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Multiple Reservoir Creation and Evaluation in the Ogachi and Hijiori HDR Projects, Japan

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ABSTRACT

It was considered to be necessary to create a multiple reservoirs and multiple wells system for extracting heat effectively from relatively shallow Hot Dry Rock (HDR) geothermal reservoirs in Japan. In the Ogachi HDR project, two reservoirs were created at different depths from one 1,000 m deep injection well and two production wells were drilled to penetrate the reservoirs. In the Hijiori HDR project, two reservoirs were also created from two 1,800 m deep and 2,200 m deep injection wells and two production wells were drilled to penetrate the reservoirs. These project results showed that the production wells succeeded to penetrate the reservoirs based on the micro-earthquake hypocenter distributions but it was difficult to control balance of water flow in the reservoirs. In the Ogachi project most of water flowed and short cut occurred in the lower reservoir. In the Hijiori the lower reservoir was cool down faster than the upper reservoir and this phenomenon made scaling problem in the production wells. The author reviewed the characteristics and performances of the multiple reservoirs and multiple wells systems.

1. INTRODUCTION

In Japan there are many volcanos where we can access high temperature formations or rocks at relatively shallow depth. If permeability of natural fractures in the formations and rocks is high enough for water flowing, geothermal reservoirs containing steam and hot water will be developed and we can extract steam and hot water for electric power generation by drilling production wells into the geothermal reservoirs. However, if the natural fractures are sealed by carbonate and/or silicate minerals, the permeability of the formations or rocks will not be enough for water flowing, geothermal reservoir will not be developed. Hot Dry Rock (HDR) or Enhanced Geothermal Systems (EGS) geothermal energy development technologies can be applied to extract heat energy from these low permeability formations or rocks. When hydraulic stimulation operations are applied to the low permeability formation or rocks, many fractures will be developed. In this case it is necessary for extracting heat effectively from these rocks to create a multiple reservoirs and multiple wells systems.

An HDR project was conducted from 1989 to 2002 at Ogachi in Akita prefecture, Japan by the Central Research Institute of Electric Power Industry (CRIEPI). The main purposes of this project were to show that large reservoirs could be created and large heat energy could be extracted at a depth of around 1,000 m. Two reservoirs were created from one injection well, OGC-1, at different depths of around 710 m and 1,000 m where temperatures were measured 170 degree C and 230 degree C, respectively. Two production wells, OGC-2 and OGC-3 were drilled based on the micro-earthquake hypocenter distribution, and succeeded to penetrate the reservoirs. Steam and hot water at a temperature of 165 degree C were produced from OGC-2 by injecting river water into the OGC-1. However the water recovery during the water circulation tests was small of a maximum of 30 % (Kaieda et al., 2005, Kaieda, 2012).

Another HDR project was conducted from 1986 to 2003 at Hijiori in Yamagata prefecture, Japan by the New Energy and Industrial Technology Development Organization (NEDO). The main purposes of this project were to show that a multiple reservoirs and multiple wells system could be created and heat energy extraction performance could be predicted and confirmed until temperature decline of several tens degree C during water circulation tests. Two injection wells, SKG-2 and HDR-1, were drilled to create reservoirs at different depths of around 1,800 m and 2,200 m where temperatures were measured 230 degree C and 270 degree C, respectively. Two production wells, HDR-2 and HDR-3 were drilled based on the micro-earthquake hypocenter distributions with a distance from 40m to 130m from the injection wells, and succeeded to penetrate both the reservoirs. Steam and hot water were produced from the production wells and a small of 50 kW binary power plant was operated during water circulation tests. The water recovery during the water circulation tests reached a maximum of 70.4 % from three production wells (NEDO, 2003).

In this paper the author reviewed the Ogachi and Hijiori HDR projects and summarized the characteristics and performances of the multiple reservoirs and multiple well systems.

2. RESERVOIR CREATION AND CIRCULATION TESTS IN THE OGACHI HDR PROJECT

2.1 Two reservoirs creation from one injection well

The concept of the Ogachi HDR project is shown in Figure 1. The Ogachi site is located in the caldera of northern Japan. The geology of the Ogachi site consists of the Cretaceous granodiorite covered with Tertialy lapilli tuff to a depth of 300m from the ground surface. Many natural fractures are developed in the granodiorite, with an average spacing of about 8 cm and predominant direction in the north-north-east as observed from geological investigations of oriented cores and with a comparably low natural permeability. Some of joints are sealed by carbonate minerals. An injection well, OGC-1 was completed with casings to a depth of 990 m and the interval of 990 to 1,000 m (bottom) with a diameter of 76 mm left uncased (open-hole) (Kaieda et al., 2002)

For a first (lower) HDR reservoir creation, water from a river was injected into rock from the open-hole interval between 990 m to 1,000 m of OGC-1 in 1991. A total of 10,140 tons of water was injected for 7 days with an injection pressure at a maximum of 20 MPa and a flow rate of an average of 40 tons per hour. The purpose of this stimulation was to show that large reservoirs (at least

300 m from OGC-1) could be created even at shallow depth by hydraulic stimulation operations. The created reservoir progression was monitored by the micro-earthquake hypocenter distributions. Water injection was stopped when the micro-earthquake hypocenter distribution was estimated to spread more than 400 m in radius from OGC-1.

