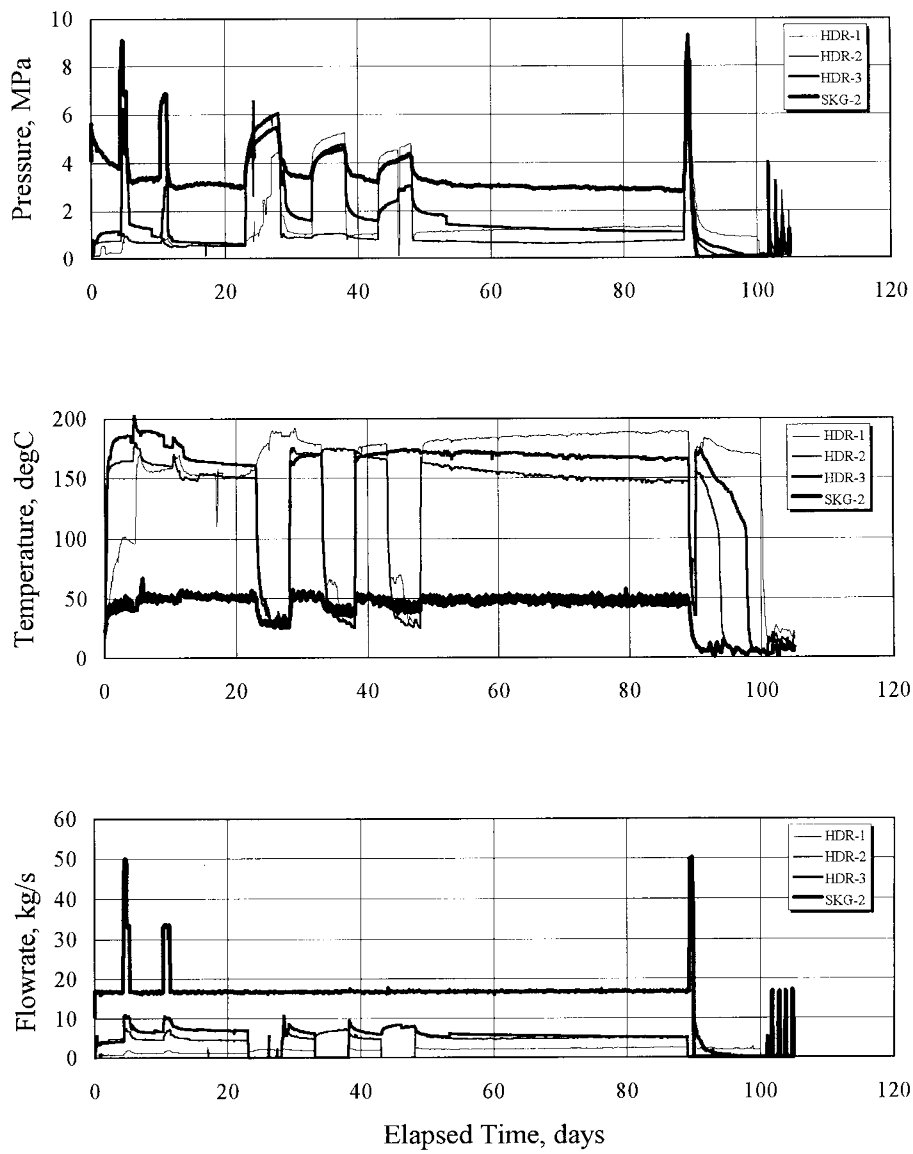

Fig. 3. Histories of pressure, temperature and flow rate during the 1991 circulation test Exp.9102.

4.9 kg/s from HDR-2. The production temperature from HDR-1 increased gradually to 150°C. In HDR-2 it increased to 170°C and then decreased to 150°C. A KI tracer was injected 12 and 22 days after the start of circulation. The recovered tracer was more concentrated in HDR-2 than in HDR-1, and the time for tracer to travel to HDR-2 was shorter than to HDR-1. These results indicate that there is a predominant flow path between SKG-2 and HDR-2, and that HDR-1 is located outside the range of this path. The recovery rate in this test was about 35–40%. To increase the recovery rate and obtain more reservoir information, one more production well, HDR-3, was drilled in 1990. The trajectories of all wells are shown in Fig. 2.

