Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

CORRECTION OF BACKGROUND GRAVITY CHANGES DUE TO PRECIPITATION: OGUNI GEOTHERMAL FIELD, JAPAN

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Key Words: microgravity, reservoir monitoring, precipitation, water table, Oguni

ABSTRACT

The Oguni geothermal power station will be constructed in central Kyushu, Japan. To identify and study reservoir behavior after exploitation begins, microgravity monitoring has been planned and the background gravity changes have been monitored frequently since 1996. So far, only the background level measurements have been made, in which seasonal changes in gravity were detected. The change of shallow groundwater table is thought to be the primary factor causing background gravity changes because substantial changes in water table depth were observed in this field. To remove the effects due to shallow ground water table changes from measured gravity changes, we tried at first to calibrate gravity change from precipitation through water table at a benchmark where water table was known. To extend the calibration method to benchmarks which do not have nearby observation wells, the empirical equation was applied to precipitation data to estimate the water level changes that might occur near the benchmark. Porosity was determined from the relationship between precipitation and gravity changes associated with water table changes. The microgravity changes estimated from the precipitation data were compared with the actual gravity measurement data, however, no obvious relationship between precipitation and gravity change could be obtained. Repeat gravity measurement should be continued for further examination of procedure for noise reduction.

1. INTRODUCTION

The Oguni geothermal field is located in central Kyushu, southwestern Japan (Figure 1). The Oguni geothermal power plant will be constructed as a 20MW (gross) double flash plant by Electric Power Development Company (EPDC). The geothermal power plant will be located in the western to northwestern flank of the Mt. Waita (1,500m, asl). The boundary zone of the geothermal field has been defined by well logs and pressure transient tests. The extent of the reservoir is approximately 4km $\times$2km, and a cap rock exits from 300 to 750 m asl (450m in thickness). Below the cap rock, temperatures range from 200 to 240℃ and there is a small steam zone at a top of the reservoir. Above the cap rock, a shallow unconfined aquifer exists with a groundwater table of the depth of around 100m from the subsurface in northern part of the field (see Abe et al., 1995).

We have planned microgravity monitoring in order to understand reservoir behavior during field exploitation. Nakanishi et al. (1998) estimated the change in gravity caused by exploitation by using a numerical simulation technique. The calculated result suggests that after 30 years there will be slight gravity increases (about $35\times10^{-8}ms^{-2}=35\,\mu$ gal) in the main reinjection wellfield at Northern area, and relatively large gravity decreases (about $-130\,\mu$ gal) centered on the middle of the production wellfield, caused by boiling arising from production-induced local pressure decline (Figure 2). Because the expected gravity disturbances are small, accurate measurement and careful noise reduction techniques need to be established.

In rugged mountain areas, groundwater table tends to show rapid and large changes. Natural changes in groundwater level in the northern part of this area between 1990 and 1999, due to rainfall, were observed to be more than 16 m. Therefore a significant part of any measured gravity changes is likely to be caused by changes in groundwater level. If microgravity would be corrected directly from precipitation, this method could be applied to areas where there are no observation wells. Moreover, gravity changes due to changes in not only water table but also water saturation in the vadoze zone would be possibly corrected for.

2. PROCEDURE

2.1 Microgravity observation

A total of 41 benchmarks have been established for gravity monitoring in the Oguni geothermal field (Figure 3), and vary in elevation from 519 m to 1,095 m asl. These benchmarks were distributed to where gravity changes were estimated by disturbance of reservoir caused by operation of geothermal power plant. STAR reservoir simulator and surface gravity postprocessor (Pritchett, 1995) were used to predict gravity changes. We had started precise microgravity observation in May 1996 and have continued measurements for about 3 years with a frequency of once a month for all 41 benchmarks. The reference benchmark used is located in about 11km away from the geothermal field. Geographical Survey Institute (GSI) as first order leveling benchmark sets up this benchmark. This benchmark should be far enough away from the geothermal field that exploitation induced gravity changes would not occur. A CG-3M gravity meter (S/N 9507281) was used to measure gravity as relative gravity difference from the reference benchmark. Precise leveling has been conducted twice during the period of gravity measurements, and show that ground level changes were less than the permitted error for a leveling network, so gravity change caused by elevation changes were negligible.

