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Micro-Gravity Monitoring and Repeated GPS Survey at Hatchobaru Geothermal Field, Central Kyushu, Japan

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ABSTRACT

Hatchobaru geothermal field is located 5km northwest of Kuju volcano, central Kyushu, and it shows a fractured type of geothermal reservoir. We have been conducted GPS and micro-gravity monitoring to detect the ground deformations and mass fluid movement caused by the production and reinjection.

Increases in gravity were observed in the reinjection zone and part of the production zone just after the commencement of No. 2 unit. After that, in the production area, a rapid decrease of gravity (up to 200 μgal) was observed. Since 1998 the gravity change became steady. A contour map of recent gravity changes show that the areas of gravity changes became very small. And these areas are limited in the part of the production and reinjection zone. We suppose that the recharge from surrounding area became gradually stable and reached a new equilibrium state.

Changes of baseline up to 64 mm, were detected from August 2000 to October 2003. We tried to estimate the location of pressure source applying a point source model on the changes in length of baselines. The location of a pressure source is estimated to be Komatsuike sub fault and approximately 750m in depth. This pressure source is located the upper zone of reservoir. There is possibility of detecting the pressure change of reservoir. As a result of observations, the sufficient accuracy proved to be achieved in this case of sort baseline observation.

1. INTRODUCTION

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

The production and reinjection of geothermal fluid cause mass fluid movement and mass redistributions, which can cause measurable gravity changes and ground deformation at the surface. Micro-gravity monitoring have been carried out in some geothermal fields.

We have measured the ground deformation and gravity changes in order to clarify the geothermal fluid movement caused by the production and reinjection. This paper summarizes the effectively of the monitoring methods that integrate three dimensional ground deformation by GPS and micro-gravity monitoring to monitor mass changes in geothermal reservoir.

2. HATCHOBARU GEOTHERMAL FIELD

Hatchobaru geothermal field is located 5km northwest of Kuju volcano, central Kyushu (Figure 1). 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. and the main reinjection points are 1000m to 1500m in depth. The reservoir permeability is mainly controlled by fractures. The deep geothermal fluid rises along some fractures in the southeastern part of the field and flows towards the northwest laterally.

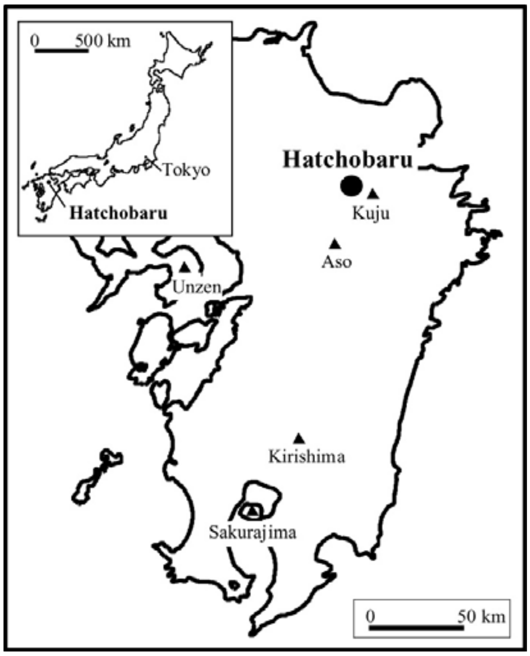


Figure 1: Location of Hatchobaru geothermal field.

3. REPEAT GRAVITY MEASUREMENTS

We have been regularly making micro-gravity monitoring at Hatchobaru geothermal field. There are 59 observation stations for micro-gravity monitoring (Figure 2). We used Scintrex CG-3 (with resolution ±5 μgal) and CG-3M (with resolution ±1 μgal) gravimeters to precisely measure microscopic gravity changes.