The hypocenter distributions were estimated nearly north-north-east direction with length of 200 m to the south and 400 m to the north from OGC-1 as shown in Figure 2 (Kaieda and Sasaki, 2002). After the water injection stopped, the well-head valve was opened immediately to prevent for fractures progressing longer. The injected water was discharged for 6 days and the amount of discharged water was measured 640 ton which was 6 % of the total injected water amount (Kaieda et al., 2005).

In 1992 the casing of OGC-1 was milled from 711 m to 719 m to create a window where natural fractures were not so many observed as in the lower reservoir area. The permeability of the window area was measured $1*10^{-16}$ m^2 which was one-third of the first fracturing area. Sand plug was set in OGC-1 below the window to prevent water flowing into the lower reservoir. During a second (upper) HDR reservoir creation, water was injected into rock from the window of OGC-1. A total of 5,440 tons of water was injected for 6 days with an injection pressure at a maximum of 22 MPa and a flow rate of an average of 30 tons per hour. The water injection was stopped when the micro-earthquake hypocenter distributions were estimated to extend more than 400 m.

The hypocenter distributed eastward with length of more than 400 m as shown in Figure 2. After the water injection stopped, the injected water was flowed back from OGC-1 for more than 25 days and the amount of the discharged water was measured 1,349 ton which was more than 25 % of the total injected water amount (Kaieda et al., 1993). It was found that the micro-earthquake hypocenter distributions of the upper and lower reservoirs were different of nearly 90 degree. The upper distributed in north-north-east direction but the lower did east from OGC-1 (Kaieda and Sasaki, 2002).

The main hydraulic operations at Ogachi are summarized in Table 1.

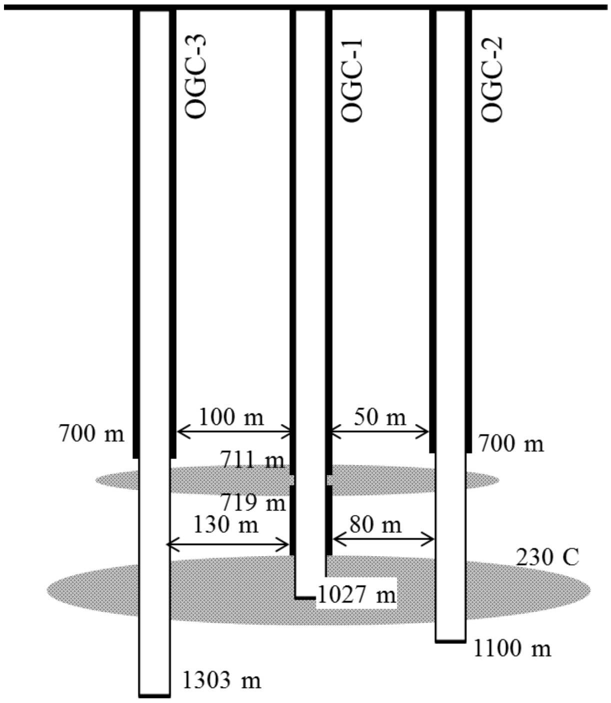

Figure 1: Concept of the Ogachi HDR project

Table 1: List of the main hydraulic operations in the Ogachi HDR project

Year	Operation	Remark
1991	Lower reservoir creation	Injection: OGC-1
1992	Upper reservoir stimulation	Injection: OGC-1
1993, 1994, 1995, 1997	Circulation through both reservoirs	Injection: OGC-1 Production: OGC-2

