SP MONITORING FOR RESERVOIR MASS AND HEAT FLOW CHARACTERIZATION

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ABSTRACT

The New Energy and Industrial Technology Development Organization (NEDO) has been developing a self-potential monitoring technology for geothermal reservoir characterization and management since 1997. Preliminary self-potential survey was carried out in 1998 at the Ogiri geothermal field where a geothermal power plant started operations in March 1996.

As a result of this survey, positive self-potential anomalies were observed around surface geothermal manifestations and the Ogiri fountains, suggesting that fluids are flowing upward. Low self-potential anomalies were observed at a reinjection zone and the vicinity of production zone. It has been interpreted that fluids were flowing downward at the reinjection zone and that fluids had been boiling in underground at the production zone. Consequently, self-potential anomalies reflect dynamic change, such as fluid flow and boiling.

1.0 INTRODUCTION

As a part of MITI's "New Sunshine" program, NEDO has conducted a new project named "Reservoir Mass and Heat Flow Characterization" since 1997, aiming to establish a technology for reservoir characterization and management.

The results from repeat SP (self-potential) surveys of several Japanese geothermal fields reveal that SP anomalies reflect production-induced fluid movements in geothermal reservoirs. Ishido et al. (1997) propose a possible mechanism that positive charges carried by the hot water upflow from depth is accumulated around a zone where separation into the vapor and the liquid phases occurs.

NEDO is developing SP monitoring system to characterize geothermal reservoir by observing time-dependent change in SP. In this paper, results of SP monitoring in the Ogiri geothermal field, Kyushu, are introduced.

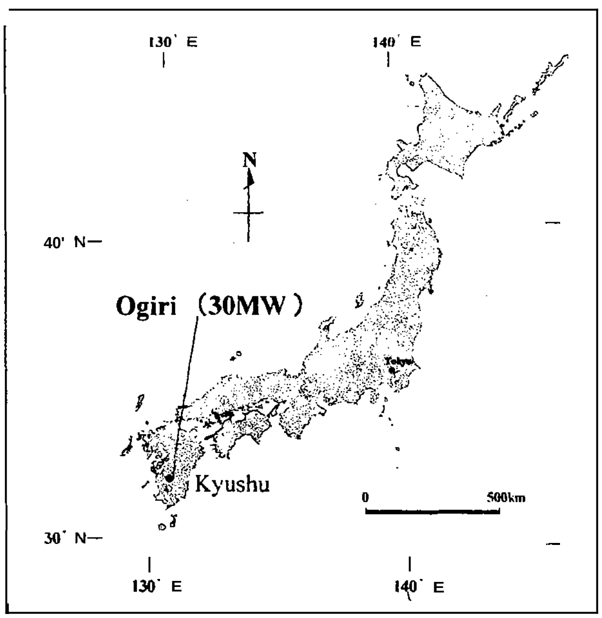

Figure 1. Location map of Ogiri geothermal field.

2.0 SP FIELD TEST

2.1 Studied Area

The Ogiri geothermal field is located in the southern part of Kyushu island, Japan (Figure 1). The field lies at an elevation between 500m and 1000m above sea level. Numerous hot springs and fumaroles are distributed along faults in this area. Faults and surface lineaments trending **NW-SE** and **ENE-WSW** are remarkable in this area (Figure **2).** The "Ginyu fault" and the "Shiramizugoe" fault are important for geothermal explorations in the area. The Ginyu fault forms a productive geothermal reservoir. Around the fault, there is **an** argillized and unpermeable zone between **200m** and **500m** below the surface, which forms a cap-rock above the geothermal reservoir (Horikoshi **et** al., **1996).**

