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REPEAT SP MEASUREMENTS AT THE SUMIKAWA GEOTHERMAL FIELD, JAPAN

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ABSTRACT

Baseline self-potential (SP) surveys at the Sumikawa geothermal field were carried out in 1983. Similar SP surveys were done in 1993, two years before the startup of the Sumikawa geothermal power plant, and repeated in 1996, 1997 and 1998. The result of 1997 survey shows a negative anomaly of about -100mV in the central part of the exploitation area. Unfortunately, no data free from artificial noises are available from the 1993, 1996 and 1998 surveys in most of the central area. Comparing the result taken in 1997 with the observation in 1983, we found remarkable reduction in SP over the wellfield. This change in SP is thought to be caused by production-induced fluid flows in the reservoir through electrokinetic coupling. The pressure decline due to production causes the expansion of the two-phase zone within the upper part of the reservoir. Downward flow of the liquid phase in the two-phase region transports positive charge with it and induces negative and positive sources of conduction current at shallower and deeper part of the two-phase zone, respectively. Since both of the current sources have the same magnitude, the effect of the shallower negative one dominates on the ground surface. In addition to this effect, negative SP anomalies expected for the reinjection region, which are also caused through electrokinetic coupling, might be responsible for the observed SP changes.

1. INTRODUCTION

Self-potential (SP) surveys have been carried out on a number of geothermal areas in Japan during the last two decades. In most cases, SP anomalies of positive polarity (50 to 500 mV in amplitude and 0.5 to 5 km in spatial extent) were found to overlie high temperature upflow zones. The streaming (electrokinetic) potential generated by hydrothermal circulation is believed to be the most likely cause of the observed positive anomalies (Ishido et al., 1989).

In addition to SP anomalies under natural state conditions, Ishido et al. (1989) predicted the possibility that production-induced fluid flows also cause changes in SP through electrokinetic coupling. In the early stages of exploitation, the natural flow pattern is likely to be overwhelmed by perturbations caused by production and injection wells, which will bring about changes in the SP distribution through electrokinetic coupling. No other effects such as thermoelectric coupling and chemical diffusion potential will play significant roles, since production-induced changes in the distributions of temperature and fluid chemistry are minor compared to flow pattern changes. In order to detect changes in SP associated with fluid production, we repeated SP surveys in the Sumikawa geothermal field, Japan. In this paper, we report the results of SP surveys and discuss the mechanism of the observed SP changes.

2. SUMIKAWA GEOTHERMAL FIELD

The Sumikawa geothermal field is located in the Hachimantai volcanic zone of the Sengan thermal area in northern Honshu, Japan. Exploratory studies have been carried out at Sumikawa since 1981 by Mitsubishi Materials Corporation (MMC) and Mitsubishi Gas Chemical Corporation (MGC); this comprehensive program incorporated a variety of geochemical and geophysical surveys and an extensive drilling investigation. The drilling program revealed a complex geological structure and made possible a very thorough pressure-transient testing program involving both short-term single-well and long-term multi-well pressure interference tests. These studies were first carried out jointly by MMC and NEDO (the New Energy and Industrial Technology Development Organization) from 1985 to 1989, and then by MMC and GSJ (Geological Survey of Japan) from 1990 to present. Based upon the reservoir engineering data, a mathematical model of the reservoir under natural-state condition was developed (Pritchett et al., 1991) before the startup of the Sumikawa geothermal power plant (50 MW) in the spring of 1995. Within the survey area (Fig. 1), the ground surface averages about 1000 meters above sea level (ASL), but slopes sharply down from south (> 1300 m ASL near Mt. Yakeyama) to north (< 700 m ASL near the Akagawa hot spring area). The major geological formations in the area are the Quaternary volcanic rocks, lake sediments, the Tertiary volcanic rocks and crystalline intrusive rocks, in order of increasing depth (Kubota, 1985). Lake sediments, which are located below about 400 m in depth, work as caprocks for the geothermal reservoir within the Tertiary formations. In the upper part of the reservoir, a vapor-dominated zone is present below the caprock in the pre-production state (Kubota, 1985).

