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Repeat Microgravity Measurements Using Absolute and Relative Gravimeters for Geothermal Reservoir Monitoring in Ogiri Geothermal Power Plant, South Kyushu, Japan

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ABSTRACT

Repeat microgravity measurements using absolute and relative gravimeters (hybrid microgravity measurements) have been applied at Ogiri geothermal power plant (30MW) on the western slope of Kirishima volcano, southern Kyushu, Japan. In this study we tried to detect the short-term gravity change caused by the temporary shut of production and reinjection wells for regular power plant maintenance in 2011 and 2013. Repeat microgravity measurements were conducted using A-10 absolute gravimeter (Micro-g LaCoste) and CG-5 relative gravimeter (Scintrex) in the period before and after the regular power plant maintenance. We set up 27 gravity stations (6 stations for absolute gravimeter and 26 stations for relative one). The accuracy of these instruments is 10 micro gals. After removing some effects (Earth tide, precipitation, shallow groundwater level changes, and so on), the residual gravity changes can be subdivided into five types of responses. We detected decreases in gravity by as much as 20 micro gal in the reinjection area, and increases in gravity by as much as 30 micro gal in the production area one month after the temporal shut-in. Then almost all of the gravity stations recovered the gravity after the maintenance period. We estimated the temporal change in density in the geothermal reservoir using these gravity changes.

1. INTRODUCTION

Repeat microgravity measurements have been using for an assessment of groundwater storage and geothermal reservoir monitoring. Production and reinjection of geothermal fluid cause movement and redistribution of mass, which can cause measurable gravity change on the ground surface. We can monitor the mass balance between production and recharge in the geothermal reservoir. Repeat microgravity measurements have been carried out in some geothermal fields (Allis and Hunt, 1986; Nordquist et al., 2004; Nishijima et al., 2010).

Those results included the gravity change at reference gravity stations. The absolute gravimeter was introduced in order to evaluate the gravity change in the reference station. We carried out absolute measurements at some reference stations, and used the relative gravimeter at other gravity stations. Combination of absolute and relative gravity measurement is called hybrid gravity measurement by Okubo et al. (2002). Hybrid gravity measurement has been applied to volcanologic and geothermal monitoring (Furuya, 2003; Sugihara, 2008).

The Ogiri geothermal power plant is located in the southern part of Kyushu, Japan (Figure 1). Geothermal exploration started in 1973 with various geophysical surveys and drilling. The power plant (30MW) was completed in March 1996. Nittetsu Mining Co., Ltd has conducted the geothermal steam production and Kyushu Electric Power Co., Inc. has operated the electric power generation. The production area is located in the eastern part of the geothermal field. The depths of the production wells are about 1000-1500m. The amount of production is about 9.4Mt/year, and about 78% of production (hot water) is reinjected to the western part of the geothermal field (Thermal and Nuclear Power Engineering Society, 2013).

We conducted hybrid gravity measurements three times (Mar., Apr. and May, 2011). Regular power plant maintenance was carried out in April 2011. The production and reinjection were interrupted in this period. We tried to detect the influence of stopping and restarting the production and reinjection of geothermal fluid.

2. GRAVITY MEASUREMENT

2.1 Absolute gravity measurement

A10 absolute gravimeter is a portable absolute gravimeter produced by Micro-g LaCoste Inc. It is operated on a 12V DC power supply. We measured the absolute gravity using the vehicle battery at the field. A test mass was dropped vertically in a vacuum chamber, and then allowed to fall an average distance of 7 cm. The A10 consists of a laser, a interferometer, a long period inertial isolation device and an atomic clock to measure the position of the test mass very accurately.

The raw gravity data were processed with the software ‘g’ version 7. This software is designed to work with Micro-g LaCoste absolute gravimeter to acquire and process the gravity data. This software requires to input some parameters, including the location of the site (Latitude, Longitude and Altitude), geophysical corrections, and so on. We can correct the effect of the earth tide, ocean load, barometric pressure and polar motion in acquiring the gravity data (Micro-g LaCoste, 2008).

2.2 Relative gravity measurement

Repeat gravity measurements have been applied at Ogiri geothermal power plant in southern Kyushu, Japan. We conducted repeat gravity measurement in March, April and May 2011, at 26 observation points. The repeat gravity measurements had been conducted for one month. The two-way measurement method was taken to evaluate the instrumental drift and precision. We estimated the errors of observation as ±10 μgal.