2.2 Estimation of water table change from precipitation

Precipitation in the northern part of this field and the water level in observation well BW-2 located near the benchmark 201 are shown in Figure 4. This area is the rainy area; we have had rainfall of 1,130 to 3,450 mm in the last 10 years, and the average annual rainfall is 2,250mm/year. Well BW-2 was drilled to observe the shallow unconfined water table above the cap rock. Here, the maximum amplitude of the groundwater table changes varied up to 16.9 meters in this period; typical seasonal changes are shown in Figure 4. Moreover ground water level changes in this well clearly correspond to rainfall. When the rains fall, the water level in the well increases suddenly and decreases gradually afterward. An Empirical exponential decrease equation (Yuhara and Seno, 1969) was applied to correlate precipitation with water level.

$$H(t) = H_1 + \alpha \Sigma_n R_n \exp\{-c(t-t_n)\} \quad (1)$$

where H_1 is an initial water level before rainfall, t represents time, α and c are constants, R_n is precipitation at t_n-th day from beginning (in mm).

2.3 Calculation of gravity change from precipitation

When we get water table changes from precipitation, the gravity changes associated with a change in water level will be given by Allis and Hunt (1986);

$$\Delta g = 2\pi G \phi \rho_w \Delta h \quad (2)$$

where Δg is the gravity change (μgal = 10^{-8} m/s^2), G is the universal gravity constant (6.67×10^{-11}m^{3}kg^{-1}sec^{-2}), ϕ is the porosity at the depth of water table, ρ_w is the density of ground water (kg・m^{-3}), Δh is the change in water level (m). Several shallow observation wells over a relatively wide area in the northern part of Oguni show similar elevation of water table suggests this equation can therefore be employed as an infinite plane approximation for the whole field.

3. RESULTS

The measured changes in gravity at benchmarks 201 and OG-15 are shown in Figure 5 and 6 as representative example. Long-term microgravity changes were observed at both benchmarks. The result at station 201 has a large amount of change, moreover, abrupt large shifts have occurred twice (November 1996 and November 1998) for unknown reasons. On the other hand the date for Benchmark OG-15 indicate relatively small fluctuations and seasonal changes. Large shifts that occurred at benchmark 201 were not observed at OG-15. The relative gravity difference due to variations in the elevation between lowest and highest measurement benchmark were more then 130×10^{-5}ms^{-2} (mgal). The amount of gravity change at each benchmark seems to be proportional to gravity difference from the reference benchmark, and so we suspected there are systematic errors caused by measurement or processing of the data. Analysis of the data was therefore limited to the stable period between the two big shifts.

Applying the equation (1) to precipitation data and the water table in well BW-2, we finally got a set of parameters by least squares fitting as follows:

$$H_1=671 \text{ (m ASL)},\ \alpha=0.00932 \text{ and } c=0.00985 \text{ (day}^{-1})$$

The estimated groundwater level using these parameters is shown in Figure 7. The porosity at the water table was estimated to be 0.11 by least square fitting of the water table change and the measured gravity change data: this value is reasonable for shallow ground water aquifer in the area. The calculated gravity changes using the inferred changes of water table depth are shown in Figure 8 with the observed change in gravity at station 201. It seems that the general trend of changes in observed gravity could be produced by calculation, on the whole. Then we applied these parameters to nearby station 202. The calculated gravity history does not correlate very well with measured values (Figure 9), although both benchmarks are obviously located on the same unconfined ground water system and would therefore be expected to exhibit similar water table depth histories and resulting microgravity changes.