3. REPEATED SP SURVEYS

A SP survey was carried out in and around the Sumikawa field by GSJ in 1983. The measurements were made with copper-copper sulfate nonpolarizing electrodes and a high impedance voltmeter. For each survey line, the maximum wire length (from a fixed base electrode) and the data sampling intervals were 2000 and 100 meters respectively. Telluric activity was monitored by recording potentials across stationary dipoles in the survey area; no significant telluric variation was observed during the survey period (in November, 1983). In compiling the contour map (Fig. 2) showing the distribution of SP, the potentials measured along the various survey lines were tied to a common ground reference and then subjected to a smoothing process (variations shorter than about 500 m in wavelength were removed). Closure offsets were relatively small: for example, a 48.7 km loop traverse was closed with an error of 5.0 mV. As seen in Fig. 2, an obvious anomaly of positive polarity appears over the Sumikawa wellfield. This anomaly is thought to be caused by high temperature upflow through electrokinetic coupling (see Fig. 8). In contrast, there is no obvious anomaly overlying the hot spring areas. This is mainly because the thermal waters in these areas are characterized by very small coupling coefficient under near surface conditions and generate no measurable anomaly associated with their discharge at the surface (Kikuchi et al., 1987).

We repeated the SP survey in the falls of 1993, 1996, 1997 and 1998. Although the startup of the power plant was in 1995, long term flow tests involving most of production and reinjection wells were conducted in the fall of 1993, during which the SP survey was carried out. For these surveys, silver-silver chloride nonpolarizing electrodes were used; other survey procedures were the same as those in the first survey in 1983. Closure offsets of typical loops were slightly larger than that in 1983: 10 to 30 mV in 1993. As shown in Fig. 1, well sites A, B, C, D and E and pipelines for transport of vapor and separated hot water were present when the surveys were conducted after 1993. Although all the points shown by open circles in Fig. 1 were covered in the 1993 survey, only the central part was covered in 1996, 1997 and 1998 surveys: region I in 1996, regions I and II in 1997 and a part of region I in 1998. The location of the common ground reference is that shown in Fig. 1 for all the surveys other than 1998.

Fig. 3 compares the data from the 1983, 1993, 1996 and 1997 surveys for region I. In the 1993, 1996 and 1997 surveys large decreases in SP compared to that in 1983 are seen at the points that are near the foundations supporting the pipelines. The 1997 data for region II (Fig. 4) clearly shows that these large negative anomalies (close to –400 mV) appear locally near the artificial constructions. Fig. 5 shows the 1998 data along a closed-loop starting from a point to the southeast of well site C, passing by well site A and the power plant, and returning to the starting point. As seen in Fig. 5, large negative anomalies appear only at points less than 20 m away from the artificial constructions, which suggests that the anomalies are caused by near-surface effects. One possible explanation is the presence of iron reinforcing rods in the pipeline foundations; it serves as a path for electrons to travel upward from the less oxidizing (reducing) environment at depth of several meters to the more oxidizing environment near the ground surface.

Since the data taken near the pipelines and power plant suffered from artificial noises, we abandoned those data on contour maps. Unfortunately we do not have enough data in the central part (regions I and II) for the 1993, 1996 and 1998 surveys. However, for the 1997 survey, we have substantial data taken at points more than 100 m away from the artificial constructions, which are thought to be free from the artificial noises, in the central part. To draw a contour map for the "1997 survey" (Fig. 6), we used the 1997 data taken at points more than 100 m away from the artificial constructions for regions I and II and the 1993 data for the peripheral area outside of regions I and II. Although no data were taken in the peripheral area in 1997, the SP distribution there can be assumed to be the same as that in 1993. This is because the SP distribution (especially long-wavelength pattern) is thought to be quite stable in the peripheral area (comparing the 1983 and 1993 data) and both of the 1993 and 1997 surveys show almost the same potentials at the points in the westernmost part of region II.

