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GRAVITY MONITORING IN YANAIZU-NISHIYAMA GEOTHERMAL FIELD, JAPAN

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ABSTRACT

Yanaizu-Nishiyama Geothermal Field is located in the western part of Fukushima Prefecture, northeast Japan. In this field, sixteen production wells have been drilled. A 65 MWe power station was built and has been operated commercially by Tohoku Electric Power Co., Inc. since May 1995. Okuaizu Geothermal Co., Ltd. has supplied steam to the power station.

Gravity monitoring survey was started in September 1994. The original survey area was about 15km^2, covered the production and reinjection areas and contained 83 gravity stations. Annual gravity monitoring surveys were carried out from 1994 to 1997 by Okuaizu Geothermal Co., Ltd. and Tohoku Electric Power Co., Inc.

Since 1997, New Energy and Industrial Technology Development Organization (NEDO) has sponsored the survey, and the survey area has been expanded by 30km^2. In the new survey area, 138 gravity stations were set, and 10 groundwater-monitoring wells were drilled to study the effect of the change in groundwater level. A gravity station and a weather monitoring system were installed at a monitoring well in the central part of the survey area. Seasonal gravity monitoring surveys have been carried out three times a year since 1998. Between the seasonal monitoring surveys, gravity has been monitored near the groundwater-monitoring wells. At these wells, groundwater levels have been monitored every 30 minutes. At the gravity station with the weather monitoring system, gravity, barometric pressure, air temperature, precipitation and water content in the vadose zone have been monitored together with groundwater level.

From examination of gravity and barometric pressure data recorded in the central part of survey area, a precise earth tidal model and correlation between gravity and barometric pressure were established. These models enable us to reduce "noise" in gravity monitoring results and to study the effect of groundwater level change on gravity monitoring.

1. INTRODUCTION

In geothermal exploitation, various types of measurements are conducted for monitoring fluid behavior in the geothermal reservoir. Typically, measurements of pressure and temperature change in the reservoir are carried out in the wells. Recently, geophysical measurements such as gravity, electrical, electromagnetic and seismic at the earth surface have been carried out in some areas by NEDO.

Gravity changes observed on the earth surface, other than short-term variations associated with earth-tidal and barometric pressure variations, reflect the change in subsurface density distribution. Therefore, gravity monitoring in a geothermal field is useful for assessing the mass change in the reservoir and/or the growth of the two-phase zone with the production and reinjection of geothermal fluids. For reservoir monitoring, accuracy less than 10 μgal (= 0.1 μms^{-2}) will be required in the gravity measurement. On the other hand, changes in groundwater level also can affect the gravity changes measured on the surface. Furthermore, incomplete earth tidal correction may also distort the results. The magnitude of these distortions is greater than the accuracy required for the reservoir monitoring.

We present here the outline of gravity monitoring in Yanaizu-Nishiyama Geothermal Field. The purpose of the survey is to develop an optimal gravity survey method and noise reduction techniques for geothermal reservoir monitoring.

2. YANAIZU-NISHIYAMA GEOTHERMAL FIELD

Yanaizu-Nishiyama Geothermal Field is located in Fukushima Prefecture, northeastern part of Japan (Fig.1). In this field, sixteen production wells have been drilled. Production began in December 1994, and a 65 MWe power station was built and has been operated commercially by Tohoku Electric Power Co., Inc. since May 1995. Okuaizu Geothermal Co., Ltd. has supplied steam to the power station.

The production zone of the field is formed by two fault systems, Chinoikezawa fault system and Sarukurazawa fault system (Fig.2). The reinjection zone is in the Oizawa fault system. These three fault systems have NW-SE strikes and are steeply dipping to NE. Major feed points are located at depths from 1,000 to 2,600m (Nitta et al, 1995).