4. DISCUSSION

A poor correlation was observed between water table change and surface gravity change. Indeed, a mutual relationship between there could not be sufficiently determined from the results of the measurements. Continuous gravity measurements seem to be necessary during periods of rapid change in water table caused by heavy rainfall; 10 meters order of change in water table would be expected to occur only with in a few months. The gravity meter can obtain data continuously, moreover precipitation changes significantly at rainy season in this area. If continuous gravity monitoring were curried out, gravity changes caused by water table changes could be detected more clearly.

The gravity changes have been detected at all of 41 benchmarks. It appears form the data that the changes in gravity are large at places of high elevation, and that the changes occur in proportion to relative gravity difference from the reference station to observatory benchmarks. The most stable benchmark (OG-15) has the lowest gravity difference benchmark from the reference benchmark.

To increase the accuracy of measurement, the absolute value of gravity as fundamental benchmark should be measured using an absolute gravity meter. Alternatively we can connect an absolute gravity point to the fundamental benchmark with a relative gravity meter. Since gravity may change, even at the fundamental benchmark, it would be important in the case of precise gravity measurements.

5. SUMMARY

Microgravity changes during the 3 years period before exploitation began. Water table changes are considered to be the primary reason for these gravity changes. We attempted to establish a relationship between ground water level and gravity, but a good correlation was not obtained. On the other hand obvious changes of microgravity were detected at some benchmarks, which has not so large gravity difference from fundamental benchmark. To solve the problems continuous microgravity monitoring should be carried out. Measurement of absolute gravity at the fundamental benchmark will be essential in precise measurement of the change in gravity of the field, although there is a difficulty of decision of absolute gravity value for the fundamental benchmark.

ACKNOWLEDGEMENTS

The precipitation and ground water level data were acquired by New Energy and Industrial Technology Development

Organization (NEDO) project "Development of binary cycle plant" as part of the "New Sunshine Project" supported by the Agency of Industrial Science and Technology (AIST) of the Japanese Ministry of International Trade and Industry (MITI). Mr. T. Nuruyu (Kaihatsu Koji Co.) acquired the microgravity data. All digital data processing was carried out by Mr. H. Oshima of the Kaihatsu Computing Center.

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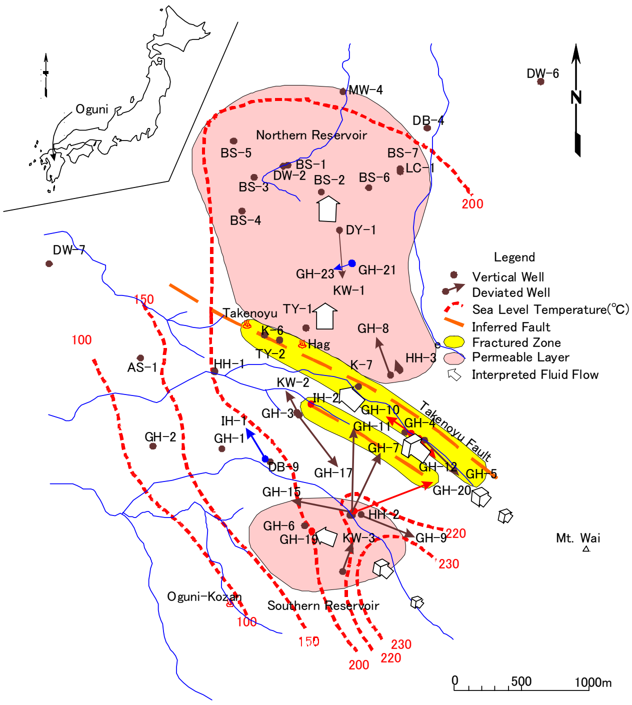