In a 90-day circulation test using four wells (Exp.9102), water was injected in SKG-2 and produced from HDR-1, HDR-2 and HDR-3. The distances from SKG-2 to HDR-1, HDR-2 and HDR-3 are about 40, 50 and 55 m, respectively, at a depth of 1800 m. At the beginning of the test the flow rate was increased to 50 kg/s to improve the hydraulic conductivity of the fractures between the injection well and production wells, and then held constant at 16 kg/s. Fig. 3 shows the wellhead pressures, temperatures, and flow rates of these wells. Production flow rate was highest in HDR-3, followed by HDR-2 and HDR-1, at the beginning of the test. The flow rates of HDR-1 and HDR-2 increased slightly with time, while the flow rate of HDR-3 decreased. Finally the flow rate of HDR-2 and HDR-3 became almost the same. During the test, PTS (pressure, temperature and flow rate) logging was repeated in the three production wells about once a week. The results indicate that there are some zones in each production well where injected water flows in. The temperature of water flowing out of fractures into the production wells increased in the middle of the test. Two KI tracer tests were conducted 14 and 58 days after the start of circulation. The travel time of the tracer was longer at 58 days than at 14 days. These results indicate that the heat extraction area increased in the middle of this test. The amount of hot water and steam produced from the three production wells was about 80% of the total injected water (Yamaguchi et al., 1992).

These results suggest that an HDR system can be developed in an area with highly developed natural features such as Hijiori, by judicious siting of the injection and production wells.

3. Development of the deep reservoir

As a next step, we decided to develop a deep reservoir at Hijiori. In 1992 hydraulic stimulation was conducted in an openhole section of HDR-1 between 2151 and 2205 m to create the deep reservoir. About 2000 m^3 of water were injected. In 1993 and 1994, HDR-3 and HDR-2 were deepened to 2303 and 2302 m, respectively, to intersect the deep reservoir, and a three-well system was established. The distance from HDR-1 to HDR-3 was about 130 m at 2200 m depth and about 90 m from HDR-1 to HDR-2. The Hijiori HDR system now has two reservoirs and four wells (SKG-2, HDR-1, HDR-2 and HDR-3), as shown in Fig. 4.

In 1995, a preliminary 25-day circulation test was conducted with injection well HDR-1 and the two production wells HDR-2 and HDR-3 (Sato and Ikawa, 1995). The purpose of this test was to evaluate the deep reservoir prior to the long-term circulation test and to improve the permeability of the deep reservoir between the injection and production wells. The pressure, temperature and flow rates are shown in Fig. 5.

At the beginning of the test, water was injected at the maximum flow rate of about 60 kg/s to improve the hydraulic connectivity between injection and production wells. Then the flow rate was kept at around 16.7 and 33.4 kg/s. The wellhead temperature of production wells HDR-2 and HDR-3 reached about 180°C. The recovery rate of hot water and steam was about 55–60% at the injection rate of 16.7 kg/s, but it decreased to about half at 33.4 kg/s. The total injection volume was 51,500 m^3. About 13,200 m^3 were recovered from HDR-2 and about 6900 m^3 from HDR-3. Thermal output was around 8.5 MW.