3. MEASUREMENT

Gravity monitoring survey in this field was started in September 1994. The survey area was originally about 15km^2 and covered the production zone and reinjection zone with 83 gravity stations. At these stations, gravity measurements and leveling were carried out every year until 1997. Since then, New Energy and Industrial Technology Development Organization (NEDO) has sponsored the surveys, and the survey area has been expanded to 30 km^2 by inclusion of the original gravity stations. In the new survey area, there are 138 gravity stations, and 10 groundwater-monitoring wells were drilled to study gravity change due to the change in groundwater level. At these stations, gravity measurements and leveling (and/or GPS measurement) have been carried out three times a year: May, August and November. Fig.3 shows the locations of gravity stations and monitoring well sites in 1998. To grasp short-term gravity changes associated with groundwater level changes, additional gravity measurements at these well sites have been carried out between the seasonal gravity surveys. Reference station for this project is in the Aizu-Wakamatsu observatory, located more than 20km away from the survey area. Gravity difference between GS2125 and this station has been measured (e.g., This measurements were conducted twice a month between the seasonal surveys in 1999).

Groundwater levels have been monitored every 30 minutes since April 1998. At the monitoring well site No.5 near the gravity station GS2125, a weather monitoring system was installed and barometric pressure, air temperature and precipitation have been monitored every 30 minutes since May 1998. These data are obtained for a study of the precise noise reduction of the gravity data, and for the determining gravity change due to the groundwater level change. From July 1999, the vertical distribution of water content in the vadose zone down to 2.5m has been monitored using Time Domain Reflectometry (TDR).

4. RESULTS

4.1 Gravity changes in the survey area

Using the results of the seasonal gravity surveys at 138 gravity stations in this field, the distribution of gravity changes has been calculated. Fig.4 shows gravity change from November 1997 to November 1998. During this period, gravity changes from -20 to +20 μgal occurred at the most of the gravity stations. Magnitude of gravity change is small and precise noise reduction is required. Precise tidal reduction and the reduction of barometric response are discussed in later section.

To determine the gravity change due to elevation change at each gravity station, GPS measurements and leveling were carried out along with the seasonal gravity surveys. According to the elevation change calculated from four seasonal survey results, GPS results at some stations show several centimeters of irregular fluctuation in elevation. Therefore, in the final process for the elevation determination, the leveling data were used in preference to the GPS data. However, since GPS surveys are much cheaper than leveling. The stability of GPS results and optimal usage in this field are being studied.

4.2 Gravity, groundwater level and weather monitoring at GS2125

At the gravity station GS2125, located adjacent of monitoring well No.5, gravity, groundwater level, barometric pressure, air temperature and precipitation have been monitored every 30 minutes since May 1998.

Fig.5 shows a part of the monitoring record. More than 120 days of continuous gravity data have been obtained, in spite of some short breaks and replacement of the gravimeter. Using these gravity data and barometric pressure data, precise tidal correction has been made for gravity measurements in this survey area. Details of the precise tidal correction are given in the next section.

In the groundwater level record (Fig.5(b)), there are some abrupt changes associated with precipitation (Fig.5(e)). The correlation between gravity change and groundwater level change is being examined. Since the gravity response to groundwater level change might be smaller than that to tidal or barometric changes, the gravity data should be corrected for those effects before studying its correlation with groundwater level change.

5. DISCUSSION

5.1 Precise earth tidal correction

The Earth experiences elastic deformation due to tidal forces coupled by movement of the Sun and Moon. The ocean tides cause additional deformation by their loading. These deformations lead to changes in gravity values observed on the surface of the earth. The tidal correction is generally calculated from the expansion of tidal potential for the rigid earth with an amplification factor δ=1.16 and a phase shift of zero (Torge, 1989). For gravity monitoring surveys that require an accuracy less than 20 μgal, more precise earth tidal correction is needed.

Precise tidal correction (accuracy less than 10 μgal) can be made based on measurements at GS2125. With more than several weeks of gravity data, the amplitude and the phase of the principal tidal components can be determined precisely.