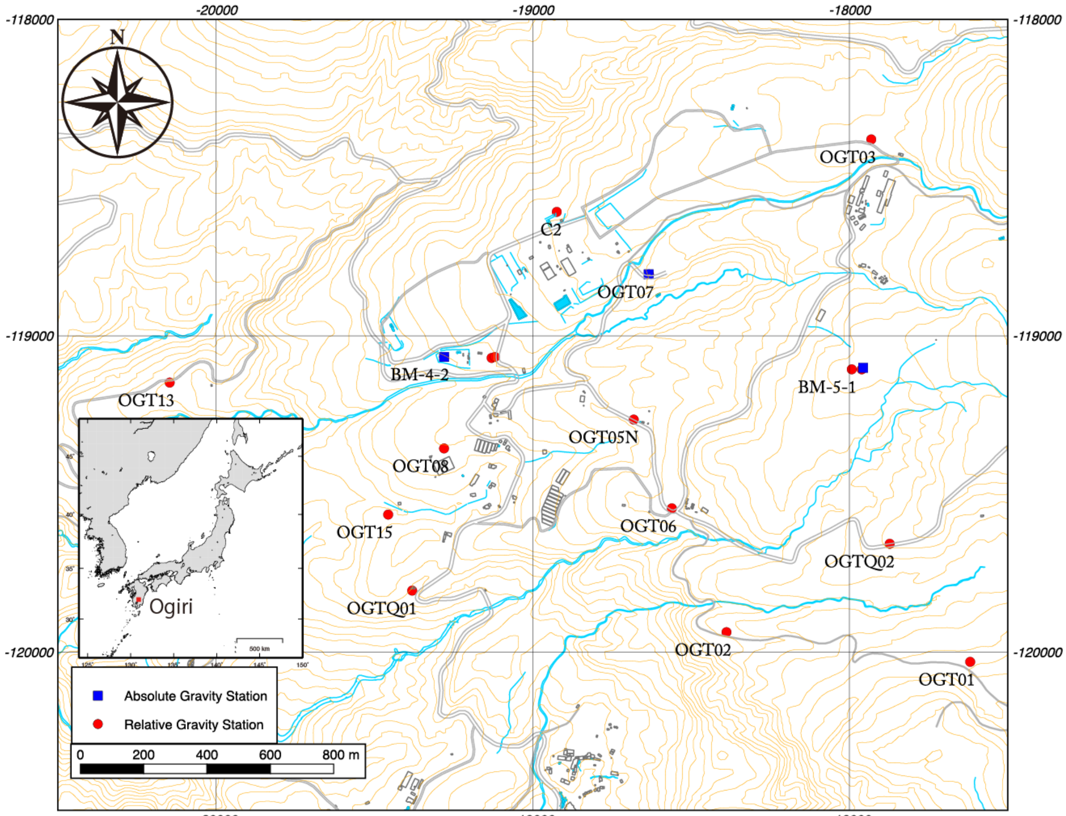

Figure 1: Location of gravity stations at Ogiri geothermal field.

3. RESULT AND DISCUSSION

3.1 Absolute gravity measurement

We set three stations (BM4-2, BM5-1A, OGT07) to conduct the repeat absolute gravity measurement.

The obtained gravity data is combined into a set, which usually consist of 100-150 drops. Our typical setup parameters are listed below:

Drop interval: 1 second

Number of drops/ 1 set: 100

Set interval: 3 minutes

Number of sets: 10

Figure 2 shows the results of absolute gravity measurements. We observed a gravity decrease just after the regular power plant maintenance in April 2011 in the reinjection area (BM4-2). After that the gravity recovered in May. In the production area (OGT07, BM5-1A), we observed a small gravity increase just after the regular maintenance, and then gravity was stable after the maintenance. These changes seem to be caused by the storage change in the reinjection area. Based on these data, we used BM4-2 as reference gravity station for relative gravity measurement.