The AE locations are shown in Fig. 6. The size of the circles indicates the

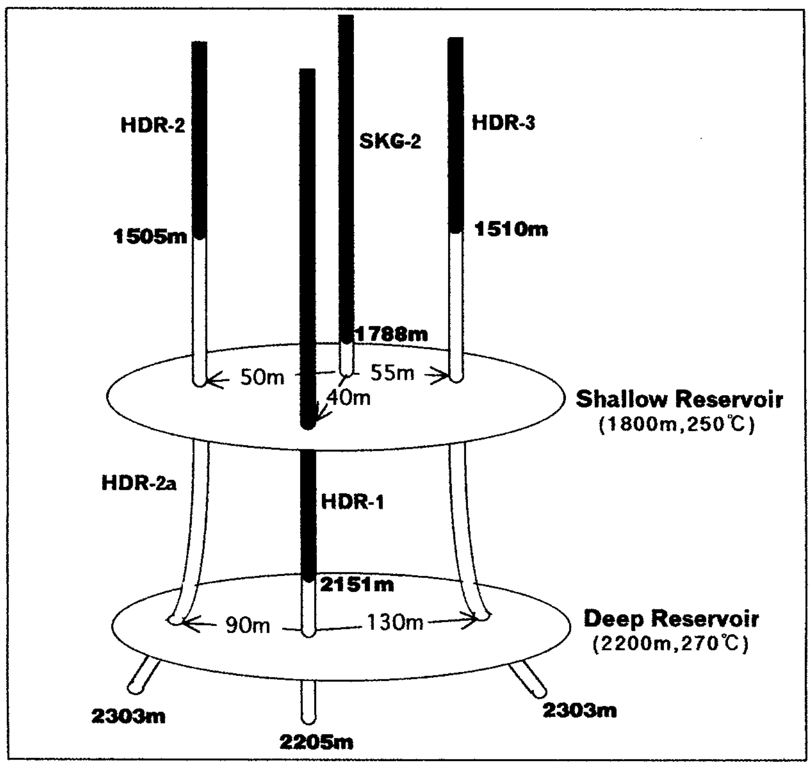

Fig. 4. Schematic of position of wells and reservoirs at Hijiori.

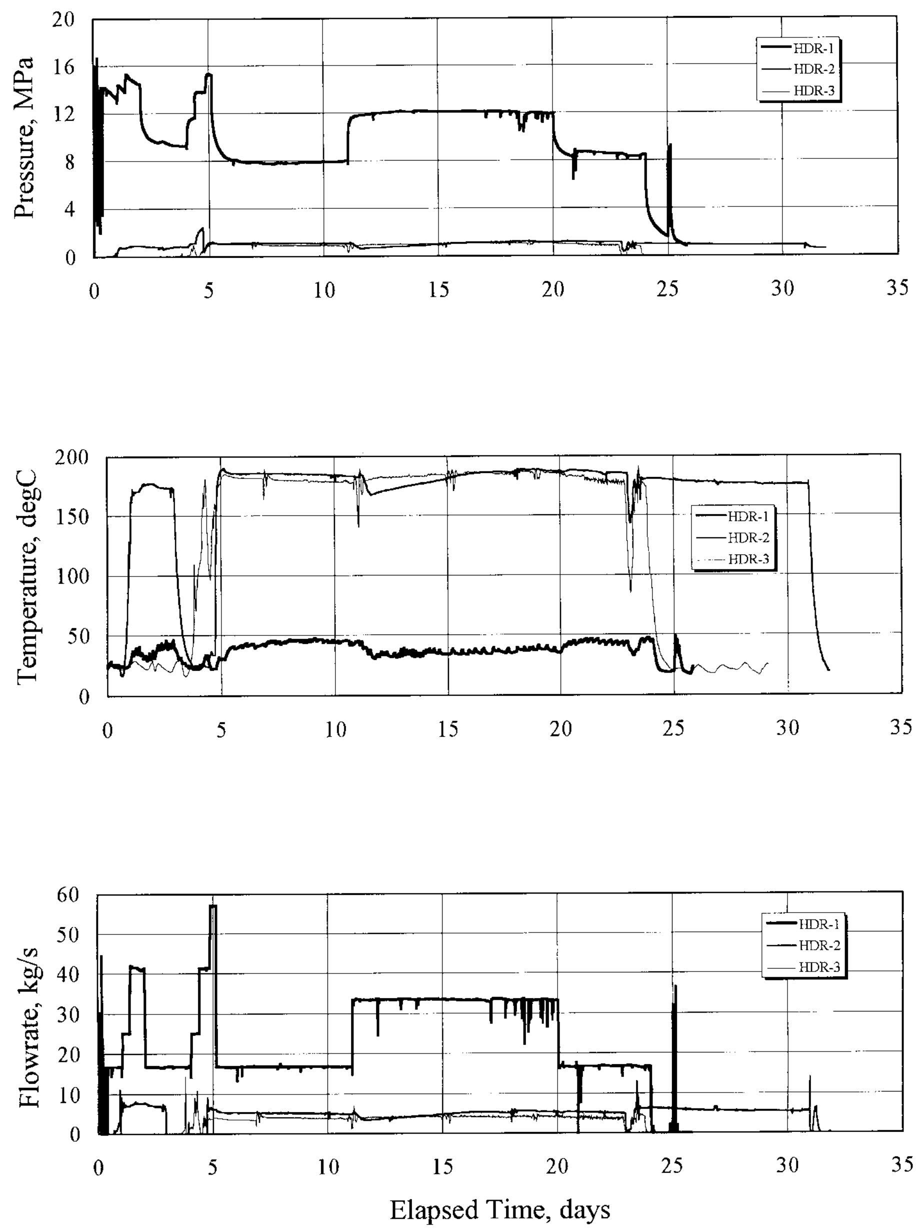

Fig. 5. Histories of pressure, temperature and flow rate during the 1995 circulation test (Exp.9501).

