Gravity Monitoring of Geothermal Reservoirs-A Case Study of the Production and Reinjection Test at the Takigami Geothermal Field, Central Kyushu, Japan-

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Keywords: gravity monitoring, production, reinjection, geothermal reservoir, reservoir monitoring

Abstract

Takigami geothermal field is a hot water dominated geothermal system, central Kyushu, Japan. A new 25MW geothermal power plant is expected to commence the operation in 1996 at this field. A short period production and reinjection test was conducted from November 1991 to February 1992. We conducted repeated gravity surveys at specified intervals (one to three months) for two years includig the test period to detect gravity changes caused by production and reinjection. Gravity changes of up to 150 microgal have been observed during the two years. Most of such large changes are found to be due to seasonal variations of shallow water level. After correction of such shallow water level effect, we detected gravity increases of up to 30 microgal in the reinjection zone. This change is reasonable if we assume that the reinjected water stays for a while beneath the reinjection zone.

Introduction

The precise repeated gravity survey is one of the effective techniques for the geothermal reservoir monitoring. Allis and Hunt(1986) gave a clear interpretation of changes in the state of the reservoir at Wairakei during the long term exploitation by using the data of gravity changes for more than 30 years. We are also trying to monitor several geothermal reservoirs in Japan. In order to detect clearly changes in gravity during exploitation, it is very important to start gravity surveys from before exploitation. This paper discusses the background gravity changes before exploitation and the result for the short period production and reinjection test at the Takigami geothermal field in central Kyushu, Japan.

Takigami geothermal field

The Takigami geothermal field is located in the southwestern part of Oita prefecture, central Kyushu, Japan (Fig. 1). The Hatchobaru geothermal power station is about 15km southwest of the Takigami field. Although there are so many geothermal manifestations in geothermal fields of central Kyushu, no surface manifestations exist in the Takigami geothermal field. More than 20 exploration wells have been drilled in the field since 1974. As the results, the geothermal reservoir with high temperatuture was detected, which is covered with the thick impermeable layer. The maximum temperature of the reservoir is 252℃.

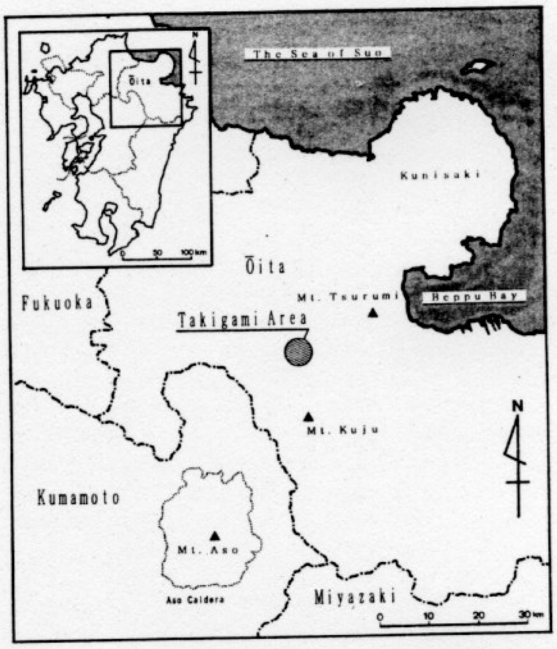

Fig. 1 Location map of the Takigami geothermal field, central Kyushu, Japan

The geothermal model of the field as shown in Fig. 2 is outlined as follows (Yamamoto, 1988, Hayashi et al., 1988): The field is devided into three parts from the geological and thermal viewpoints. The upper layer, which is composed of Quaternary Noine-dake volcanic rocks and Ajibaru formation, shows low thermal gradient and low temperarure below 50℃. The middle layer, which is composed of Tertiary dacitic and andesitic volcanics called the Takigami formation, shows high thermal gradient. The lower layer, which is composed of Tertiary andesitic rocks, shows isothermal gradient and high temperarure (160-260℃). This layer is the geothermal reservoir of the field. The reservoir is devided regionally into two, that is, the deeper western and shallower eastern parts. The geothermal fluids move from the deeper western part to the shallower eastern part. Then the production and reinjection wells are drilled in the western and eastern parts, respectively. The most adequate capacity of the production was estimated at 55MW of power generation(Hayashi et al., 1988).