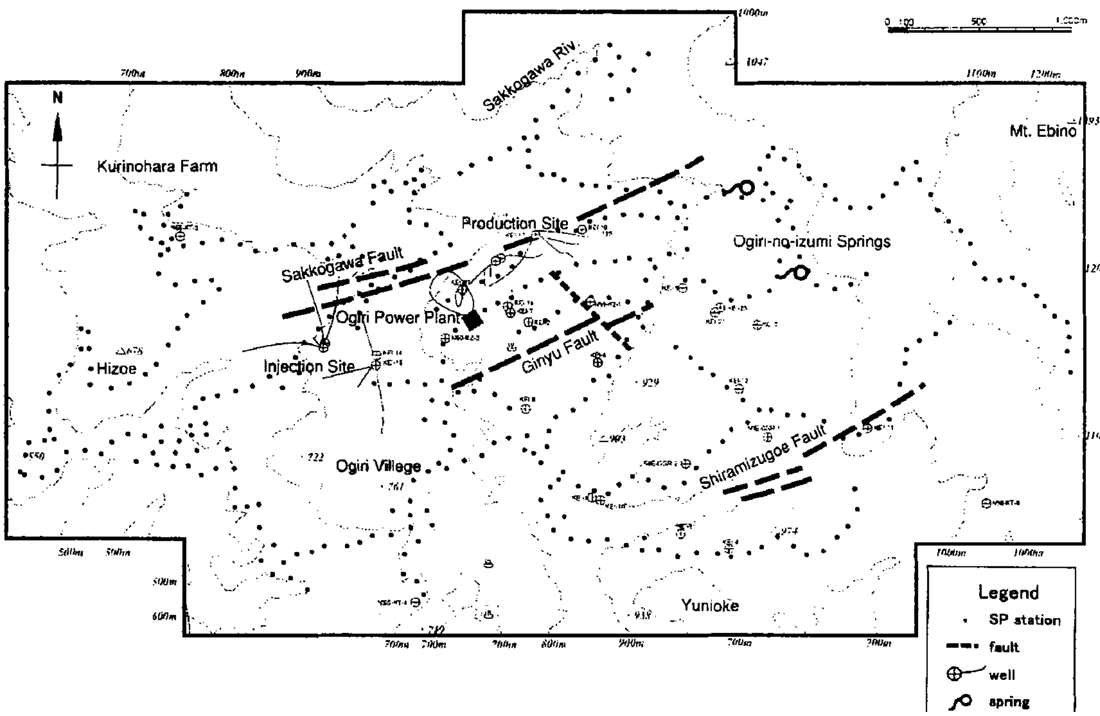

Figure 2. Distribution of location of survey points in the preliminary SP survey.

A 30 **MWe** geothermal power plant began operation in March **1996.** Since that time, **270-280** tons of vapor and **950-1000** tons of liquid (separated at 2.5 bars) per hour have been produced. The total amount of production of vapor and liquid is calculated to be about 32 mega-tons and that of reinjected fluid is about **25** mega-tons for three years. One of the production wells produced only steam phase fluid without hot water during the full scale production test in **1991.**

2.2 Stability Test of Electrodes

A stability test of non-polarizable electrodes and a preliminary SP survey were carried out in the Ogiri geothermal field in **1998.**

In order to monitor SP in geothermal reservoirs for a long period, it is necessary to select stable non-polarizable electrodes. Two types of PbCl-Pb non-polarizable electrode have been used for a long-term measurement in Japan. The two types of electrode were tested in the Ogiri field in order to clarify influences of soil condition, installation depth and weather changes. To evaluate the depth dependence, electrodes were planted at the depth of **1m, 0.5m** and **0.1m,** respectively. **A** long-term SP change was monitored by using one type of electrode because it is known that different types of electrode could cause an electric potential difference. Smectite was sheeted below the **bottom of** electrodes to decrease the contact resistance at the first stage of the test, then electric polarization of about **-**50mV occurred. Therefore, smectite was removed and potassium chloride solution was replaced in soil below the electrodes. In order to test the possibility of decreasing the rainfall influence, one of electrodes was covered with bucket. Temperatures and precipitation have been measured continuously to clarify influences of weather through the SP measurement.

2.3 Preliminary SP Survey

SP Measuring Method

The study area is 6km (in E-W direction) by 3km (in S-N direction) as shown in Figure 2. In 1987, before the geothermal power plant was built, an SP survey had been performed at Ogiri (Ishido et al., 1990). Under this program, another SP survey was carried out in 1998 over the Same survey lines as those of the 1987 survey to study SP changes after operation of the geothermal power plant.