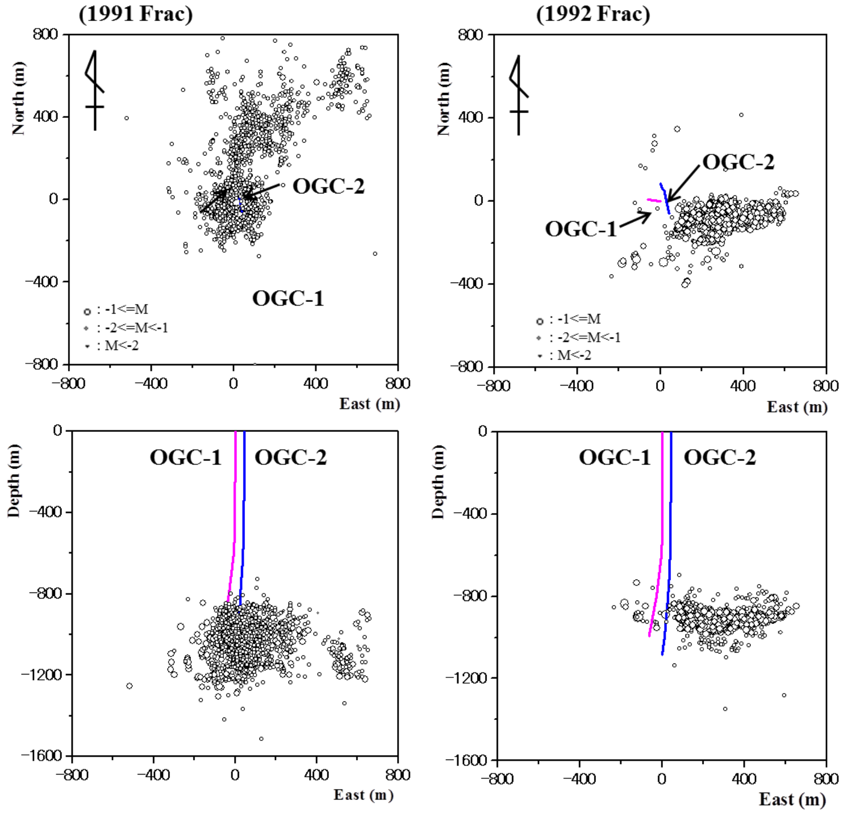

Figure 2: Micro-earthquake hypocenter distributions in the Ogachi HDR project. The upper figures are plan view and the lower are east-west cross section view looking north. The left figures are obtained in the 1991 hydraulic fracturing and the rights are in the 1992.

2.2 Reservoir stimulation and water circulation

A production well, OGC-2, was planned to penetrate both the upper and lower reservoirs based on the micro-earthquake hypocenter distributions. However the created reservoirs were progressed different directions. Therefore OGC-2 well-head was located east of OGC-1 and directionally drilled to the north to a depth of 1,100 m of OGC-1. The first water circulation test was conducted by injecting surface water into OGC-1 and the hot water recovered from OGC-2 through the two reservoirs in 1993. The water recovery during the circulation test was so small of a few % that both the wells of OGC-1 and OGC-2 were stimulated by hydraulic fracturing to improve hydraulic connection between OGC-1 and OGC-2 in 1994. After the OGC-1 and OGC-2 stimulation, water recovery from OGC-2 increased to 10 % during the 5-month water circulation test in 1994 (Kaieda et al., 2002). Micro-earthquake events were distributed around OGC-1, 400 m north-north-east, 400 m west and 200 m south-east from OGC-1. There are seismically quiet areas around OGC-1 as shown in Figure 3. Particularly larger events of micro-earthquake occurred at the edge of the hypocenter distributions.

In 1995 OGC-1 was re-drilled from 1,000 m to 1,027 m to increase the water injection interval for decreasing water injection pressure. After this drilling, OGC-1 and OGC-2 were hydraulically stimulated again. Water was injected into OGC-1 at a flow rate of 1.75 ton/min and at a well-head pressure of 18 MPa, and into OGC-2 at a flow rate of 2.25 ton/min and at a well-head pressure of 18 MPa. A 1-month water circulation test was performed in succession to these stimulation operations. During this circulation test water recovery increased to 25 % with a temporally maximum of 30 % and the water injection pressure at well-head of OGC-1 decreased less than 10 MPa at a flow rate of 500 kg/min (Kaieda et al., 2002). Few micro-earthquake events were observed during this circulation test.

In 1997, a sand plug was set below the window of OGC-1 to conduct a 9-day water circulation test through only the upper reservoir to evaluate the upper reservoir characteristics. Water level in OGC-2 increased several tens meters, but no water was produced from OGC-2 in this circulation test. After the sand plug was removed, another 9-day water circulation test was conducted between OGC-1 and OGC-2 through both the upper and lower reservoirs. During this water circulation test hot water and steam was recovered from OGC-2 at a recovery of 15 %. A second production well (OGC-3) was drilled in 2000 (kaieda et al., 2005). Using OGC-3 many hydraulic tests and temperature monitoring were performed with the fiber-optic thermometer. But no water circulation test was conducted using OGC-3, because the budget for the project was cut in 2003 (Kaieda et al., 2012).

Tracer tests were conducted during the circulation tests in 1994, 1995 and 1997. Two peaks in the tracer concentration curve were observed in the 1994 test, but only one peak was detected in the 1995 test. The tracer concentration peak value increased from the 1994 test to the 1995 test, but the modal volume of the reservoir decreased from 1994 to 1995. This may be caused by occurrence of shot cut in the reservoir. Value of width at 1/2 height which is assumed to represent dispersion of the reservoir decreased from the 1994 test to the 1995 test, but the value increased in 1997 (Kiho, 2000). This increase is considered to be caused by the plugging the fracture with the sand particles which was used in the upper reservoir circulation test in 1997.