Figure 1. Location and extent of the Oguni geothermal field in Kyushu, Japan

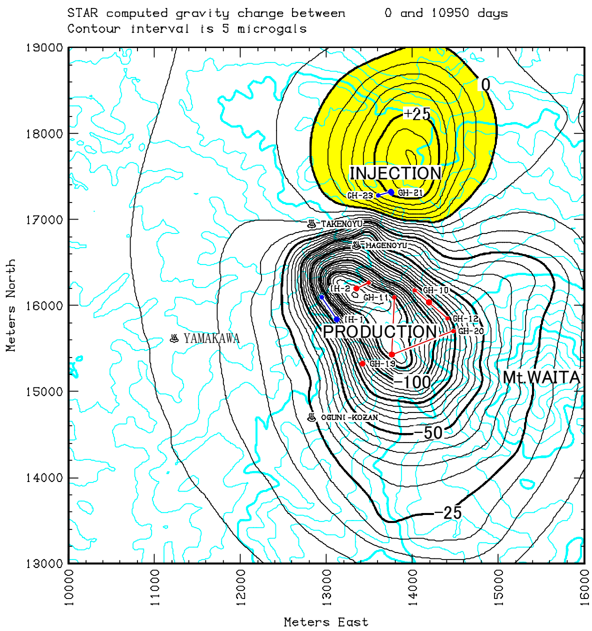

Figure 2. Calculated gravity changes caused by 30 years field operation of 20 MW geothermal power plant

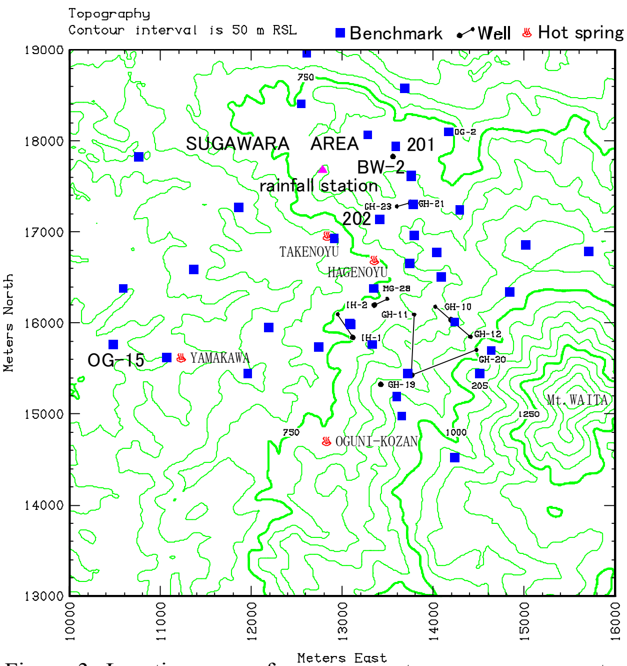

Figure 3. Location map of measurement area, measurement benchmarks, observation wells of shallow ground water table and rainfall measurement station

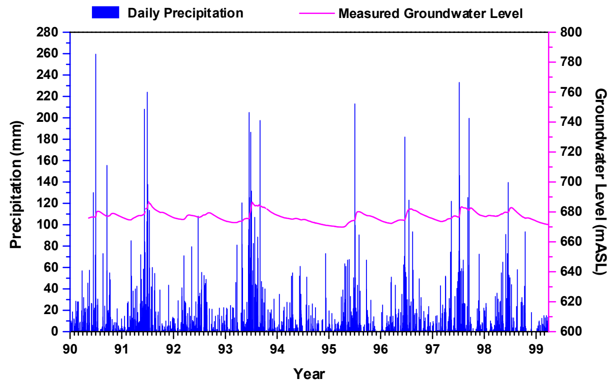

Figure 4. Precipitation and groundwater level changes measured in shallow well BW-2

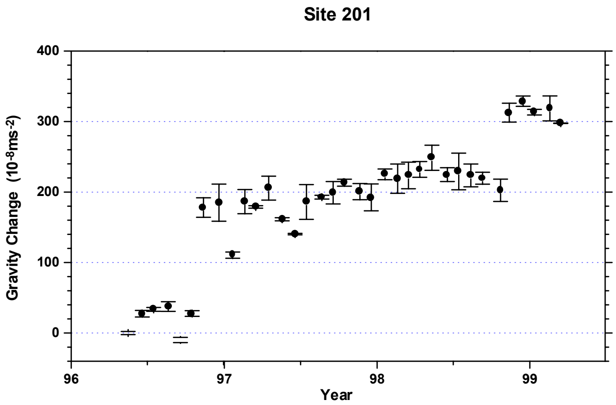

Figure 5. Measured changes in surface microgravity at benchmark 201. Note the step changes in late 1996 and 1998.

