GPS AND MICRO-GRAVITY MONITORING AT HATCHOBARU GEOTHERMAL FIELD, CENTRAL KYUSHU, JAPAN.

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SUMMARY-Hatchobaru geothermal field is located 5km northwest of Kuju volcano, central Kyushu, and it is a fractured dominated geothermal reservoir. We have conducted GPS and micro-gravity monitoring to detect the ground deformation and mass fluid movement caused by production and reinjection. The horizontal displacement vector is toward the Komatsuike fault, which is located main production zone at approximately 1100m in depth. The results of repeat gravity measurements show this is an effective method to monitor the underground hydrology.

1. INTRODUCTION

It is necessary to monitor the condition of a geothermal reservoir to maintain the stable power plant operation for a long period. Periodical leveling is conducted, because ground deformation directly reflects condition of geothermal reservoir.

The production and reinjection of geothermal fluid cause mass fluid movement and mass redistribution, which can cause measurable gravity changes and ground deformation at the surface. Repeat gravity measurements have been carried out in some geothermal fields. Gravity decreases of up to 1000 μgal have been measured after 30 years of production from the Wairakei geothermal field, New Zealand (Allis and Hunt, 1986). A strong qualitative correlation has been observed between the pressure change and gravity change at the Hatchobaru geothermal field, Oita, Japan (Tagomori et. al, 1996).

We have measured the ground deformation and gravity changes in order to clarify geothermal fluid movement caused by production and reinjection. In this paper, we describe the effectiveness of the monitoring methods that integrate three dimensional ground deformation by GPS and repeated gravity measurements to monitor mass changes in the geothermal reservoir.

2. HATCHOBARU GEOTHERMAL FIELD

Hatchobaru geothermal field is located 5km northwest of Kuju volcano, central Kyushu (Fig. 1). The reservoir permeability is mainly controlled by fractures. Hatchobaru No. 1 unit (55MW) was completed in June 1977, and Hatchobaru No. 2 unit (55MW) was completed June 1990. We started repeat gravity measurements in May 1990 just before the commencement of operation of the No. 2 unit. The production zone is in the Southeastern part and the reinjection zone is in the northwestern part of the field. The main production points range from 1000m to 2500m in depth. The main reinjection points are at 1000m to 1500m depth. The deep geothermal fluid rises along some fractures in the southeastern part of the field and flows towards the northwest laterally.

Fig. 1 Location of Hatchobaru Geothermal Field, Central Kyushu, Japan in which repeat gravity measurements and GPS survey have been made.

3. GROUND DEFORMATION MONITORING BY GPS SURVEY

There are 8 observation points and 14 baselines for ground deformation monitoring with GPS (Fig. 2).

We have conducted the observation of ground deformation with the single frequency GPS receivers (TOPCON GP-SX1) to detect the three dimensional ground deformation caused by production and reinjection. GPS monitoring were made at intervals of 2 to 3 months.

The session length is 1 hour and the sampling interval is 10 seconds. We repeated the sampling a number of times (10-20 times) at every observation point. Data processing was performed using the GPS Software Win S/D ver.1.31 made by TOPCON Corporation. The ephemeris is almanac data transmitted by the satellite, and the meteorological conditions used are standard (1013hPa, 20°C, 50%). In this study, the standard deviation is about 1-4 ppm of baseline length. The 95% confidence region depends on the number of observations, and it is defined as observational error. The accuracy in the baseline estimation is ±3mm.

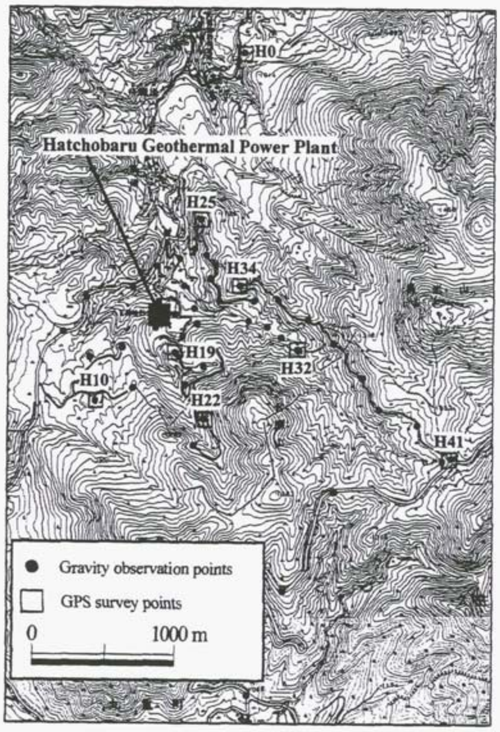

Fig. 2 Distribution of observation points for the GPS survey.