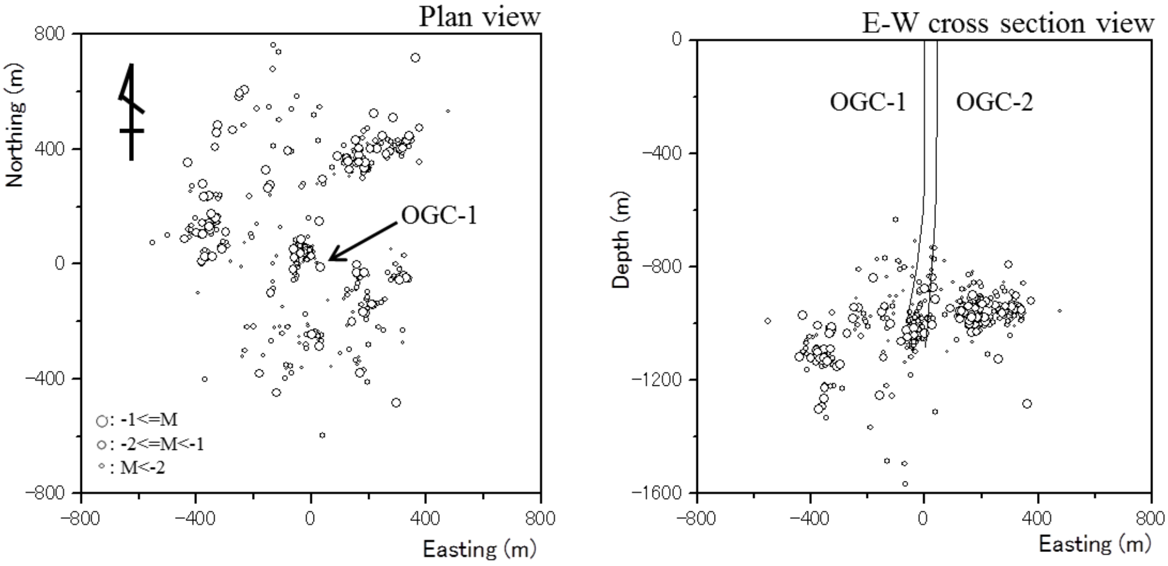

Figure 3: Micro-earthquake hypocenter distributions during the 1994 5-month circulation test in the Ogachi HDR project. The left figure is plan view and the right is east-west cross section view looking north.

3. RESERVOIR CREATION AND CIRCULATION TESTS IN THE HIJIORI HDR PROJECT

3.1 Two reservoirs creation from two injection wells

The concept of the Hijiori HDR project is shown in Figure 4. The Hijiori HDR site is located at southern edge of the Hijiori caldera in Yamagata prefecture northern Japan. From the logging results of the pre-existing geothermal survey well, SKG-2, some large natural fractures in granodiorite dipping steeply to the north with strike of nearly east-west are observed. In 1986 an upper reservoir was created at an open-hole section from 1,788 m to 1,802 m of SKG-2 by injecting a total of 1,080 tons of water for 11 hours with a maximum flow rate of 6.2 ton/min and a maximum well-head pressure of 16 MPa. The SKG-2 well-head valve was opened just after injection stopped and hot water flowed back from the fracture to the ground surface. The amount of the discharged water was measured 380 tons. This fracturing was intended to improve permeability only near SKG-2 and not intended to extend fracture longer. If the created fractures spread wider beyond the multiple well areas, water loss during the later water circulation operations may increase.

The created reservoir was evaluated by the micro-earthquake hypocenter distributions to progress nearly east-west direction within 200 m from SKG-2 and from 1,600 m to 2,000 m in depth as shown in Figure 5. Based on the hypocenter distributions, a production well, HDR-1, was drilled to penetrate the reservoir to a depth of 1,805 m with a separation of 40 m south of SKG-2 at the bottom depth. In 1988 the reservoir was stimulated to improve hydraulic connection between SKG-2 and HDR-1 by injecting a total of 1,961.1 tons of water into SKG-2 with a maximum flow rate of 6 tons/min and a maximum well-head pressure of 15.5 MPa.

The stimulated reservoir area was evaluated by the micro-earthquake hypocenter distributions to progress almost same direction of the previous hypocenter distributions and a few hundred meters longer than before from SKG-2 (Sasaki, 1998). A second production well of HDR-2 was drilled to a depth of 1,909.9 m with a separation of 50 m west of SKG-2 at the bottom depth in 1989 and a third production well of HDR-3 was drilled to a depth of 1,907.0 m with a separation of 55 m east of SKG-2 at the bottom depth in 1990 (NEDO, 2003).