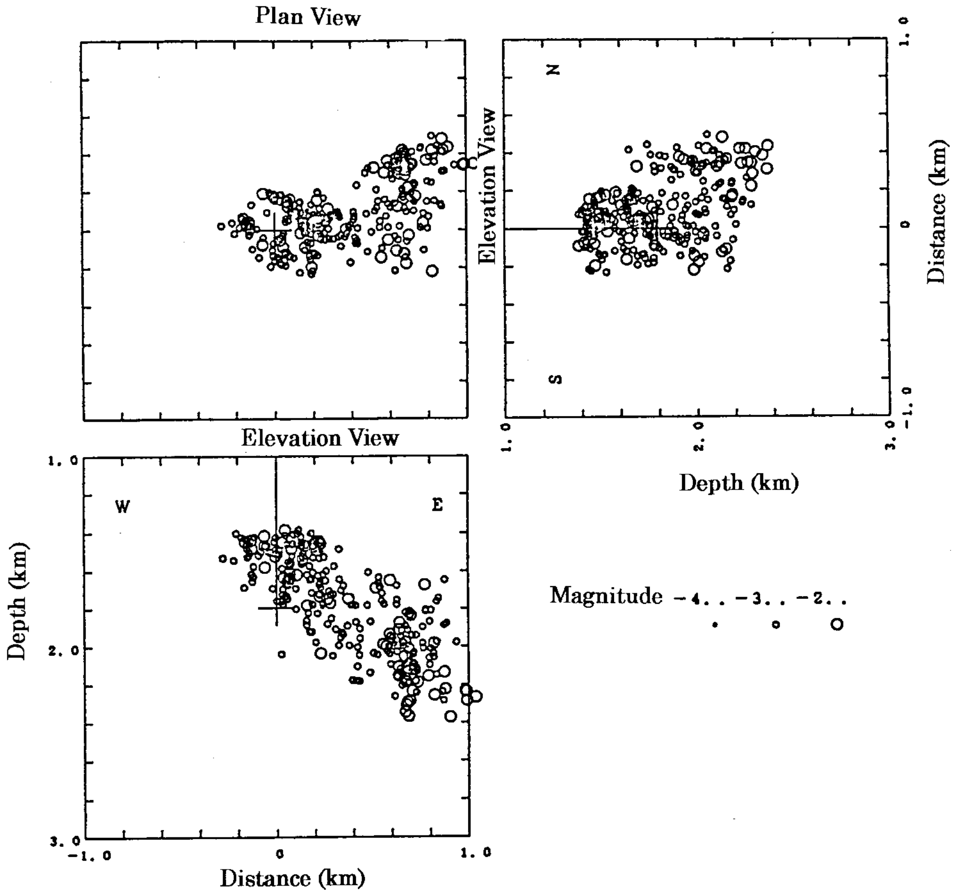

Fig. 6. AE sources during the 1995 circulation test (Exp.9501).

magnitude of the AE. AE sources were mostly distributed in an east–west direction around HDR-1, and ranged from 1500 m to 2700 m deep. The AE sources were extensively distributed compared to those produced by the hydraulic fracturing in 1992 (Exp.9201), which is shown in Fig. 7. PTS logging was periodically carried out in the two production wells during the test. Hot water flowed into the production wells from ten zones in HDR-2 and nine zones in HDR-3.

In 1996, a one-month circulation test (Exp.9601) was carried out with the same arrangement of wells as Exp.9501. The purpose of this test was to improve the hydraulic connectivity between HDR-1 and HDR-3, which was poor compared to that between HDR-1 and HDR-2. The injection flow rate was kept constant at 16.7 kg/s during this test. In the first 23 days, the wellhead valve of HDR-2 was closed to force injected water to travel to HDR-3 (a single-well production test). After that, the valve of HDR-2 was opened and hot water and steam were