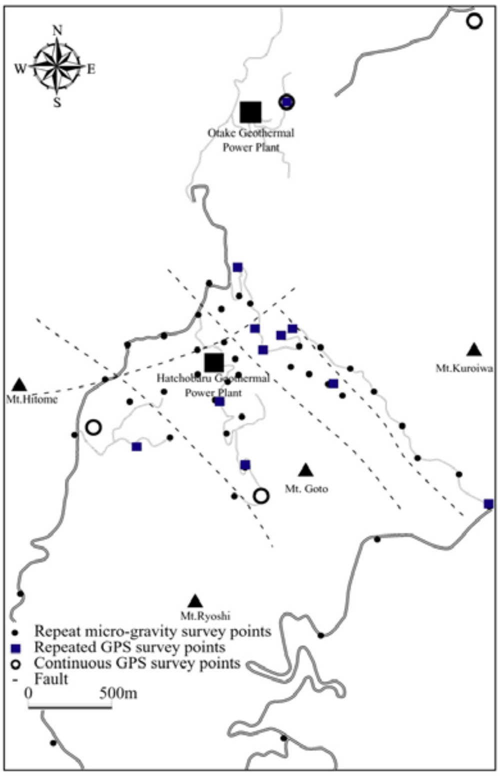
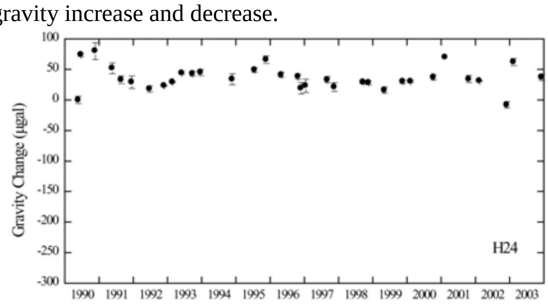


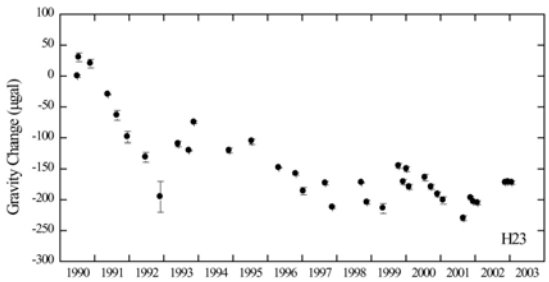
Figure 2: Distribution of observation points.

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.

Increases in gravity were observed in the reinjection zone and part of the production zone just after the start of No. 2 unit operation (Figure 3 (a)). After that, there is no change in the reinjection area, although we can see the small gravity increase and decrease.



(a)



(b)

Figure 3: Examples of gravity changes at Hatchobaru geothermal field. (a) in the reinjection zone; (b) in the production zone

In the production area, a rapid decrease of gravity (up to 200 μgal) was observed between 1990 and 1992 extending south part of production zone. In this period, about 110MW of electricity, which is the installed capacity, was produced. After the rapid gravity decrease period, the gravity was recovered (up to 100 μgal) in the south part of production zone. In this period, about 90MW of electricity was produced. From 1993 to 1997, we observed gravity decrease but the rate of gravity decrease became smaller. In this period, about 110MW of electricity was produced. Since 1998, the gravity change became steady. We suppose that the recharge from surrounding area became gradually stable and reached a new equilibrium state.

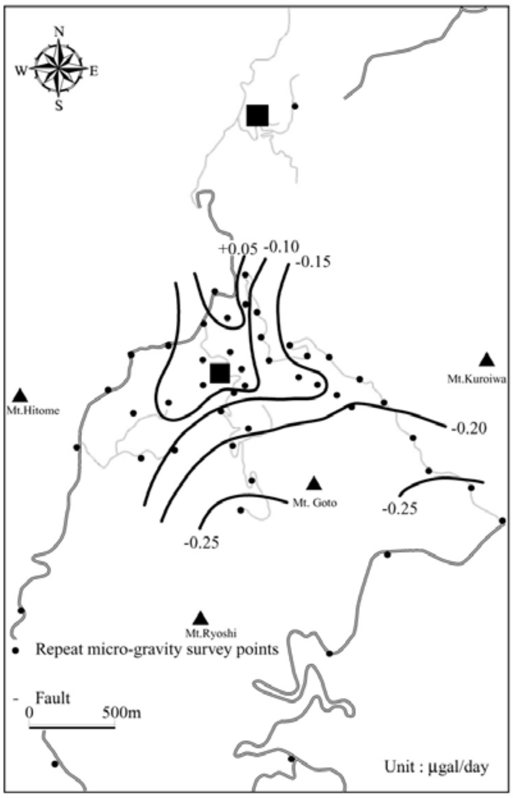
A contour map of gravity change from 1990 to 1992 shows there is the zone of gravity decrease around the production zone, especially towards to southern part of production zone (Figure 4(a)). In the north part of reinjention zone, we can see the small gravity increase area.