HDR-1 was re-drilled to a depth of 2,205 m and was cased to a depth of 2,151 m, in 1992. A second (lower) reservoir was created from 2,151 m to 2,205 m of HDR-1 by injecting a total of 2,115 tons of water for 12 hours with a maximum flow rate of 4.3 tons/min and a maximum well-head pressure of 25.5 MPa. The HDR-1 well-head valve was opened just after injection stopped and the volume of the discharged water was measured 324 tons.

The created reservoir was evaluated by the micro-earthquake hypocenter distributions to progress nearly east-west direction within 400 m from SKG-2 and from 2,000 m to 2,400 m in depth as shown in Figure 5 (Sasaki, 1998). Based on the hypocenter distribution, HDR-3 was re-drilled to a depth of 2,303 m with a separation of 130 m east from HDR-1 at the bottom depth in 1993, and HDR-2 was re-drilled to a depth of 2,300.9 m with a separation of 90 m west from HDR-1 at the bottom depth in 1994 (NEDO, 2003).

The main hydraulic operations in Hijiori are summarized in Table 2.

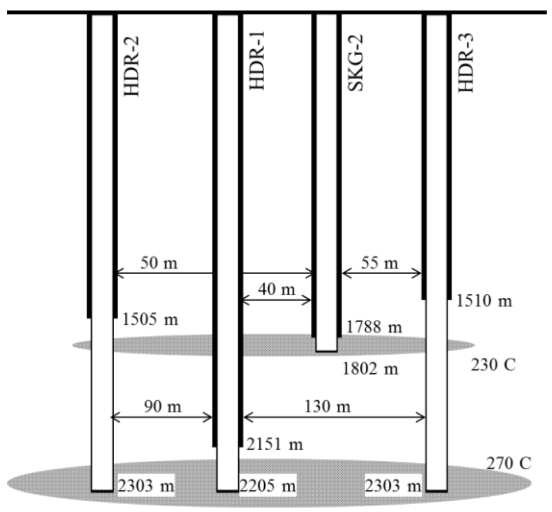

Figure 4: Concept of the Hijiori HDR project

Table 2: List of the main hydraulic operations in the Hijiori HDR project

Year	Operation	Remark
1986	Upper reservoir creation	Injection: SKG-2
1988	Upper reservoir stimulation	Injection: SKG-2
1991	Circulation through upper reservoir	Injection: SKG-2 Production: HDR-1, 2, 3
1992	Lower reservoir creation	Injection: HDR-1
1995	Circulation through lower reservoir	Injection: HDR-1 Production: HDR-2, 3
2000-2002	Circulation through both reservoirs	Injection: SKG-2 & HDR-1 Production: HDR-2, 3

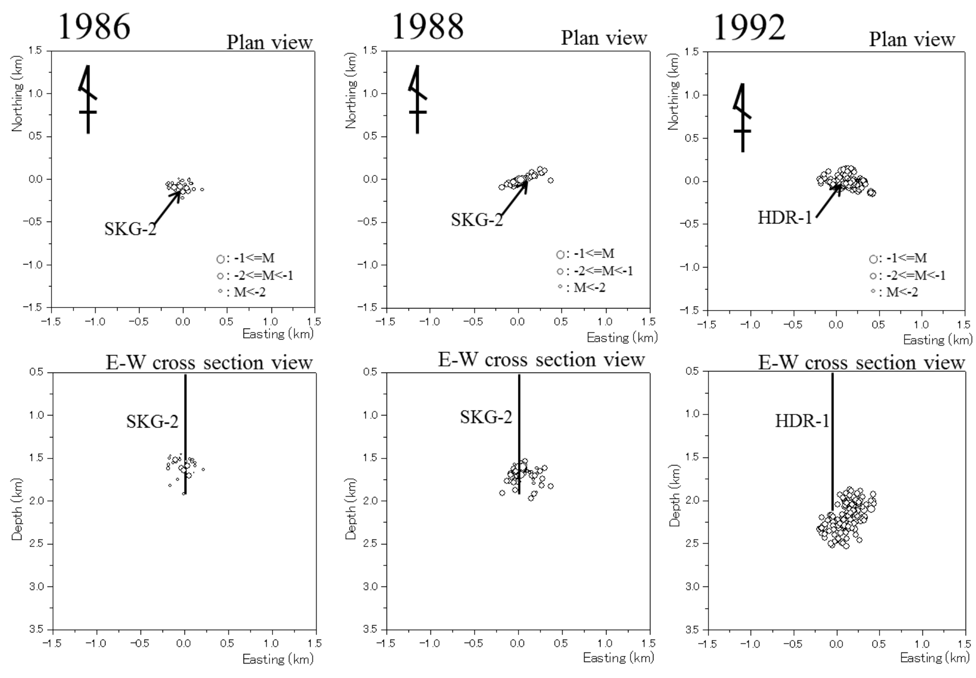

Figure 5: Micro-earthquake hypocenter distributions in the Hijiori HDR project. The upper figures are plan view and the lower are east-west cross section view looking north. The left figures are obtained in the 1986 hydraulic fracturing, the middle in the 1988 SKG-2 stimulation and the right in the 1992 HDR-1 hydraulic fracturing.