As can been seen in Figs. 2 and 6, the distribution of SP observed in 1997 is substantially different from that in 1983. Fig. 7 compares the SP profiles in 1983 and 1997 for region III (shown in Fig. 1) passing through the central area in the east-west direction. A negative anomaly appears in the central area and replaces the positive anomaly observed in 1983. Although we cannot draw a definite conclusion since most of the sampling points in 1997 are different in location from those in 1983 in the central area and the nature of the artificial noises is not fully understood, the observed change is thought to be related to deep reservoir processes.

4. ELECTROKINETIC MECHANISM

Underground fluid flows resulting from the production and reinjection of geothermal fluids can generate SP changes through electrokinetic coupling. One possible mechanism is associated with substantial production-induced expansion of the vapor-dominated zone due to reservoir pressure decline. The expansion of the two-phase zone was predicted by mathematical modeling studies of the Sumikawa reservoir (Pritchett et al., 1991) and partly confirmed by the change in enthalpy of produced fluids after 1995. As shown in Fig. 8, counterflows of vapor (upward) and liquid (downward) are produced in the expanding two-phase zone. Although the vapor phase alone cannot move charge, the downward liquid-phase flow carries positive charge with it and induces negative and positive sources of conduction current at shallower and deeper parts of the two-phase zone, respectively. Since the zeta-potential of the electrical double layer at the interface between mineral and pore fluid is expected to be negative for the reservoir fluid at Sumikawa (neutral in pH and chloride concentration of about 300 ppm, Ueda et al., 1991) under high temperatures above 100 °C (Ishido and Mizutani, 1981), the flow of liquid phase carries positive charge with it. Since both of the current sources have the same magnitude, the effect of the shallower negative one dominates on the ground surface and brings about a negative SP anomaly (see Ishido and Pritchett, 1999 for more quantitative discussion of the conceptual model shown in Fig. 8).

A negative potential generated by fluid injection may also be responsible for the negative anomaly observed in 1997. Liquid-phase fluid flows from the reinjection wells remove positive charges from the neighbor of feedpoints of the wells, resulting in negative potential development in the injection zones (Ishido and Pritchett, 2000). This negative potential can be introduced to the ground surface through the conductive caprock in the area.

Ishido and Pritchett (1996) performed a preliminary simulation study to predict SP changes using the "EKP-postprocessor" based upon a 3-D natural-state model of the Sumikawa reservoir (Pritchett et al., 1991). Further modeling studies will be useful for quantitative interpretation of the observed SP changes and for making a plan of further repeat SP surveys at Sumikawa. Tosha et al. (2000) observed SP changes associated with a two-month shut-in of all the production wells at the Yanaizu-Nishiyama geothermal field. Since SP changes due to short-term shut-in of production and reinjection wells are also expected for the Sumikawa reservoir, frequently-repeated SP surveys and/or continuous SP monitoring will be useful to get clearer evidence of production-induced SP change at Sumikawa.

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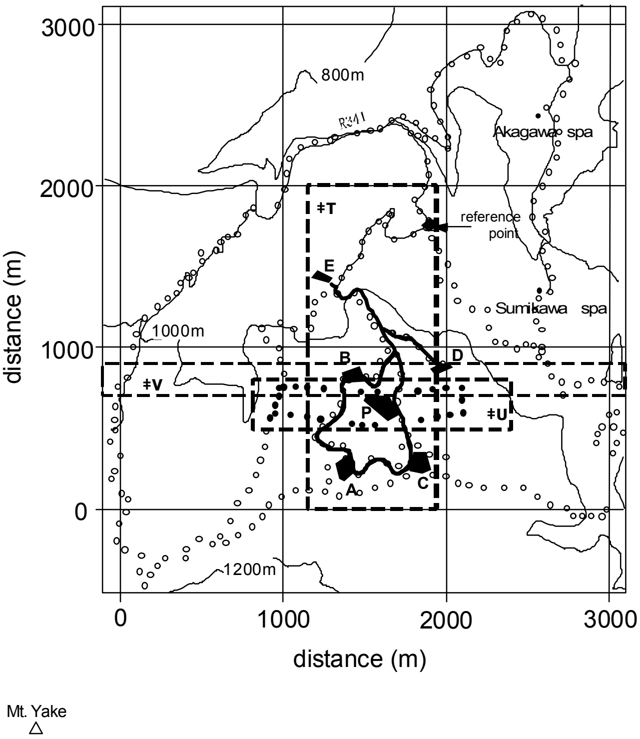