SP measurements were done with PbCl-Pb non-polarizable electrodes. The length of each survey lines was about 1km and the total length of the survey lines was about 40km. The average spacing between survey stations was 100m. The total **number** of survey stations was 438 (Figure 2).

During the SP measurement, signals were measured for about 20sec with 5Hz low-pass filter. Measurements were repeated until the average of measuring value becomes stabilized. Each survey was completed with a closed loop in a day. Closure offsets were checked to correct the measuring data. Through this survey, closure offsets were mostly under 20mV except for two survey lines with error over 30mV which were measured over again.

Comparison of the Result of the Survey in 6987 with that in 1998

To compare the survey data in 1998 with that in 1987, a contour map showing the distribution of the SP obtained in 1987 was mapped by the same contouring program as used to the map of 1998. The data of survey stations within 200m from power plant equipment were not used for the map comparison. To reduce influence of deep fluid flows, electric potential data were smoothed with low cut filter of 1500m in wavelength. Ishido et al. (1987) suggest that there is strong correlation between SP and elevation. In the Ogiri geothermal field, the following equation given by Ishido et al. (1990), which is a linear equation obtained by the least-squares regression analysis from the data of 1987 SP survey, is applied.

$$SP = 251.8 - 0.253 \times H, \qquad (1)$$

where SP is self-potential in mV and H is sampling point elevation in meters above sea level, respectively. In this paper, this correlation equation was adopted for the survey data correction (Figure 3a).

Figure 3a represents systematic differences between the data of 1987 and 1998. First, SP data of 12 survey stations at flank of Mt. Ebino, which are relatively stable , were selected. Then two SP averages of 1987 and 1998 data were calculated. All the data of 1998 were shifted toward the average of 1987. The result of correction is shown in Figure 3b.

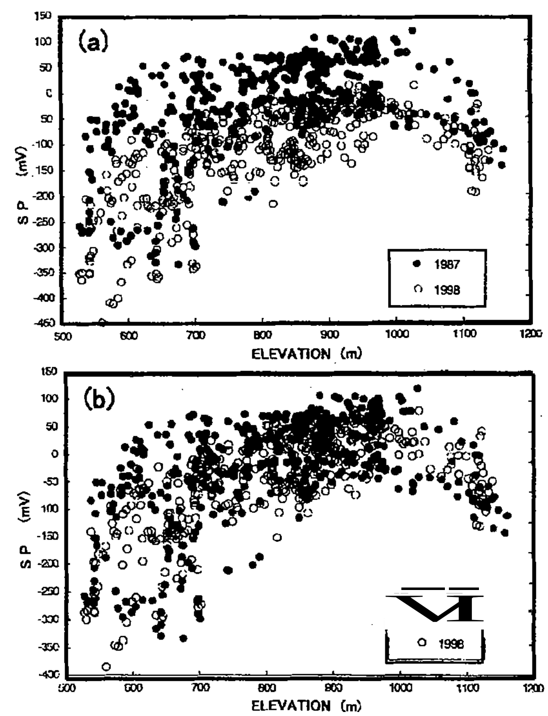

Figure 3. (a) SP vs. elevation, (b) Corrected SP vs. elevation. Solid circles show SP **data** of 1987 by Ishido et al. (1990). **Open** circles show SP **data** of 1998.