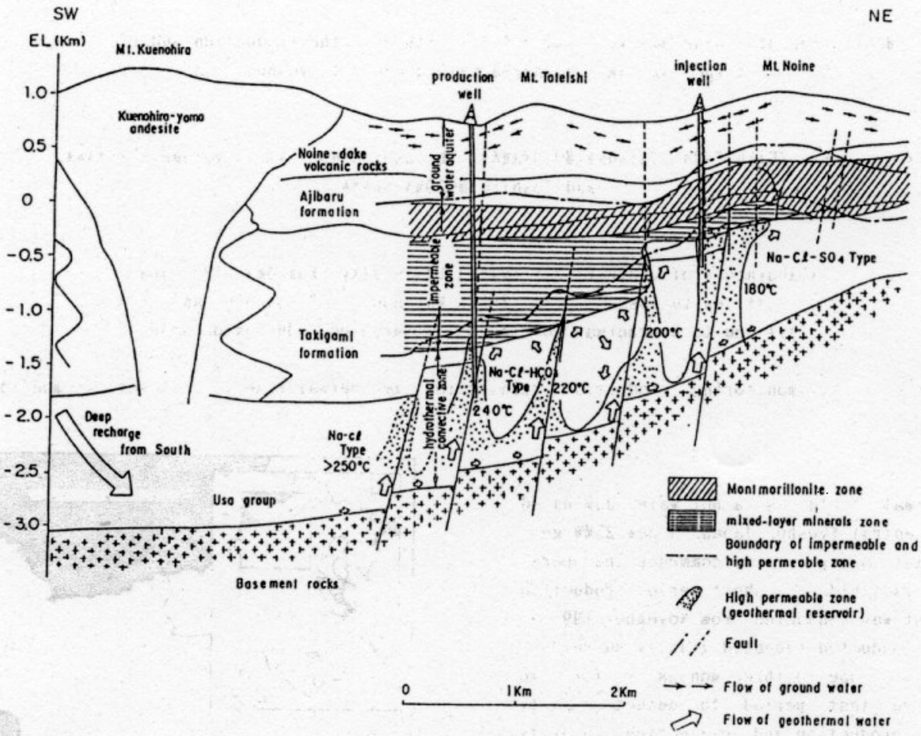

Fig. 2 Reservoir model of the Takigami geothermal field (Hayashi et al., 1988)

Gravity measurements

A short period production and reinjection test was conducted from November 1991 to February 1992. We conducted precise repeated gravity surveys with SCINTREX CG-3 Gravimeter at specified intervals (one to three months) for two years including the test period to detect gravity changes caused by production and reinjection. The observation points are shown in Fig. 3 with production and reinjection wells.

Results and discussions

Standard observation and reduction techniques were employed through the gravity surveys in the field. The gravity differences between at the reference benchmark outside the field and at respective observation points in the fields are calculated. The correction for the effects of elevation changes were not calculated because the levelling survey did not show significant changes during the observation period.

The significance level of the gravity changes was less than 20 microgal through the gravity surveys.

Gravity changes of up to 150 microgal have been observed during two years. Some of examples are shown in Fig. 4. They show the similar trend of gravity changes. By applying the Gauss's theory to the map of gravity changes from May 1991 (initial state) to February 1992 (show lowest gravity values), we obtained the mass deficiency of 15.7 Mt. During the production and re-injection test, the quantities of produced and reinjected water are about 3Mt and 2Mt, respectively. Then it is impossible to interpret the observed gravity changes by the test. The changes of two shallow