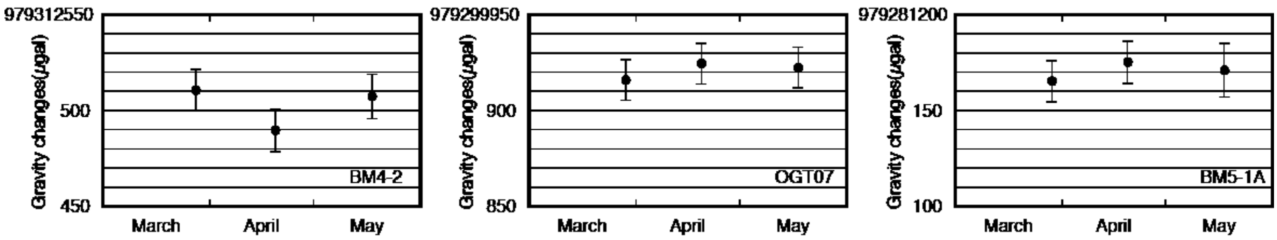

Figure 2: Absolute gravity data at the Ogiri geothermal field. BM4-2 is located in the reinjection area; the others are located in the production area.

3.2 Relative gravity measurement

According to the result of leveling surveys, the vertical ground movements were less than a few mm/year. Assuming a normal free-air gradient of -308.6 µgal/m, ground movement caused less than 3 µgal. This effect is very small in comparison with the observed gravity change. Consequently, the effect of vertical ground movement is negligible on the observed gravity in short term.

Measurements in groundwater level at the monitoring wells showed that the difference of the levels in March and May was 1.2 m. The gravity effect on the change in groundwater level was about 6µgal in the case where we assumed that the aquifer was infinite slab and removed this effect from the observed gravity changes.

The residuals of gravity change due to reservoir effects, which were the difference between the observed and the calculated gravity effects of the changes in ground water level at each observation station, can be subdivided into five types of response (Figure 3). The data shows residual gravity increased by as much as 30 µgal in the production zone and decreased by as much as 20 µgal in the reinjection zone immediately after the production and the reinjection stopped.