3.0 RESULT

3.1 Stability Test of Non-polarizable Electorodes

Example of measured SP change data are shown in Figure 4, with electrodes temperature and precipitation. Result of stability test of non-polarizable electrodes are as follows:

1. Smectite to improve contact resistance causes electric polarization;
2. Polarization was observed between different type of electrodes;
3. Drift of the potential is 0.1mV/day at the period later than one month after installation;
4. Daily potential variation of 1mV/30m was observed;
5. Temperature dependence of electrode is 0.5mV/deg;
6. Rainfall induced potential shift of 30mV;
7. Although a potential change caused by rainfall is remarkable, it disappeared in a few days;
8. No significant difference of contact resistance was observed between electrodes with and without bucket;
9. The daily temperature change influences on electrodes of 0.1m depth, while few influences occurred at the depth of 0.5m;

3.2 Preliminary SP Survey

The result of the SP survey of the Ogiri geothermal area in 1998 is shown in Figure 5. In general, SP is higher in the center of the study area, and is lower in the western part of the study area. Negative SP anomalies were observed near the power plant and in the reinjection area. These areas are Hizoe, Kurinohara farm, Ogiri power station, reinjection zone, the upper *stream* of Sakkogawa river and western flank of Mt. Ebino. Positive SP anomalies appeared in the areas of natural geothermal manifestations along the Ginyu and the Shiramizugoe faults. Yunoike, Shiramizugoe and Ginyu, and Ogiri-no-izumi cold spring areas (2km east from Ogiri power station), and east part of Ogiri village are examples.

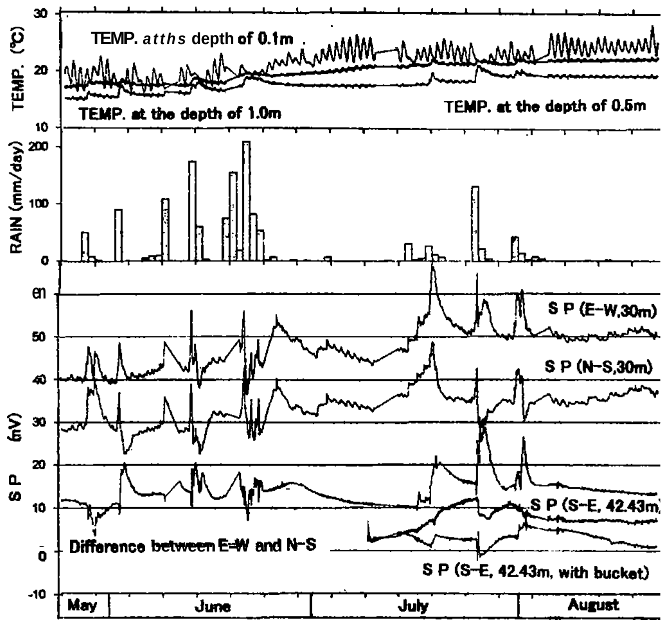

Figure 4. An example of SP change, electrode temperature and precipitation observed in stability test of non-polarizable electrodes.

Apparent changes in SP between the 1987 and 1998 surveys are mapped in Figure 6. The small-scale anomalies were observed around the artificial constructions such as the power plant and the wellfield. They are excluded to map Figure 6. Decreases in potential occurred around the reinjection well sites and in the Ginyu production area, whereas SP increased in the Ogiri-no-izumi cold spring area. Negative SP changes occurred around the center of Ginyu production zone, western part of reinjection zone, and Shiramizugoe fault.

4.0 DISCUSSION

The result of SP survey in 1998 indicates four positive anomaly areas. In Yunoike, Shiramizugoe and Ginyu, there are several fumaroles caused by the high temperature fluid upflows. A possible model to explain the anomalies is that electric charge carried by the hot water upflow from depth produces a positive anomaly. Positive SP anomalies are observed around east part of Ogiri village, suggesting that there is some hot water or ground water flow below this area.

The wells with low temperature water (90°C) and deeper water level around that area suggest that the negative SP anomalies at Hizoe and Kurinohara farm reflect a subsurface downflow. Negative SP anomalies around Ogiri power station may be caused by artificial structures of the power station.

Negative SP anomalies around reinjection zone observed are expected to be caused by reinjection of hot water. The areas of the upper *stream* of Sakkogawa river and western flank of Mt. Ebino are topographically higher, therefore ground water probably forms a downflow producing negative SP anomalies.