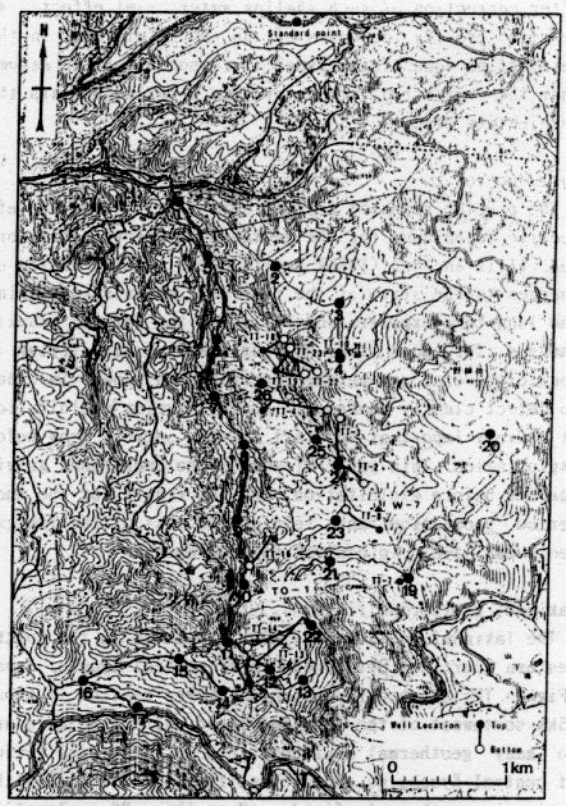

Fig. 3 Distribution of production and reinjection wells (●: well head, ○: well bottom) and observation points (No. 1 to 26) for the repeated gravity surveys at the Takigami geothermal field.

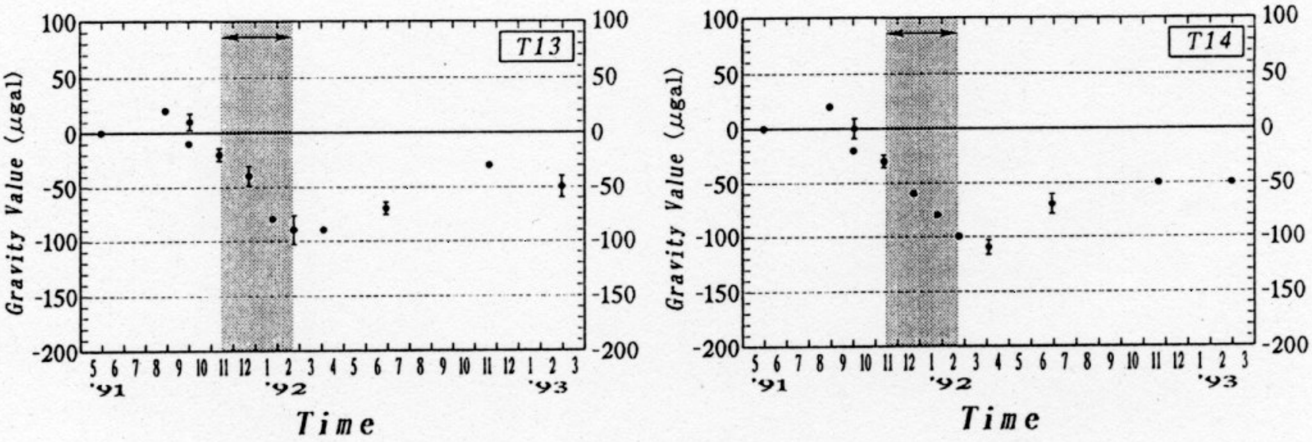

Fig. 4 Examples of gravity changes with time. The dotted parts show the period of the production and reinjection test.