Using 42 days of gravity data measured at GS2125, the amplitudes and the phases of twelve principal tidal components were determined using tidal analysis program BAYTAP-G (Ishiguro et al., 1981; Tamura et al., 1991). Fig.6 shows the comparison between the conventional tidal correction and the precise tidal correction. Fig.6 (a) shows the gravity data after tidal correction using Longman's (1959) formula (amplification factor=1.16). The gravimeter used for these surveys (Scintrex CG-3M) employs Longman's formula. Fig.6 (b) shows the results of precise correction of the same data as Fig.6 (a), but calculated using BAYTAP-G. The data after conventional correction has some periodical gravity changes not present after precise correction. The amplitude of this periodical gravity change is less than 20 μgal, but it could be one of the noise sources.

5.2 Correction for barometric pressure change

The barometric pressure changes associated with weather changes can cause changes in gravity. Fig.5 (c) shows the barometric pressure changes recorded at GS2125. Part of these changes was up to 20 hPa, over the few days period of this record. The tidal analysis program BAYTAP-G can calculate the response coefficient for barometric pressure change for this record is about -0.4 μgal/hPa. Therefore, the gravity effect does not exceed 10 μgal in amplitude for the data shown in Fig.5.

Barometric pressure changes may not be a major source of noise for relative gravity measurements, because the pressure change rarely exceeds 20 hPa and it changes slowly with respect to gravity measurement cycle. However, it affects the estimation of the instrumental drift. Pressure changes over 30 hPa are observed in a day when typhoons are passing near the survey area. In such cases, a gravity change of over 20 μgal would be expected and correction is strongly recommended.

6. CONCLUSIONS

Gravity monitoring at more than 80 stations has been carried out in Yanaizu-Nishiyama Geothermal Field, Japan since 1994. In 1997, NEDO started a survey program for the development of method for geothermal reservoir monitoring.

Under NEDO's program, additional gravity surveys have been carried out and groundwater level and meteorological data have been monitored since 1998.

From barometric pressure data recorded at a gravity station, a precise earth tidal model and correlation between gravity and barometric pressure were established. These models enable us to reduce "noise" in gravity monitoring results. By using the gravity data after the precise correction described above, the correlation between gravity and groundwater level will be assessed to study the gravity change due to the groundwater level change.

Stability of the results of the GPS measurement in the survey area was examined. To minimize cost, GPS technique was applied to level the gravity stations in the survey area. With 8 hours of daily GPS measurements in the seasonal survey term, the daily ellipsoidal height fluctuation does not exceed a few centimeters. Averaging of the ellipsoidal height may be effective in stabilizing the GPS measurements.

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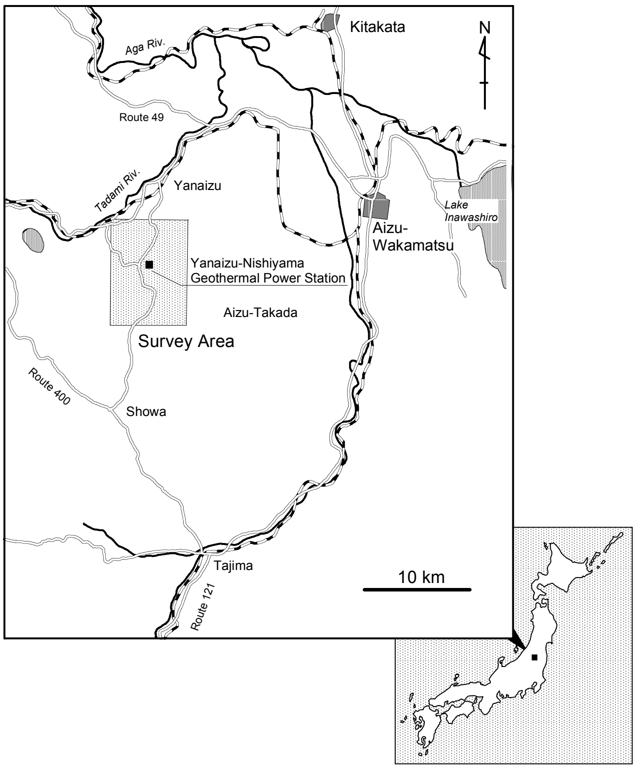