Figure 4 (b) shows a contour map of recent gravity changes. The areas of gravity changes became very small. And these areas are limited in the part of the production and reinjection zone.

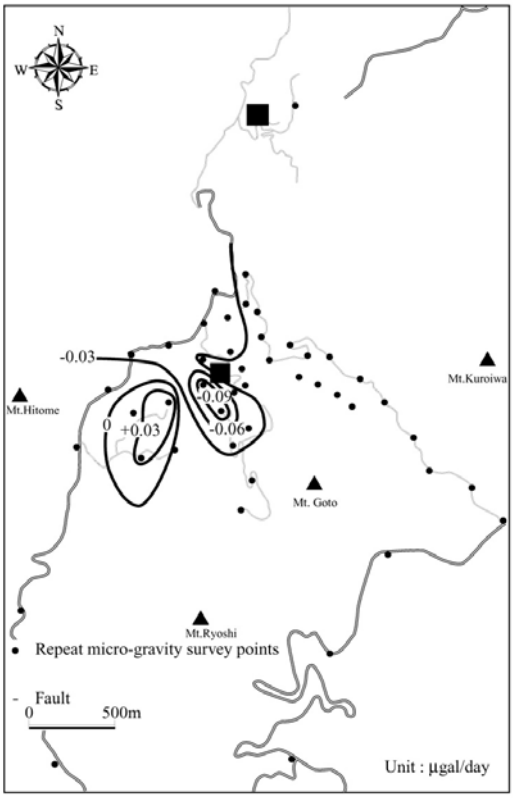
Leveling surveys showed that the rate of vertical ground movements is less than 20mm in a year. Assuming a free-air gradient of -308.6μgal/m, this ground movement caused about 6μgal of gravity change. The effect of vertical ground movement on observed gravity is therefore negligible.

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 (Saito et al., 1998). This result shows that the gravity changes in the production zone reflect the net mass loss in the reservoir.

Application of Gauss's Potential Theorem (La Fehr, 1965) to gravity changes gives quantitative estimate of the mass changes. Mass decrease estimated by gravity change from 1999 to 2000 is 1.0 Mt. The total discharge, difference between produced (22.7 Mt) and reinjected (14.4 Mt) mass, was 8.3 Mt. The difference between the total discharge and the mass decrease estimated from gravity change is thought to be a natural mass recharge (7.3Mt) from the surrounding area (Figure 5). This estimation suggest that Most of the discharge was recharged and underground fluid flow is reaching new equilibrium state.



(a)



(b)

Figure 4: Contour map of the gravity changes at Hatchobaru geothermal field. (a) from June 1990 to June 1992 (b) from October 2000 to October 2001

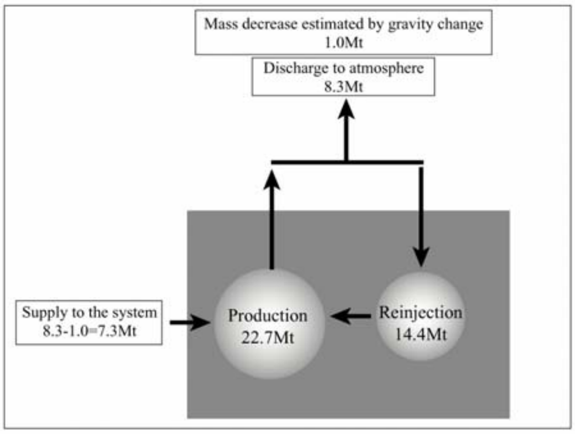


Figure 5: Mass balance in the production and reinjection zones from August 1999 to May 2000.