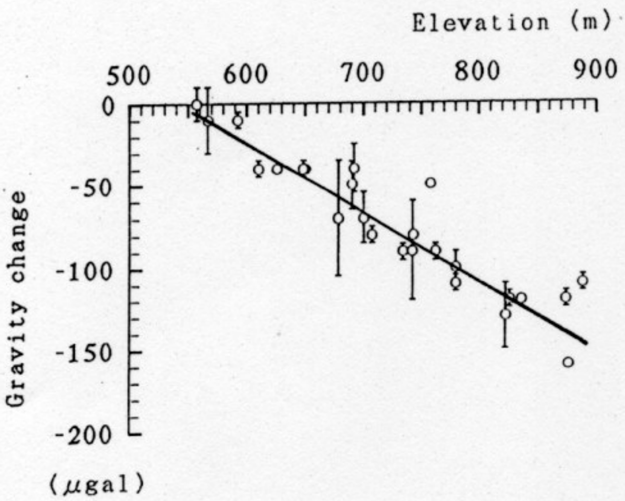

Fig. 5 Relation between gravity changes from May 1991 to February 1992 and elevations at the respective observation points.

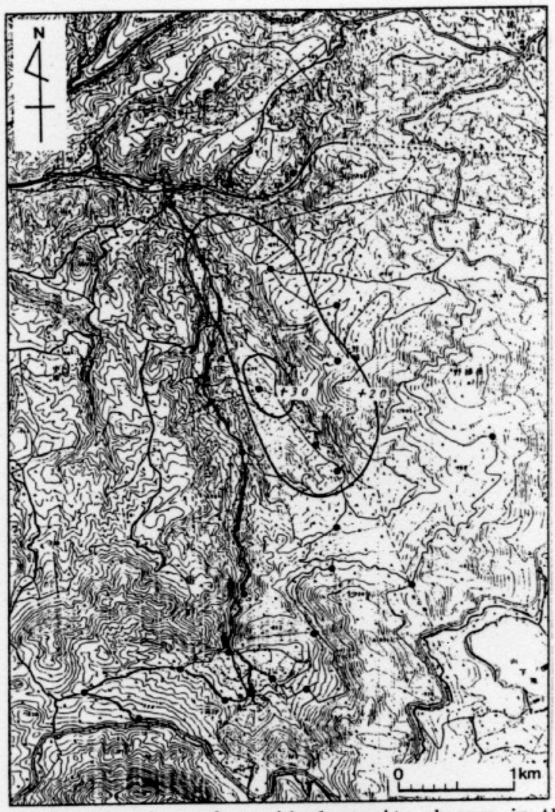

Fig. 6 Distribution of residual gravity changes in the end of the production and reinjection test. Positive anomalies up to 30 microgal are observed in the reinjection zone.

water levels were compared with the gravity changes. As a result, it was clarified that the trend in water level change was similar to that in gravity changes. Although it is not enough to interpret quantitatively the gravity changes by the effect of shallow water level, it is probable that the gravity change is originated in changes of shallow water level. In Fig 5, we show the relation between gravity changes and elevations of the respective observation points. We can see a good negative correlation between them. This result also show that gravity changes in this field may be originated in change of shallow water level, because it is reasonable to consider that the water levels at higer elevations change much more than those at lower elevations. As mentioned above, most of such large gravity changes observed in the field are considered to be due to seasonal variations of shallow water level.

Then we corrected the effects of changes in shallow water level on gravity changes, by using the gravity data before and after the test, in order to detect gravity changes during the test. As a result, we detected small gravity increases up to 30 microgal in the reinjection zone at the end of the test as shown in Fig. 6. By applying the Gauss's theory to the map (Fig. 6), we obtained an excess mass of 3Mt which is comparable to the reinjected water mass. Therefore, the residual gravity increases of up to 30 microgal are reasonable if we assume that the reinjected water stays for a while beneath the reinjection zone. The residual gravity increases were also detected in and eastward of the production zone just after the test finished, although the pattern of gravity changes is not so clear as the case in the reinjection zone. The gravity decreases have not become apparent by the end of March, 1992, that is, one month and a half after the test finished.

Conclusions

The precise repeated gravity suveys were conducted during the short period production and reinjection test at the Takigami gothermal field, central Kyushu, Japan. Gravity changes up to 150 microgal have been observed during two years. However, most of such large changes in gravity are considered to be due to seasonal changes in shallow water level. After correction of such shallow water effects, we detected gravity increases up to 30 microgal in the reinjected zone. This gravity changes are reasonable if we assume that the reinjected water stays for a while beneath the reinjected zone.

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