Baseline changes of up to 23mm were detected from August 1998 to December 2000. Horizontal displacement vector is toward Komatsuike sub fault, which is located in the main production zone (Fig. 3).

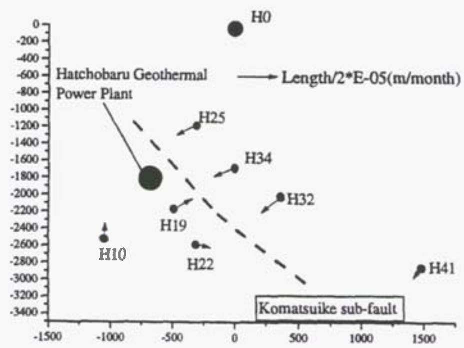

Fig. 3 Horizontal displacement vector map from November 1998 to May 2000

We tried to estimate the location of the pressure source by applying a point source model (Mogi, 1958) on the change in length of baselines. The calculated deformation of the semi-infinite elastic body (Fig. 4) is as follows (Yamakawa, 1955).

$$U_z = \frac{h}{R^3} K \qquad U_r = \frac{r}{R^3} K \qquad (1)$$

Where

$$R = (r^2 + h^2)^{1/2}$$

$$K = \frac{(\lambda + 2\mu) 3a^3 \Delta p}{2\mu(\lambda + \mu)}$$

λ, μ :Lame's constant

From equation (1), the length of the baseline ΔL (from P1 (x1, y1) to P2 (x2, y2)) is as follows (Nishi et. al, 1995)

$$\Delta L = \frac{(x2 - x1)X + (y2 - y1)Y}{R_1^{\,3} \cdot R_2^{\,3} \cdot L} K \qquad (2)$$

Where

$$X = (x2 - x)R_1^{\,3} - (x1 - x)R_2^{\,3}$$

$$Y = (y2 - y)R_1^{\,3} - (y1 - y)R_2^{\,3}$$

$$R_1 = \left\{(x1 - x)^2 + (y1 - y)^2 + h^2\right\}^{1/2}$$

$$R_2 = \left\{(x2 - x)^2 + (y2 - y)^2 + h^2\right\}^{1/2}$$

$$L = \left\{(x1 - x2)^2 + (y1 - y2)^2\right\}^{1/2}$$

From equation (2), the location of the pressure source can be estimated. The pressure source is estimated to be the Komatsuike sub fault at approximately 1100m in depth (Fig. 5). This pressure source is located in the upper zone of the reservoir. There is a possibility of detecting a pressure change in the reservoir.

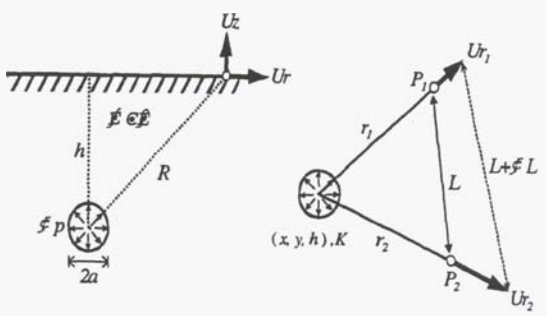

Fig. 4 Schematic illustration of a point source model and the method to calculate the length change of the baseline (modified Nishi, et. al, 1995)

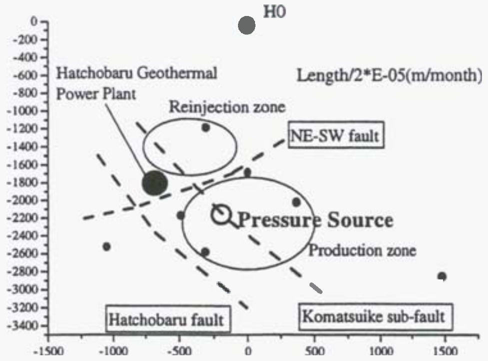

Fig. **5** Estimated pressure source applying the point source model (Mogi, 1958).