Fig.1 Location of Yanaizu-Nishiyama geothermal field

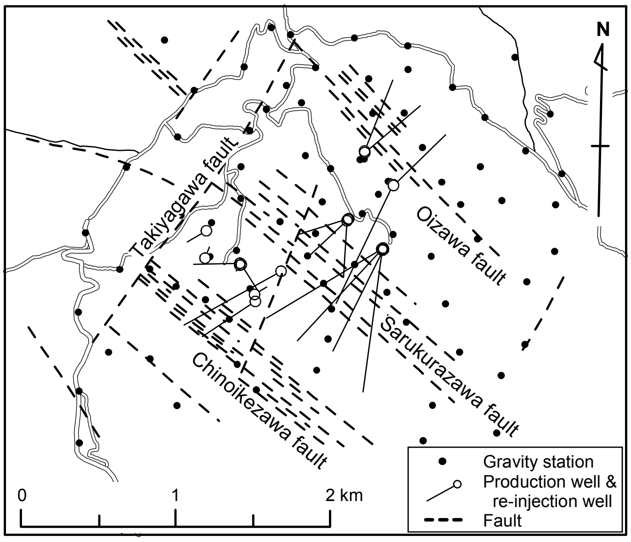

Fig.2 Fault systems in Yanaizu-Nishiyama geothermal field

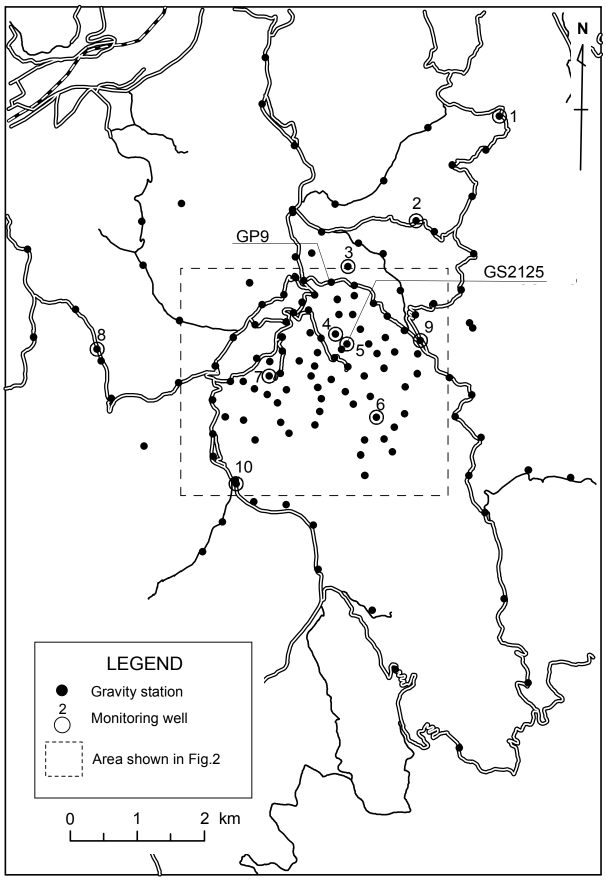

Fig.3 Location of gravity stations and monitoring wells

