# EFFECTS OF DEVELOPMENT ON GEOTHERMAL SYSTEMS DEDUCED FROM GRAVITY AND THERMAL MEASUREMENTS:JAPANESE CASE STUDIES

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## ABSTRACT

Repeated gravity measurements have been conducted at four geothermal fields (Hatchobaru, Takigami, Yamakawa and Oguni) and one erupting volcano (Kuju volcano) in Kyushu in order to monitor the underground geothermal fluid flow system. Characteristic common features of gravity changes were detected both in geothermal fields and in erupting volcano. Gravity decreased rapidly just after the commencement of production of geothermal fluid or phreatic eruption and then decreased gradually. Such a pattern of gravity change shows that the underground fluid flow is reaching to a new equilibrium state. Repeated thermal measurements were started recently in geothermal fields, although they have been conducted at Kuju volcano after the October 1995 eruption. Simultaneous measurements of thermal activity and gravity give more effective information about the changes in the geothermal system.

## INTRODUCTION

In order to understand the effects of development on geothermal systems, we have been conducting gravity and thermal measurements in geothermal fields in Kyushu such as Hatchobaru, Takigami, Oguni and Yamakawa. Recently, we are also conducting very frequent gravity and thermal measurements at Kuju volcano in central Kyushu which began to erupt in October, 1995, in order to monitor the volcanic activity. Its eruptive activity is essentially phreatic at present. We are also conducting repeated gravity surveys in non-geothermal fields to monitor ground water flow. It is very useful to compare the observational results in geothermal fields, volcanoes and non-geothermal fields in order to clarify the changes in underground water flow systems in geothermal fields.

GRAVITY AND THERMAL MEASUREMENTS IN GEOTHERMAL FIELDS OF KYUSHU

There are so many geothermal fields in Kyushu as shown in Fig. 1. Now, we are conducting repeated thermal and gravity measurements in Hatchobaru, Takigami, Oguni and Yamakawa geothermal fields. At present we are concentrating on gravity measurements to monitor underground fluid flow. Thermal measurements with a new infrared apparatus were started recently. In some geothermal fields, there are thermal data such as shallow ground temperatures and heat discharge rates obtained before developments.