3.2 water circulation tests

In the 90-day upper reservoir circulation test in 1991, a total of 134,510 tons of water was injected into SKG-2 at an average flow rate of 1 ton/min and an average well-head pressure of 3 MPa. The circulated water (hot water and steam) was recovered from HDR-1, HDR-2 and HDR-3. The water recovery of each production wells of HDR-1, HDR-2 and HDR-3 were 11.2 %, 26.9 % and

32.2 %, respectively. The total water recovery from the three wells was 70.4 % (NEDO, 2003). During this circulation test few micro-earthquake events were observed. The tracer tests during this circulation test showed that HDR-2 and HDR-3 connected SKG-2 through a main fracture in the reservoir, but HDR-1 connected another fractures. There are two flow paths in the upper reservoir (Tenma et al., 2002).

In 1995 a 25-day circulation test was conducted through the lower reservoir. A total of 51,500 tons of water was injected into HDR-1 at an average flow rate of 1 ton/min and an average well-head pressure of 8.5 MPa. The circulated water (hot water and steam) was recovered from HDR-2 and HDR-3. The water recovery from HDR-2 and HDR-3 were 25.6 % and 13.4 %, respectively. The total water recovery from the three wells was 39 % (NEDO, 2003).

From November 27, 2000 to August 31, 2002 a log-term (550 days) circulation test (LTCT) was conducted. At the beginning of this test water was injected into only the lower reservoir through HDR-1 and hot water and steam were produced from HDR-2 and HDR-3 for 333 days. A total of 484,203 tons of water was injected into HDR-1. The water recoveries from HDR-2 and HDR-3 were 92,013 ton (19.0 %) and 114,072 ton (23.6 %), respectively.

The total water recovery from the two wells was 206,085 ton (42.6 %). During the lower reservoir circulation anhydrite ($CaSO_4$) scaling problem was occurred at a shallower depth than the upper reservoir. The anhydrite scale was washed out from HDR-2 and HDR-3 by the coiled tubing system and after that scale inhibitor was added into the injection water to prevent scaling. After 38 days for preparation, water was injected into both the reservoirs through HDR-1 and SKG-2, and hot water and steam were produced from HDR-2 and HDR-3 for 217 days as the dual reservoir circulation. A total of 85,329 tons of water was injected into SKG-2 and a total of 96,210 tons of water was injected into HDR-1. The amount of recovered water from HDR-2 and HDR-3 was 69,347 tons and 27,534 tons, respectively. The total water recovery of produced steam and hot water to the injected water was 53.4 % (NEDO, 2003, Matsunaga et al., 2005).

Figure 6 shows the history of the water injection pressure, flow rate and micro-earthquake numbers per day during the LTCT. After the quiet period for one and half months in the beginning of the LTCT 62 micro-earthquake events were observed. Then the number of events deceased to a few events per day. Micro-earthquakes were observed after the water injection stopped. Three-month later micro-earthquake events were observed 45 per day and a large event with a magnitude of 2.4 was observed. Some people felt ground motion of this earthquake, but no complain was made.

Locations of these micro-earthquake hypocenters were distributed toroidal as shown in Figure 7. Near the injection well a few events were located. This is considered that the around the injection well fracture progressed so well that water flowed smoothly without seismic events but near the edge of the fracture distribution new fractures were produced. These hypocenter distributions extended beyond the upper and lower reservoir area. This means that much of the injected water flowed outward from the reservoirs and the water recovery during the LTCT decreased.