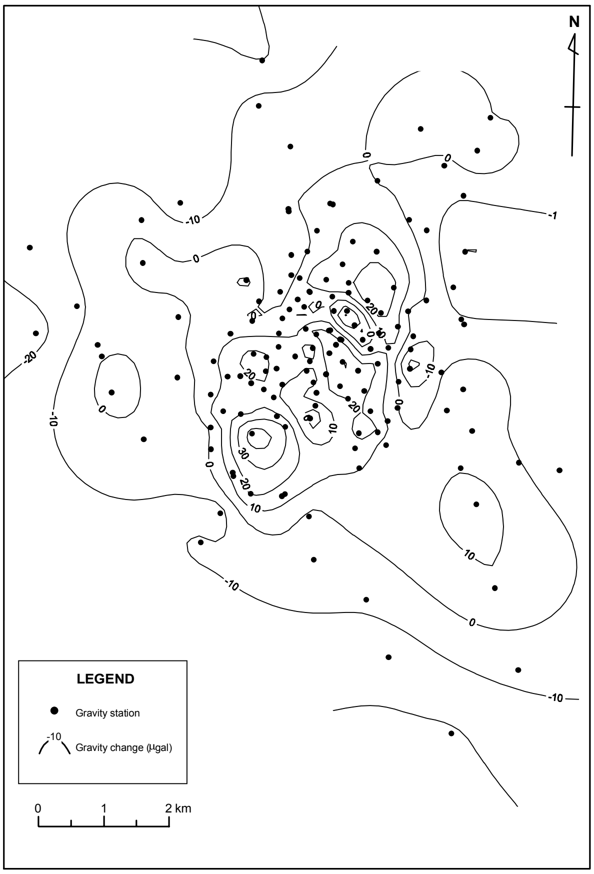

Fig.4 Gravity changes from November 1997 to November 1998

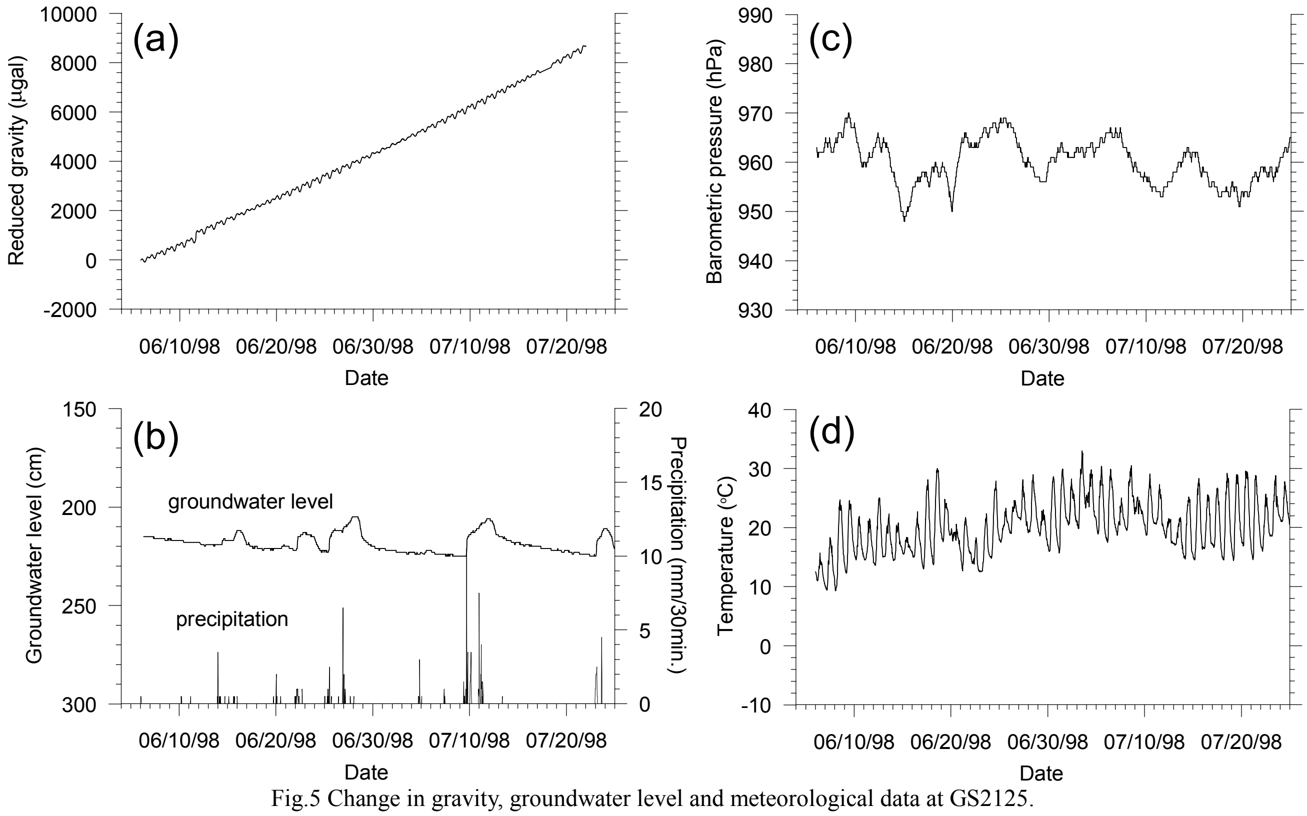

Fig.5 Change in gravity, groundwater level and meteorological data at GS2125.
(a) Gravimeter reading (no drift correction