4. GROUND DEFORMATION MONITORING BY GPS SURVEY

The repeated GPS survey began in 1998. There are 8 observation points and 14 baselines for ground deformation monitoring with GPS (Figure 2).

We have conducted the observation of ground deformation with the single frequency GPS receivers (TOPCON GP-SX1) to detect the three dimensional ground deformations caused by the production and reinjection. GPS monitoring were made at intervals of 4 or 5 months. The session length is 1 hour and the sampling interval is 10 seconds. At each observation point, the session was repeated 10 to 20 times. Data processing was performed using the GPS Software Win S/D Ver.2.5. The base station is 0833 set up by Geographical Survey Institute Japan.

The ephemeris is almanac data transmitted by the satellite, and the meteorological condition is standard conditions (1013hPa, 20°C, 50%). In this study, the standard deviation is about 1-4ppm of baseline length. We calculated the 95% confidence region depends on the number of observations respectively, it is defined as observational error. The accuracy in the baseline estimation is ±3mm.

Changes of baseline up to 64mm (Figure 6) were detected from August 2000 to October 2003. Most of baseline was contracted and Gh34 was extended.

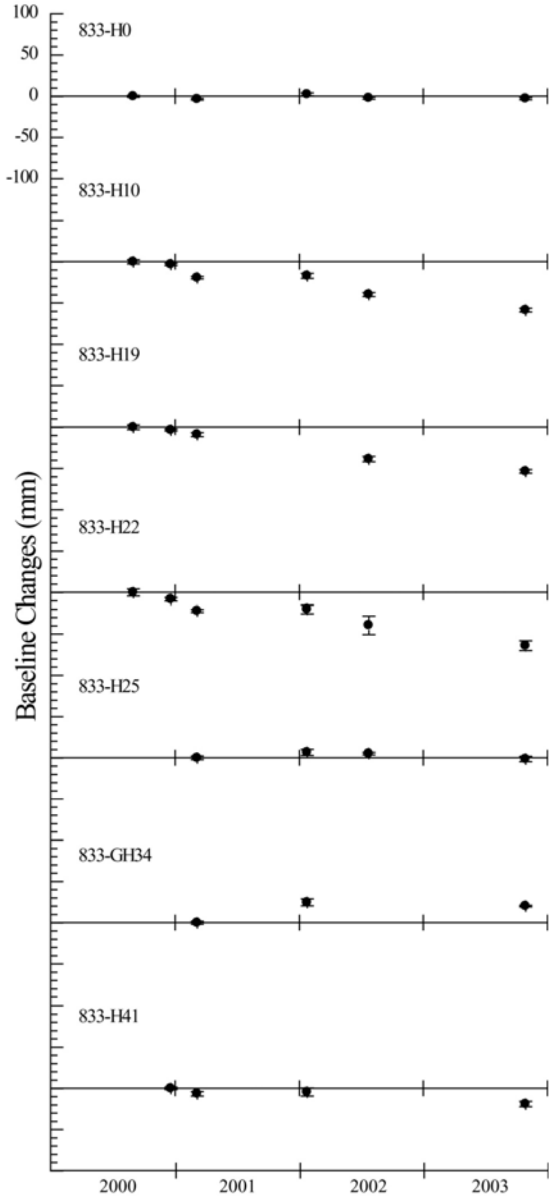


Figure 6: Baseline length changes at each station.

Horizontal displacement vector is toward Komatsuike sub fault, which is located main production zone (Figure 7). We tried to estimate the location of pressure source applying a point source model (Mogi, 1958) on the change in length of baselines. The calculated deformation of the semi-infinite elastic body (Figure 8) 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), length of baseline ΔL (from P1 (x1, y1) to P2 (x2, y2)) is as follows (Nishi et. al, 1995)

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

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 pressure source can estimate.

The pressure source is estimated to be Komatsuike sub fault and approximately 750m in depth (Figure 7). This pressure source is located the upper zone of reservoir. There is possibility of detecting the pressure change of reservoir. In this study, we did not use the dual frequency GPS receiver which is general for this kind of use, but the single frequency GPS receivers which is portable and comparative low-priced. As a result of observations, the sufficient accuracy proved to be achieved in this case of sort baseline observation.