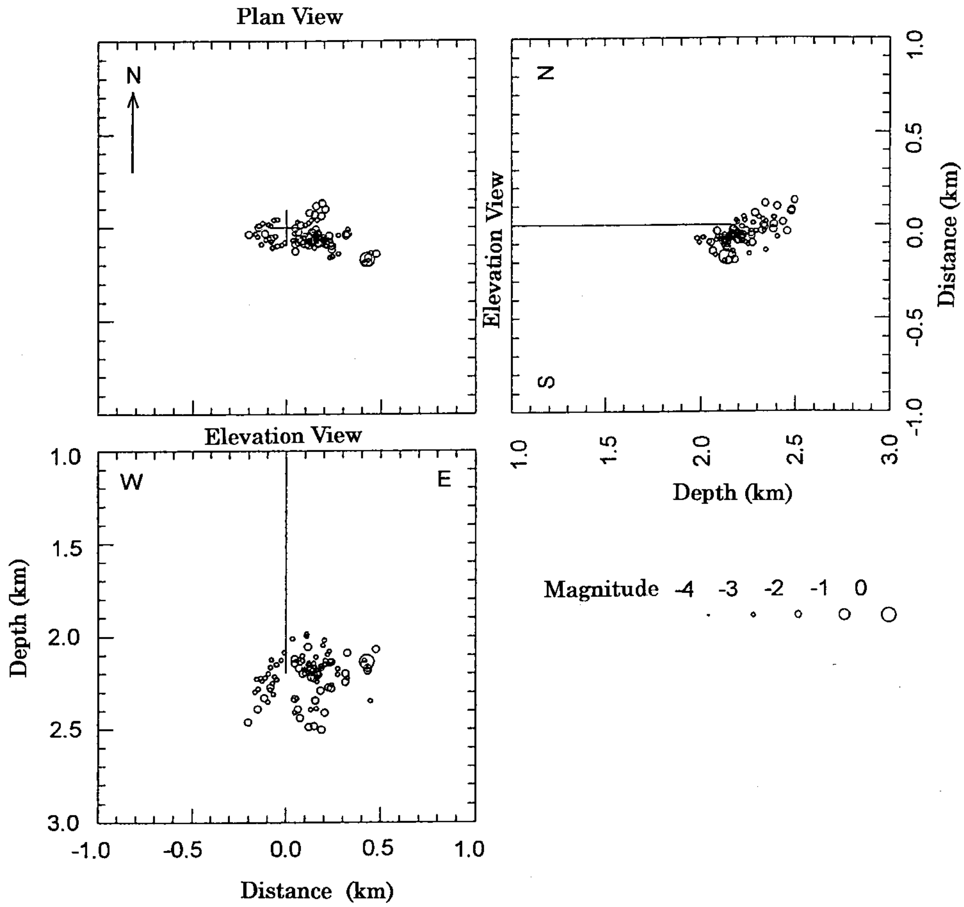

Fig. 7. AE sources during the 1992 hydraulic fracturing (Exp.9201).

produced from both production wells for 8 days (a double-well production test). About 32,200 m^3 of water were injected and about 6340 m^3 were recovered from HDR-3 during the single-well production test. In the double-well production test, about 8700 m^3 of water was injected and 72% of the water was recovered from the production wells.

4. Future plans

Based on the results of the two circulation tests, Exp.9501 and Exp.9601, the long-term circulation test for two years is being planned to start in 2000 to confirm the feasibility of hot dry rock power generation. The major objective of the long-term circulation test is to define the characteristics of the deep reservoir and to estimate the heat production lifetime. It is necessary to design and prepare infrastructure and facilities before conducting this long-term circulation test, as Hijiori is located in an area of heavy snowfall and there is no supply of electric power.

As shown in Fig. 4, we have two stimulated reservoirs, the shallow reservoir and the deep reservoir, to which two injection wells are connected independently. In designing how to circulate water through two injection wells, SKG-2 and HDR-1, and two production wells, HDR-2 and HDR-3, it is important to define the behavior of the two reservoirs in order to get the maximum power output. The details of the test schedule will be discussed by extensively analyzing the data already obtained.

References

Kuriyagawa, M., Sato, Y., Tenma, N., Yamaguchi, T., 1996. Development of Hot Dry Rock geothermal energy at Hijiori test site. J. Mining and Material Processing Inst. of Japan 112, 901–906.

Sato, Y., Ikawa, I., 1995. Stimulation of the 2200-m-deep reservoir at Hijiori HDR test site. Geothermal Resources Council Transactions 19, 275–278.

Yamaguchi, T., Hiwaki, N., Abe, T., Oikawa, Y., 1992. 90-day circulation test at Hijiori HDR test site. Geothermal Resources Council Transactions 16, 417–422.