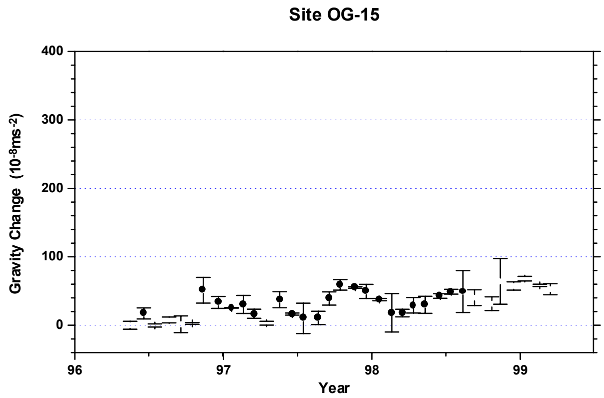

Figure 6. Measured changes in gravity at benchmark OG-15.

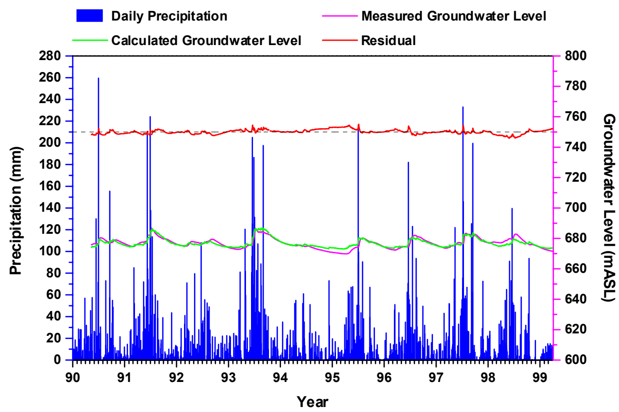

Figure 7. Precipitation and ground water table in well BW-2

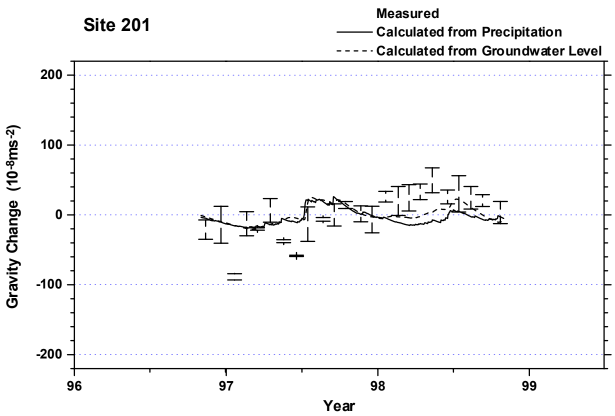

Figure 8. Comparison between the observed and estimated gravity values at the benchmark 201.

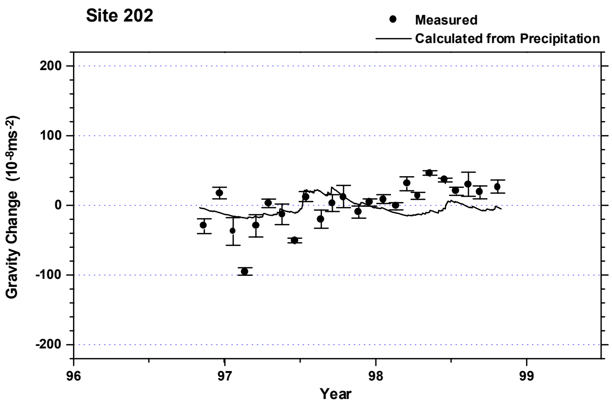

Figure 9. Comparison between the observed and estimated gravity values at the benchmark 202