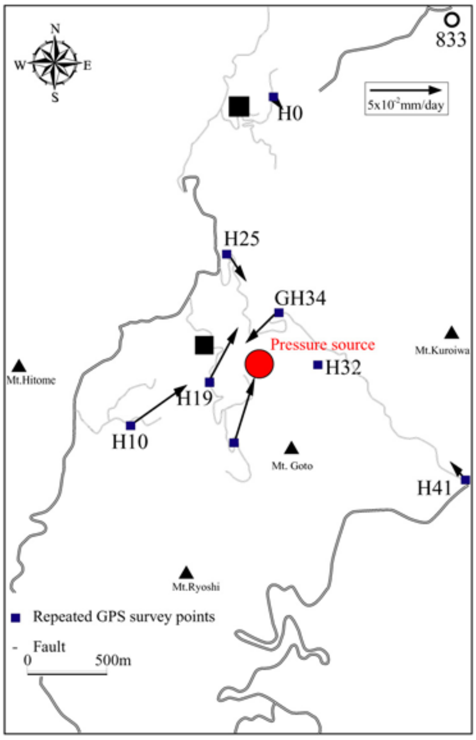


Figure 7: Horizontal displacement vector map from August 2000 to October 2003. Closed circle shows the estimated pressure source applying the point source model (Mogi, 1958).

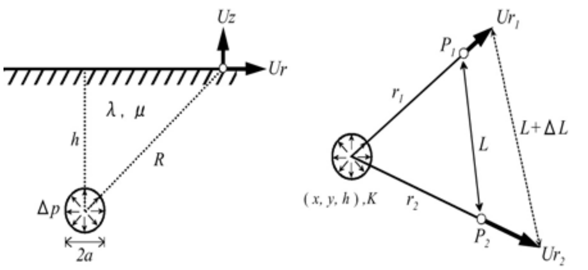


Figure 8: Scematic illustration of a point source model and the method to calculate the length change of the baseline (modified Nishi et. Al, 1995).

5.CONCLUSIONS

- In the production area, a rapid decrease of gravity (up to 200 μgal) was observed between 1990 and 1992. But, the gravity change became steady since 1998.
- A contour map of recent gravity changes shows that the areas of gravity changes became very small. And these areas are limited in the part of the production and reinjection zone.
- We suppose that the recharge from surrounding area became gradually stable and reached a new equilibrium state.
- The results of repeat gravity measurements show that repeat gravity measurements is an effective method to monitor the underground hydrological systems.
- Changes of baseline up to 64mm (Figure 6) were detected from August 2000 to October 2003. Most of baseline was contracted
- Horizontal displacement vector is toward Komatsuike sub fault, which is located main production zone and the location of a pressure source is estimated to be Komatsuike sub fault and approximately 750m in depth
- The single frequency GPS receivers which is portable and comparative low-priced. As a result of observations, the sufficient accuracy proved to be achieved in this case of sort baseline observation.

REFERENCES

La Fehr, T. R. (1965). The estimation of the total amount of anomalous mass by Gauss's Theorem, Jour. Geophys. Res., Vol. 70, 1911-1919.

Mogi, K. (1958). Relation between the eruptions various volcanos and the deformations of the ground surface around them, Bulletin of the Earthquake Research Institute, Vol. 36, 99-134

Nishi, K., Ishihara, K., Kamo, K., Ono, H., and Mori, H. (1995). Positioning of magma reservoir at Unzen volcano by GPS, Bulletin of the Volcanological Society of Japan, Vol. 40, 43-51

Saito, H., Tagomori, K., Nagano, H., Kumagai, I., Nagano, S. and Ehara, S. (1998). Reservoir behaviour Inferred from 2D modeling analysis of gravity changes in the Hatchobaru geothermal field, Jour. Geothermal Research Society of Japan, Vol. 20, 185-199.

Yamakawa, N. (1955). On the strain produced in a semi-infinite elastic solid by an interior source of stress, Journal of the Seismological Society of Japan, Vol. 8, 84-98.