In this study, we used the single frequency GPS receivers rather than the dual frequency GPS receivers, because of portability and cost. The observations show sufficient accuracy was achieved in this case to establish a baseline.

4. REPEAT GRAVITY MEASUREMENTS

We have been regularly making repeat gravity measurements at Hatchobaru Geothermal Field. There are 59 observation stations for repeat gravity measurements (Fig. 6). We used Scintrex **CG-3** and **CG-3M** gravimeters to precisely measure gravity changes. Repeat gravity measurements were made at intervals of several months. The two-way measurement method was used to evaluate the instrumental drift and precision; we estimated the errors of observation as ±10 μgal.

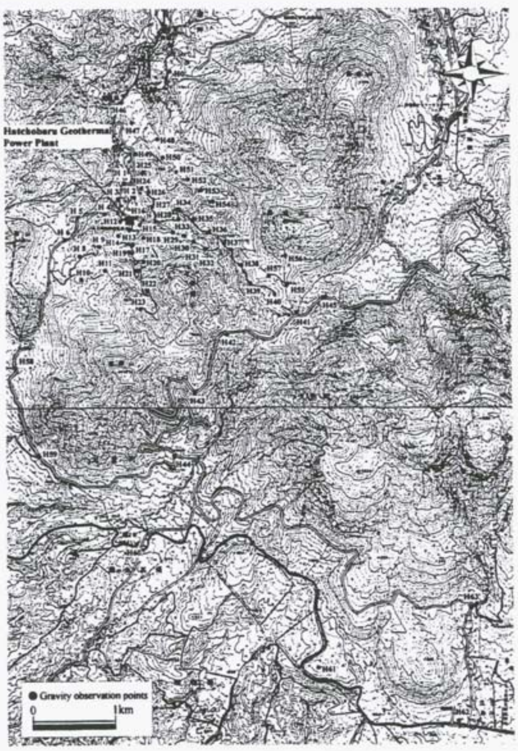

Fig. 6 Distribution of observation points for the repeat gravity measurements.

Increases in gravity were observed in the reinjection zone and part of the production zone just after the commencement of No. 2 unit (Fig. 7).

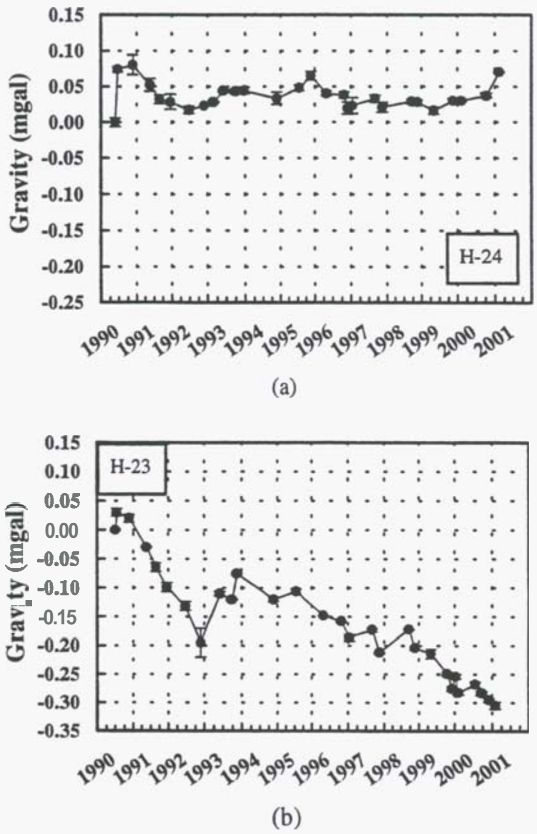

Fig. 7 Examples of gravity changes at Hatchobaru geothermal field. (a) in the reinjection zone; (b) in the production zone.