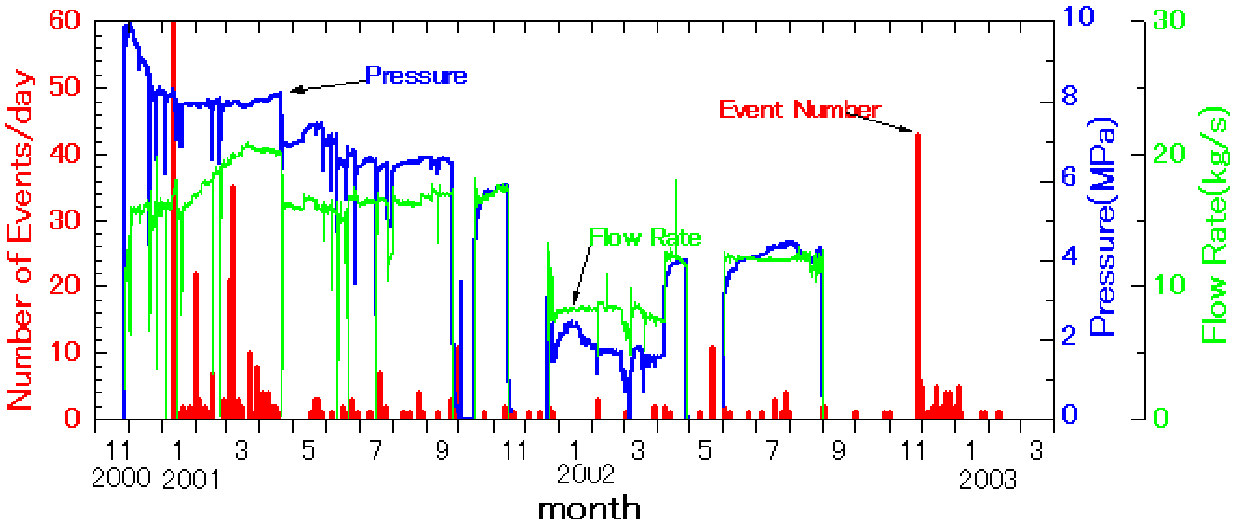

Figure 6: History of the water injection pressure, flow rate and observed micro-earthquake events numbers per day during the LTCT.

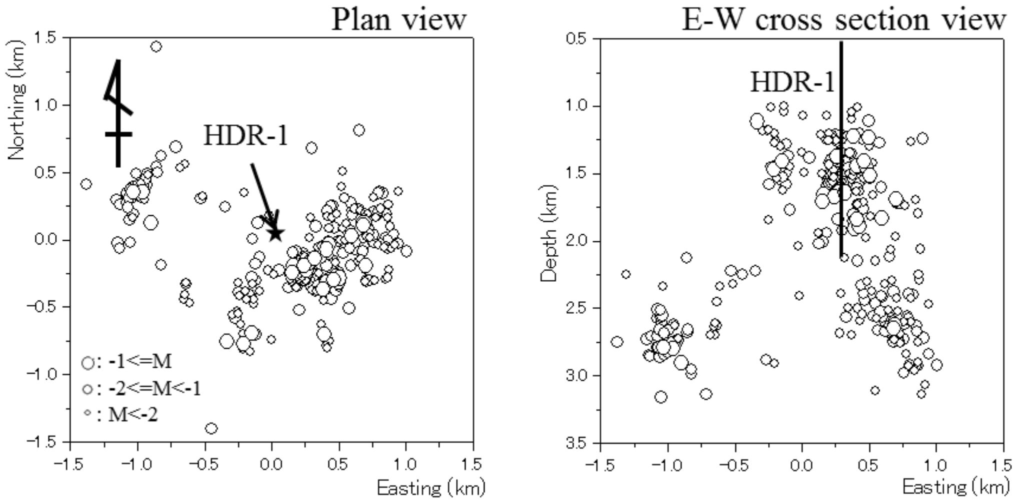

Figure 7: Micro-earthquake hypocenter distributions observed during the LTCT. The left figure is plan view and the right is east-west cross section view looking north.

4. DISCUSSION

4.1 Multiple reservoir creation

In both the projects at Ogachi and Hijiori two reservoirs were created successfully at different depths. The size and location of these created reservoirs were estimated by micro-earthquake observation. In the Ogachi project the two reservoirs were estimated to progress in different directions. The lower reservoir progressed north-north-east direction and the upper did only eastward. The lower reservoir was created in the pre-existing fractures dominant area and the created reservoir progressed along with the pre-existing fracture system. However the upper reservoir was created in a small number of pre-existing fracture area and the created reservoir progressed eastward which is consistent with the horizontal maximum stress direction. The production well of OGC-2 was intended to penetrate both the reservoirs, but OGC-2 penetrated the edge of the upper reservoir. These results show that pre-exiting fracture system strongly affected on reservoir creation. On the other hand, in the Hijiori project the created two reservoirs were estimated to progress nearly same direction of east-west along pre-existing large fractures at different depths. Therefore the production wells could penetrate both two reservoirs. It is desired to create multiple reservoirs in same or similar geological conditions.

The reservoirs extended not only during reservoir creation but also the water circulation tests. Therefore the water recoveries during the circulation tests were small. Some of the injected water flowed outward and micro-earthquakes occurred at the edge of the extended reservoirs. During the long-term circulation tests micro-earthquake hypocenters were distributed wider beyond the two reservoir areas.

4.2 Hydraulic characteristics of the reservoir change

Hydraulic characteristics of the reservoirs were changed by hydraulic stimulation and water circulation operations. Usually these operations are applied to improve permeability of fractures in the reservoirs. However these operations don’t work equally to fractures in the multiple reservoirs. Sometimes only specific fractures were stimulated and short cut of the flow paths in the reservoirs. These phenomena were detected by the Pressure Temperature and Spinner (PTS) logging and evaluated by the tracer tests. It is hard to stimulate fractures equally and to make specific fractures open or close without open-hole packers. The open-hole packers are not applicable at a high temperature of more than 200 degree C at the moment.