applied) (b) Groundwater level and precipitation
(c) Barometric pressure (d) Air temperature.

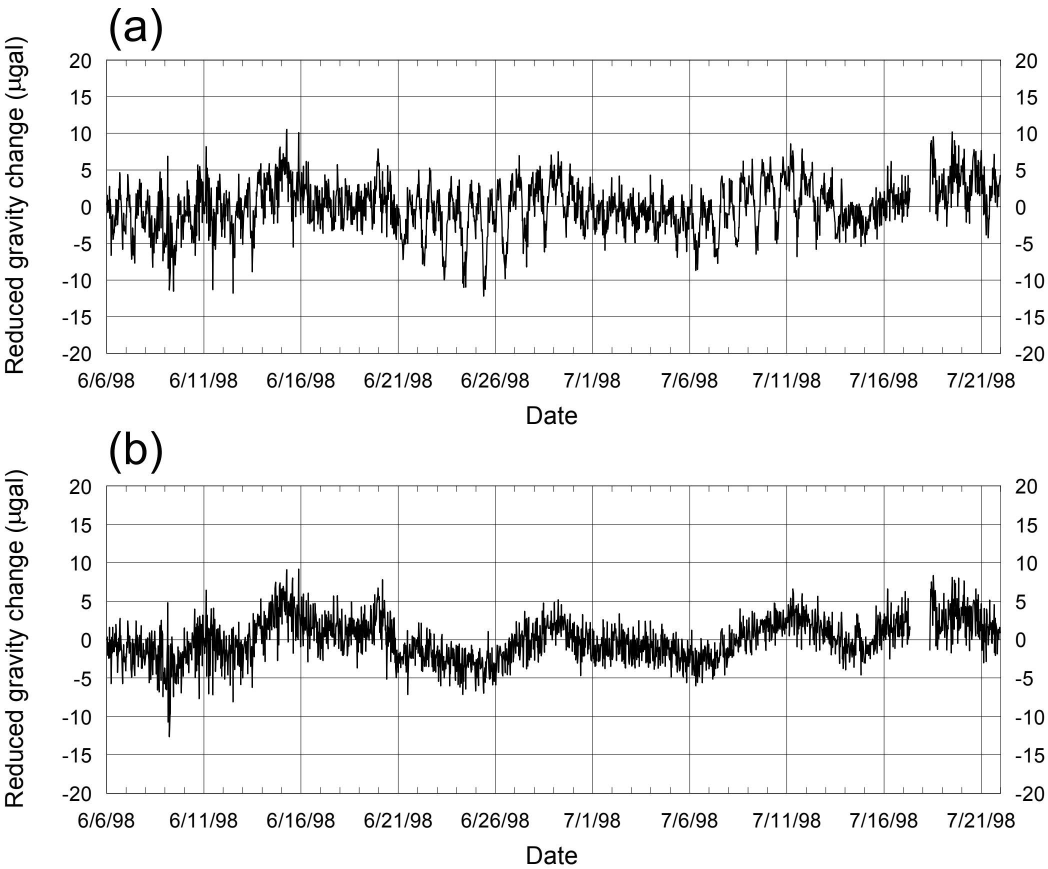

Fig.6 Comparison between the conventional and the precise tidal reductions.
(a) Conventional tidal reduction (b) Precise tidal reduction