In the reinjection area, gravity decreased gradually. In the production area, a rapid gravity decrease (up to 200 pgal) was observed. In this period, about 110 MW of electricity, which is the installed capacity, was produced. About three years later, the rate of gravity decrease became smaller. In this period, about 90 MW of electricity was produced. Since 1997 the rate of gravity decrease has increased. In this period, about 110MW of electricity was produced. It may be reasonable to consider that the most suitable production rate from the present production area is about 90 MW.

A contour map of gravity change (from October 1999 to October 2000) (Fig. 8) shows there is the zone of gravity decrease around the production zone, especially towards to southern part of production zone.

Leveling surveys showed that vertical ground movements ranged from –15mm to +35mm fiom August 1990 to March 1996. Assuming a free-air gradient of **-308.6μgal/m**, this ground movement caused about –10 to +5μgal of gravity change (Tagomori et al., 1996). The effect of vertical ground movement on observed gravity is therefore negligible.

The pattern of gravity change in the production zone is very similar to that of reservoir pressure, and there is good correlation (>0.8) between gravity change and reservoir pressure (Tagomori et al., 1996). This result shows that the gravity decrease in the production zone reflects the net mass loss in the reservoir.

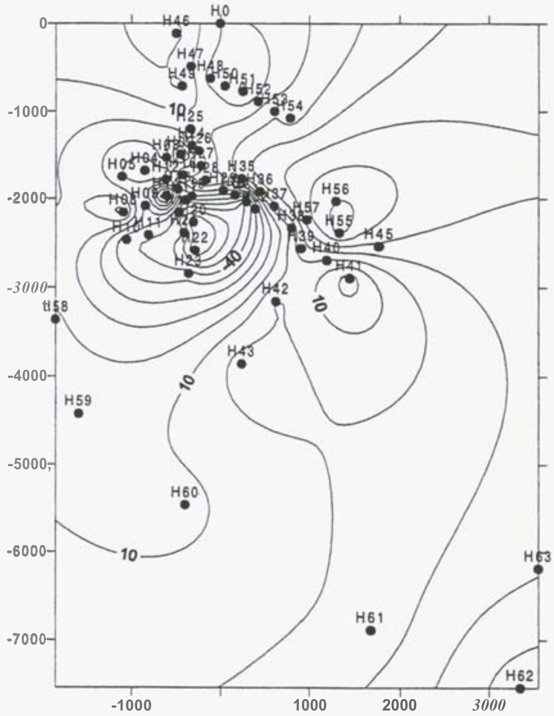

Fig. 8 Contour map of the gravity changes at Hatchobaru Geothermal Field from October 1999 to October 2000.

Application of Gauss's Potential Theorem (La Fehr, 1965) to gravity changes gives a quantitative estimate of the mass changes. Based on the produced and reinjected mass and the values of the net mass change from October 1999 to October 2000, we calculate there has been a natural mass recharge of 0.3Mt (Fig. 9).

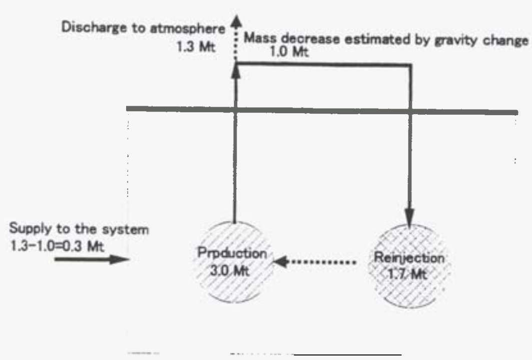

Fig. 9 Mass balance in the production and reinjection zones at Hatchobaru geothermal field, from October 1999 to October 2000.

5. CONCLUSIONS

- The horizontal displacement vector is oriented towards the Komatsuike sub fault, which is located in the main production zone. The location of the pressure source is estimated to be the Komatsuike sub fault at approximately 1100m in depth
- Single frequency GPS receivers are portable and comparatively low-priced. The observations showed the sufficient accuracy was achieved to establish a baseline.
- Increases in gravity were observed in the reinjection zone and part of the production zone just after the commencement of No. 2 unit.
- There appears to be a good correlation between reservoir pressure changes and gravity changes.
- The results show that repeat gravity measurements are an effective method to monitor the hydrology.

6. REFERENCES

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