In the Ogachi project, it was found that sand particles used for preventing water flow during the 1997 upper reservoir circulation test partially plugged the short cut flow path. Sand particles have been used for propping the fracture open in the sediment formation to keep high permeability so far, but sand particles may be effective to plug the flow path in volcanic formation. More basic study on size and density of particle is needed to use sand particles for plugging fractures. Recently AltaRock developed the thermally degrading zonal isolation materials (TZIM) to block permeable zones (Petty et al., 2013). This technology is expected to contribute to control water flow in the reservoirs.

4.3 Chemical characteristics in the reservoir

During the lower reservoir circulation in the LTCT at Hijiori scaling of anhydrite ($CaSO_4$) occurred at a shallower depth than the upper reservoir in the production wells. Temperature of the lower reservoir decreased faster than the upper by the water circulation tests. When the temperature of the lower reservoir water decreased lower than the upper reservoir, scaling was occurred in the production wells. There are a lot of anhydrite veins in the granodiorite. The injected low temperature water dissolved anhydrite during flowing in the reservoir. The anhydrite dissolved water flowed into the production wells in the lower reservoir and flowed up in the production well. When the water met hotter water from the upper reservoir in the production well, the solubility of anhydrite in water became over saturated to precipitate. Scale inhibiter was added to the injection water and water injection flow rate into the upper and lower reservoirs was controlled to prevent scale occurring (NEDO, 2003, Matsunaga et al., 2005).

Scaling was also occurred in the Ogachi project at the beginning of the 1993 circulation. A thin calcite scale was found in the well-head of OGC-2, but this phenomenon occurred only this time. No more scaling occurred in the Ogachi project. This is considered that the water flow area of the Ogachi circulation system is smaller than that of Hijiori, so the dissolved carbonate mineral volume was small.

4.4 Multiple well system

Based on the micro-earthquake hypocenter distributions production wells were successfully drilled to penetrate the artificially created reservoirs, except the upper reservoir at Ogachi. In the beginning of the water circulation tests water recovery of amount of steam and hot water from production wells to injected water amount was very small in the both projects. However hydraulic stimulation of the injection wells and production wells were very effective to improve the recovery. In the Ogachi project a maximum recovery was obtained around 30 % from one production well in the 1995 one-month circulation test (Kaieda et al., 2000) and in the Hijiori project a maximum recovery of 70.4 % was obtained by producing from three production wells in the 1991 90-day circulation test (NEDO, 2003). Therefore the multiple-well system was shown effective to increase water recovery. However water recovery during these water circulation tests was very small comparing to the other projects, for example, 87.5 % in the long-term flow test (LTFT) #1 and 92.7 % in the LTFT #2 of the Fenton Hill project in USA (Duchane, 1995) and pumped hot water from the production wells fully re-injected into the injection wells almost 100 % recovery in the Soultz project in France (Genter et al., 2013). It is desired to apply down-hole pumps in order to improve water recovery during water circulation tests in Japan. However down-hole pumps which can work at a high temperature of more than 200 degree C have been still under development.

5. CONCLUSIONS

Hot Dry Rock geothermal energy development projects were conducted at Ogachi in Akita prefecture and at Hijiori in Yamagata prefecture, Japan by NEDO and CRIEPI, respectively. In these projects two reservoirs were created at different depths from one 1,000 m deep well at Ogachi and from two of 1,800 m and 2,200 m deep wells at Hijiori. Production wells were drilled to penetrate these reservoirs based on the micro-earthquake event hypocenter distribution. At Hijiori two production wells succeeded to penetrate both the reservoirs. But the production well grazed the upper reservoir at Ogachi, because the created reservoirs progressed different directions depended on geological heterogeneity. Therefore the multiple reservoir system should be created in a same or similar geological condition.

It was difficult to control water flow in the multiple reservoirs and multiple wells system at the moment. Shot cut in the flow paths occurred and the temperature of the shot cut area decreased rapidly. At Hijiori, temperature of the lower reservoir decreased faster than the upper, so the anhydrite scaling problem occurred. Developing open-hole packers, sand plugging and AltaRock’s TZIM is desired to control water flow and prevent scaling occurring in the multiple reservoirs.

There are many natural fractures in granodiorite at Ogachi and Hijiori, but original permeability of the granodiorite was small because some fractures are sealed by carbonate minerals. During the reservoir creation and the water circulation fractures in the reservoir extended outward, therefore water recovery during the water circulation through the reservoirs was small of 10 to 30 % from one production well. However a maximum recover of injected water from three production wells at Hijiori reached 70.4 %. The multiple-well system was effective to increase water recovery.

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