Fig. 1 Map of the Sumikawa geothermal field showing SP measurement points (open and solid circles). Well sites are indicated by A, B, C, D and E; sites A, B and C are for production wells and sites B, D and E for reinjection wells. The power plant is located at P. Along the survey lines shown by thick lines, pipelines for transport of steam and separated hot water have been present since 1993.

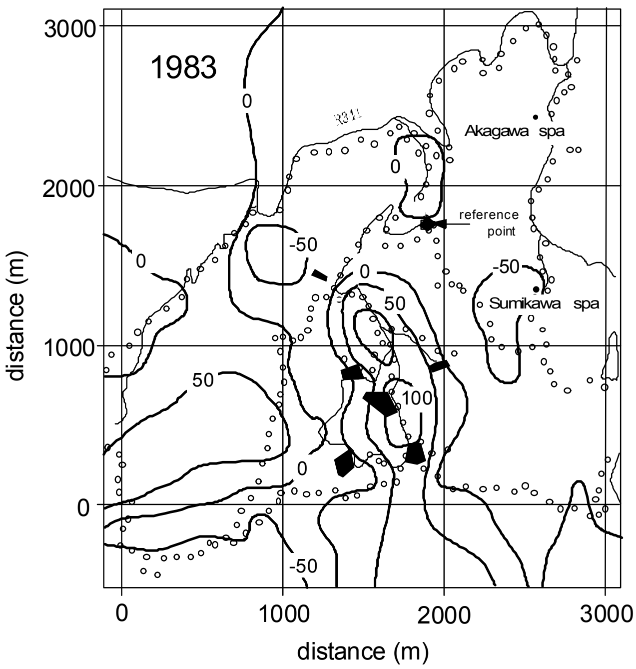

Fig. 2 Self-potential distribution in the Sumikawa field in 1983. Contour interval is 50 mV.

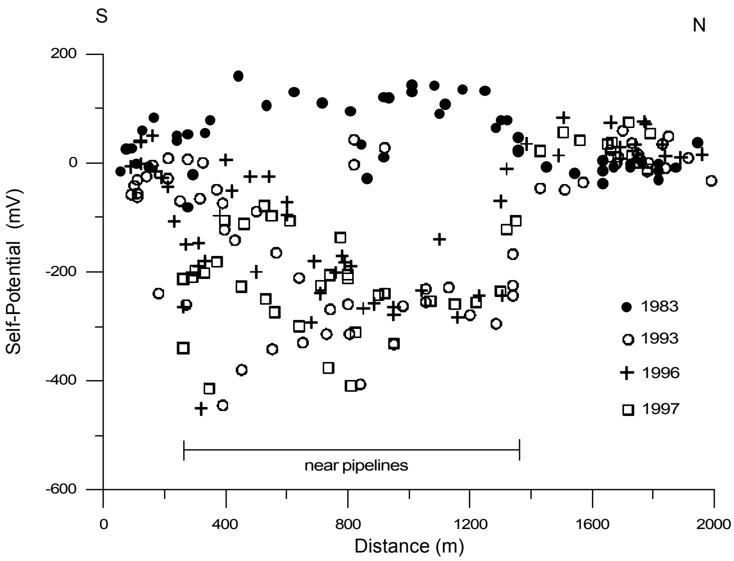

Fig. 3 Self-potential profiles along the north-south section of region I (location of region I is shown in Fig. 1). Between 250 m and 1350 m in distance, the measurement points are near (less than 20 m from) the foundations of pipelines.