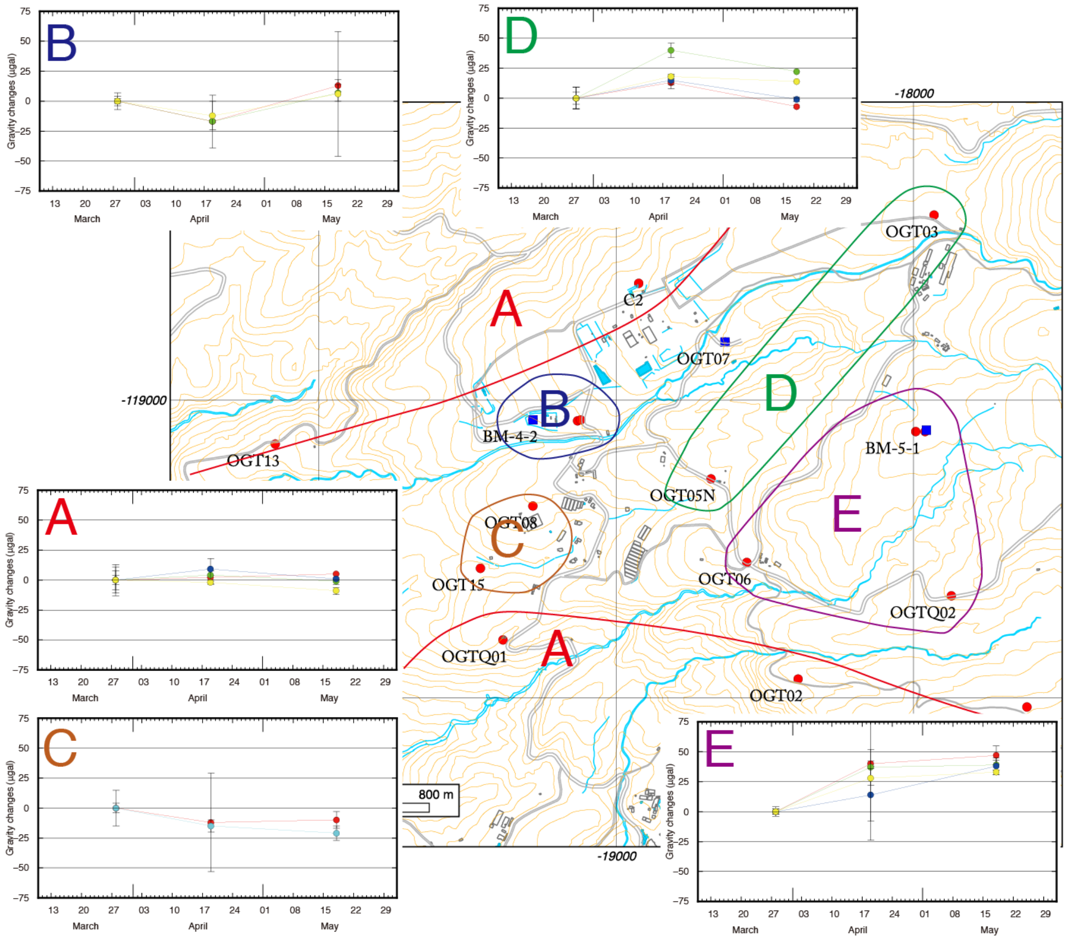

Figure 3: Distribution of typical patterns of residual gravity changes in the Ogiri geothermal power plant.

3.2.1 Northern and Southern Area (Type A)

This group was located in the out of production and reinjection zone, and the gravity changes were very small (less than 10 µgal). As soon as the production and the reinjection were operated, a slight increase of the residual gravity was observed. Gravity decreased from March 2011 until April 2011.

3.2.2 Western Area (Type B and C)

This group of response was seen at the observation points located in the reinjection zone and in the western part of the observation area. The gravity had decreased since reinjection was halted, and then recovered after reinjection was restarted (Type B). On the other hand, the gravity in the southern area of the reinjection zone kept low value (Type C).

3.2.3 Eastern Area (Type D and E)

This group of response was typical at the stations located in the eastern production zone along the Ginyu fault, in the eastern part of the observation area. An increase of residual gravity was observed after stopping the geothermal fluid production, and the gravity decreased after production was restarted (Type D). In contrast, the gravity in the southeastern part of the observation area persisted high value (Type E).

Figure 4 shows the contour map of the gravity change from March to April 2011 before and after stopping the production and reinjection in the Ogiri geothermal power plant. The residual of gravity decreased around the southwestern part of the geothermal field. The center of this change was located in the western part of Ginyu fault. This decrease in gravity indicates that the reinjected hot water flowed towards outside of the observation area. In the production area, the gravity increase by as much as 30 µgal was observed in the eastern part of the observation area. The data corresponded to the borehole pressure changes in the reservoir, so this gravity response indicates the recharge came from outside of the observation area.

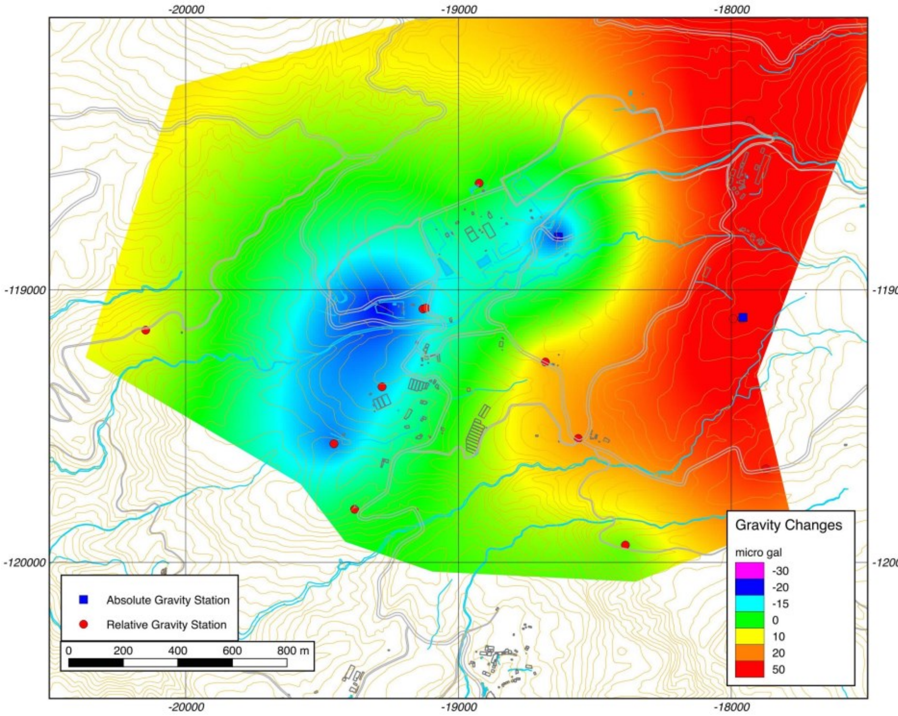

Figure 4: Distribution of gravity change from March to April 2011.