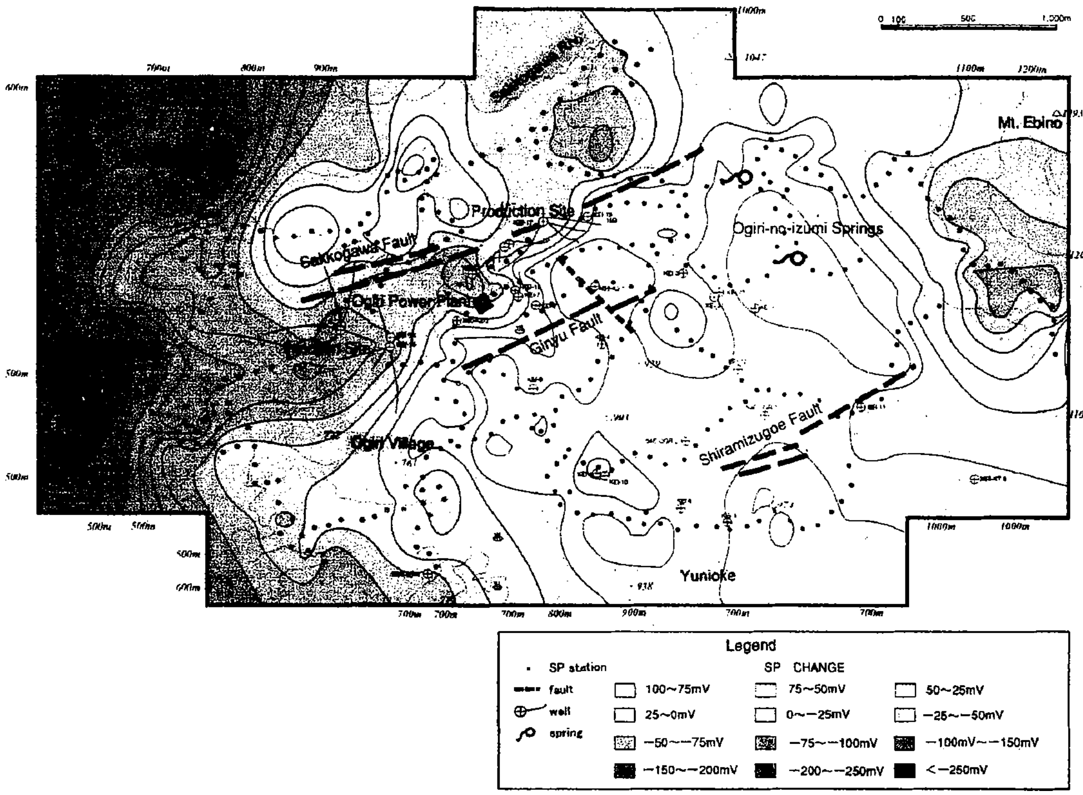

Figure 5. SP distribution of the Ogiri geothermal field in 1998

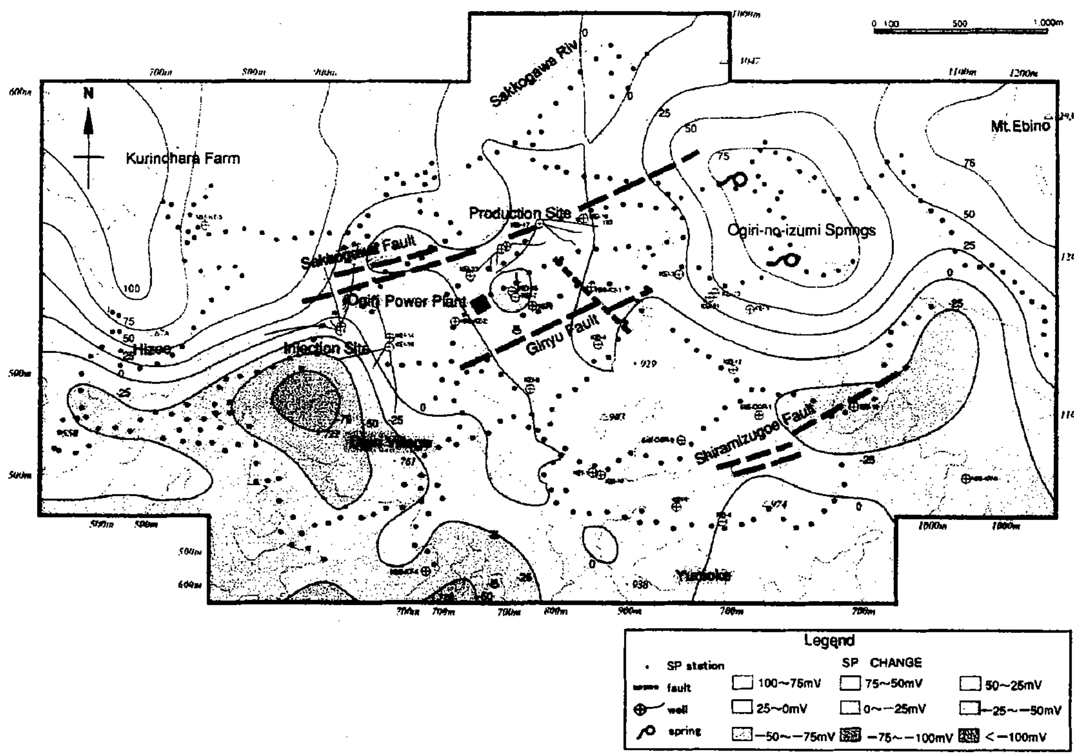

Figure 6. SP changes at the *Ogiri* geothermal field from 1987 to 1998

Positive SP changes around the Ogiri-no-izumi are supposed to reflect a flow change of the spring between **1987** and **1998.** The negative SP changes around Ginyu production zone possibly reflect a depth change of boiling zones caused by production of geothermal fluids. The negative SP changes around western part of reinjection zone could reflect hot water reinjection. A cause of negative SP change around Shiramizugoe fault is still controversial. We interpret that this negative SP change is caused by extracting hot water from the reservoir, suggesting existence of path-ways of fault trending NW-SE. This agrees with surface lineaments trending NW-SE. Possible causes are represented schematically in Figure 7.

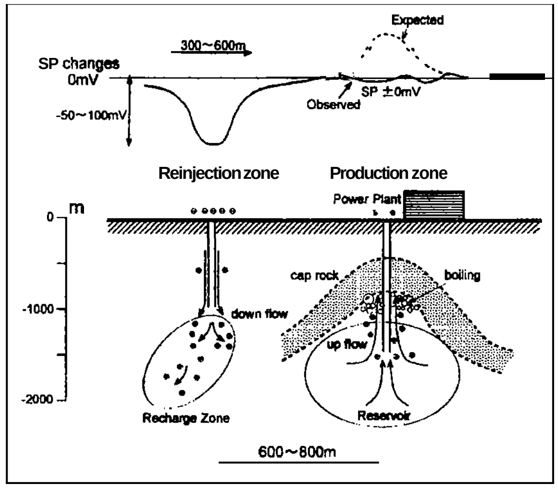

Figure 7. Conceptual model of generation of SP changes in the **Ogiri** field Top figure shows SP changes **from 1987** to **1998.** Main production and reinjection, which are expressed in the bottom figure, started in **1996.**

5.0 CONCLUDING REMARKS

The result of preliminary SP surveys reveal that there is an influence of geothermal fluids extraction. But problems still remain on noise reduction. The noise sources are rainfall, artificial structures, and so on. We preliminary corrected all **data** of **1998** survey by average of **12** stations at flank of Mt. Ebino to reduce the noise. To estimate these noise influences, a long-term continuous SP monitoring is now under way. The monitoring could give a clue to answer the exact source of SP change. We preliminary speculate sources of SP anomaly and causes of SP change as follows:

1. **A** positive SP anomaly is **caused** by artificial upflows of fluid production and natural geothermal activity such as fumaroles;
2. A negative **SP** anomaly is caused by downflows of fluid reinjection;
3. Therefore, SP changes reflect dynamic change of fluid flows;
4. Artificial structures are sources of noise, disturbing signals of dynamic fluid flows.

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