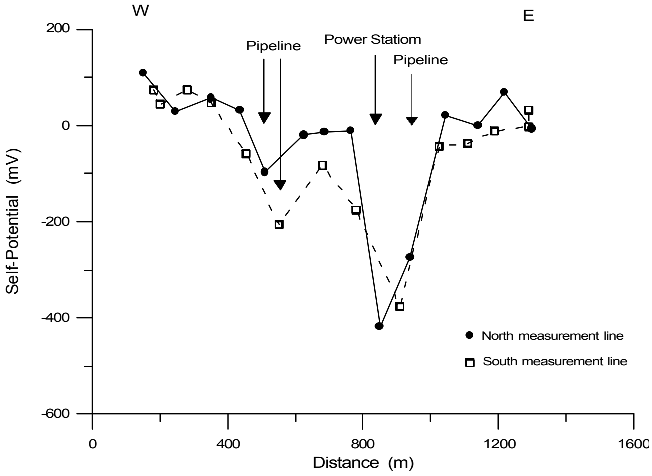

Fig. 4 Self-potential profiles in 1997 along the east-west section of region II (location of region II is shown in Fig. 1).

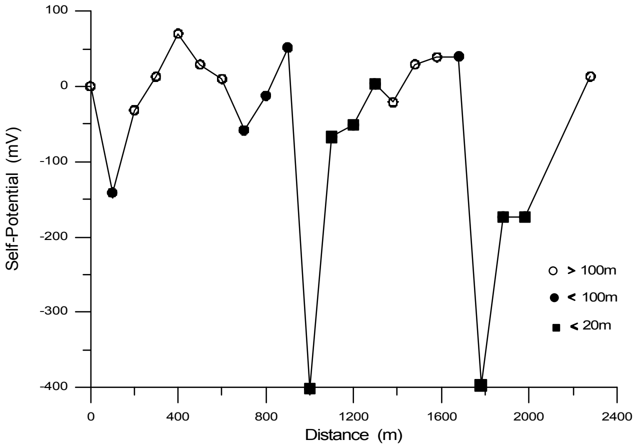

Fig. 5 Self-potential profile in 1998 along a closed loop C-A-P-C in region I. The measurement points shown by open circles, solid circles and solid squares are located more than 100 m, less than 100 m and less than 20 m away from the artificial constructions, respectively.

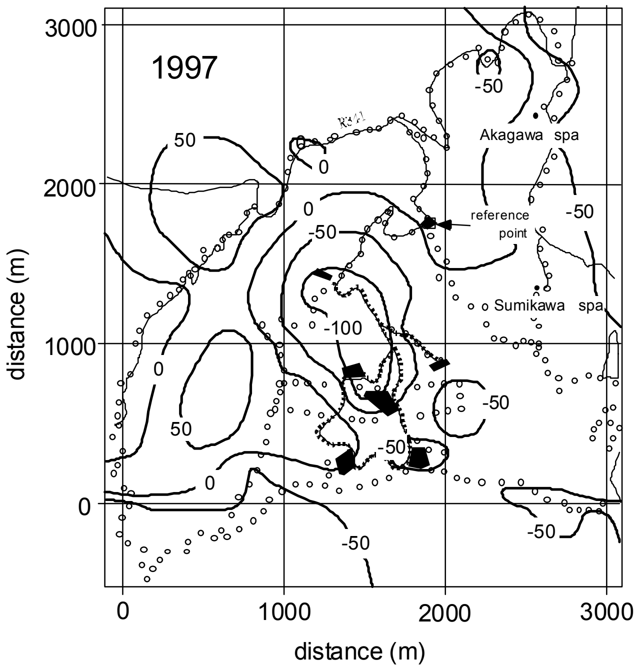

Fig. 6 Self-potential distribution in the Sumikawa field in 1997. To draw the contour, the data taken in 1993 was used for the peripheral area outside of regions I and II. Contour interval is 50 mV.