Figure 5 shows the contour map of gravity change from April to May 2011. The gravity was recovered in this period, although some stations in the southern area of the Ginyu fault still observed their former level. The residual gravity increased around the reinjection area of the geothermal field. The gravity decrease was detected in the production area on the Ginyu fault.

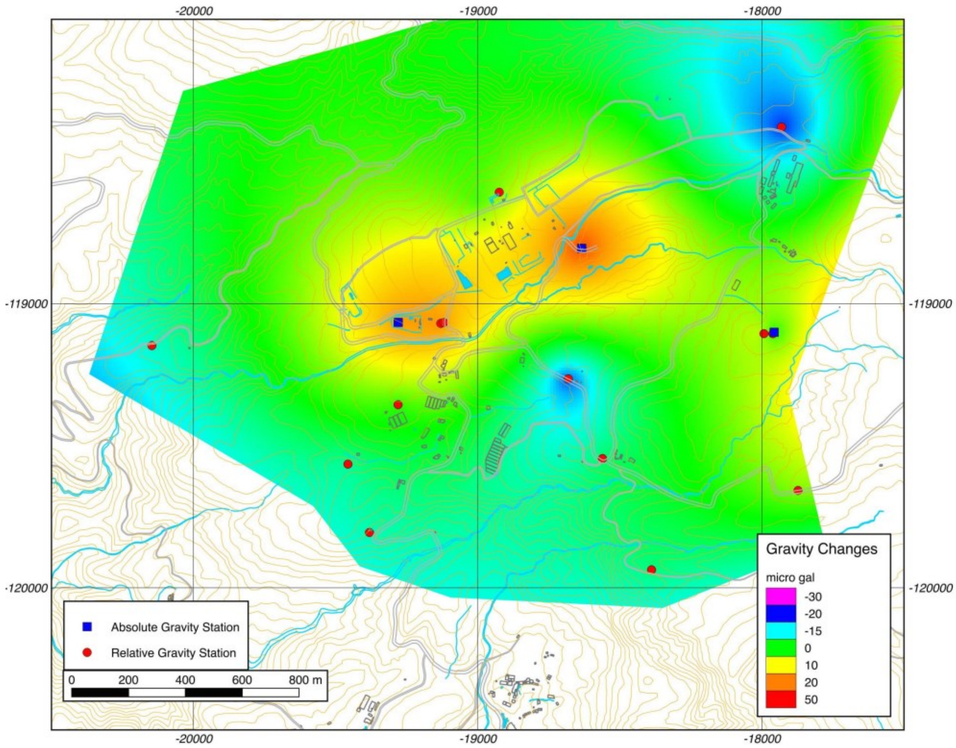

Figure 5: Distribution of gravity change from April to May 2011.

These residual gravity changes were consistent with the pressure changes in the geothermal reservoir. Especially at the gravity stations along Ginyu fault, the responses of stopping and restarting of the production and reinjection were quick. Thus, the effects of field operations can be isolated, even for fields with relatively low production rates like the Ogiri geothermal field.

4. CONCLUSION

We applied hybrid gravity measurements before and after the regular power plant maintenance at the Ogiri geothermal field. Based on these results, we removed the background gravity change that was caused by seasonal changes of shallow ground water level by using an infinite slab model. Residual gravity increased by as much as 30 µgal in the production zone, and decreased by as much as 20 µgal in the production zone. These residual gravity changes were consistent with the changes in the geothermal reservoir. Thus, the effects of field operations can be isolated, even for fields with relatively low production rates like Ogiri. This study suggests that repeated hybrid gravity measurement is an effective method to monitor geothermal reservoirs.

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