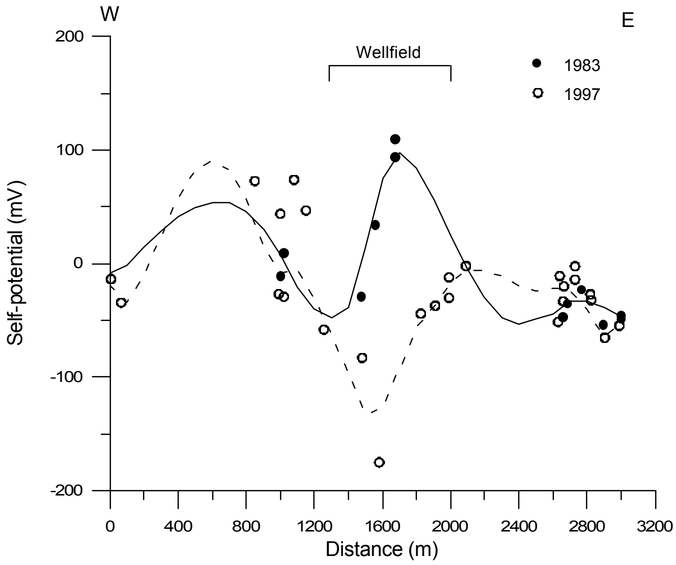

Fig. 7 Self-potential profiles along the east-west section of region III (location of region III is shown in Fig. 1).

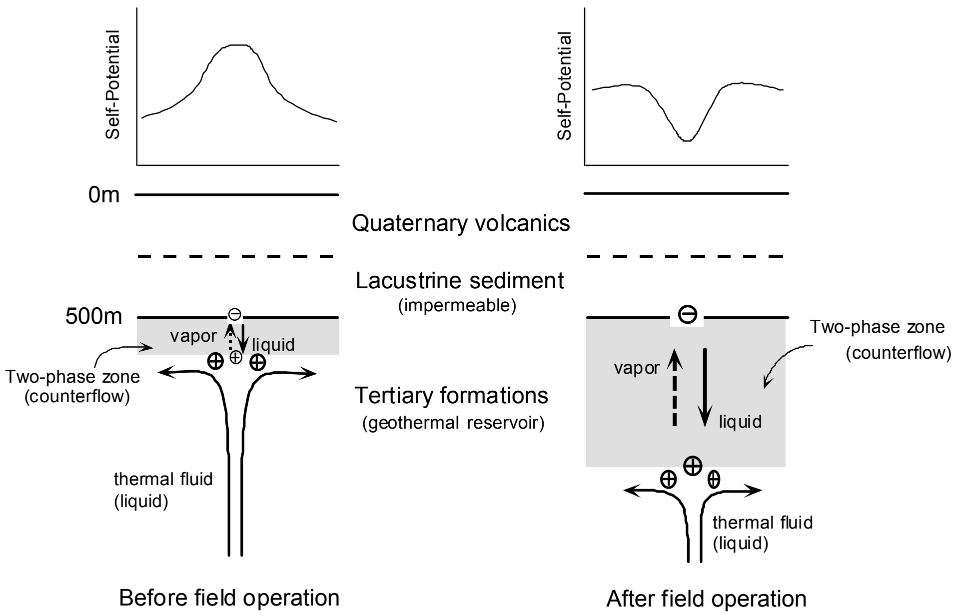

Fig. 8 Electrokinetic mechanisms of (left) positive SP anomaly under natural-state and (right) negative SP anomaly due to the expansion of two-phase zone under exploitation conditions.