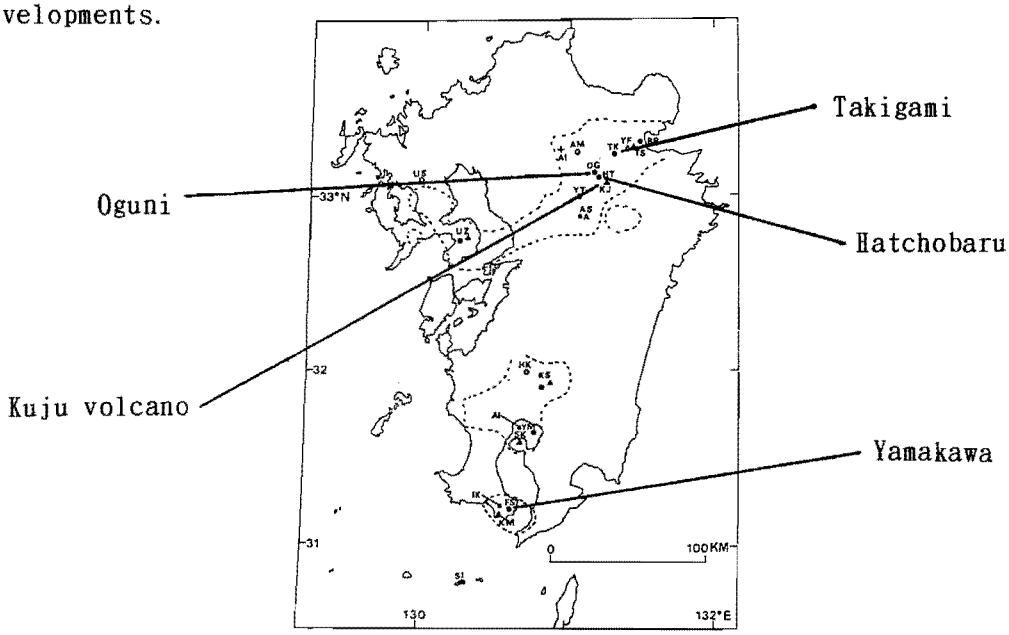


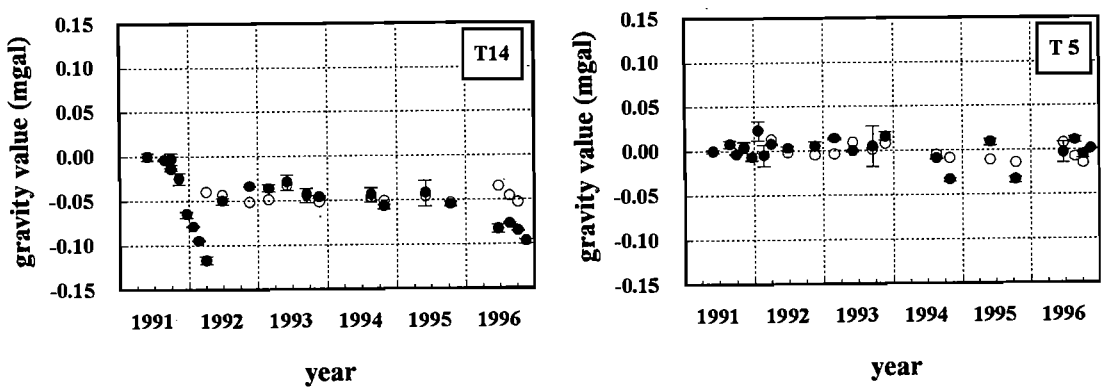

Fig. 1 Geothermal fields in Kyushu.

Present status of development in four geothermal fields are shown in Table 1 (JGEA, 1996). Hatchobaru, Takigami and Yamakawa were completed and Oguni will be completed in the near future. We are repeating gravity surveys in an interval of one to three months depending on their circumstances.

Table 1 Geothermal Power Plants in Kyushu(Study area).

| Name of Power Plant | Rated Output | Status |
|---|---|---|
| Hatchobaru I | 55MW | completed in June 1977 |
| II | 55MW | completed in June 1990 |
| Takigami | 25MW | completed in Nov. 1996 |
| Yamakawa | 30MW | completed in March 1995 |
| Oguni | 20MW | will be completed in 2000 |

One of the most important findings is the effect of shallow groundwater to gravity changes in most geothermal fields , which means that it is necessary to estimate the effect of shallow ground water changes in order to detect changes in deep geothermal fluid flow by the repeated gravity measurements. Shallow groundwater level has a contact correlaton with rainfall. Then, by using the railfall data of several months before the measurement, we can estimate the effect of shallow groundwater on gravity. Therefore, we can know the change in gravity originated in rainfall before the measurement. As an example, gravity changes in the Takimami field are shown in Fig.2, which show the changes outside and inside the production zone. The observed gravity changes outside the production zone are very similar to predicted gravity changes. On the other hand, the observed gravity changes in the production zone differ from the predicted changes after the commencement of thermal water production(middle of 1996). The observed gravity values are much lower than the predicted ones. Such rapid gravity decrease in the production zone is considered to be originated in production of geothermal fluids. However, the decreasing rate of gravity is becoming smaller and smaller after the commencement of fluid production. This means that underground water flow is reaching to a new equilibrium state, that is, a new geothermal system is forming.




-Inside the production zone- -Outside the production zone-

Fig. 2 Gravity changes inside and outside the production zone of Takigami field. ●:observed gravity ○:predicted gravity.

In Hatchobaru field, we also detected gravity changes in reinjection and production zones. Fig. 3 shows examples of gravity changes in the reinjection and production zones. In the reinjection zone, the gravity increased rapidly just after the commencement of reinjection (middle of 1990) and then decreased gradually. After the commencement of production, the gravity began to decrease rapidly in the production zone. In this period, about 110MW of electricity, which is the installed capacity, was produced. About three years later, gravity changes came to change little. In this period, about 90 MW of electricity was produced. This means also that a new equilibrium state of underground water flow is forming. And it may be reasonable to consider that the most suitable production rate from the present production zone is about 90MW.

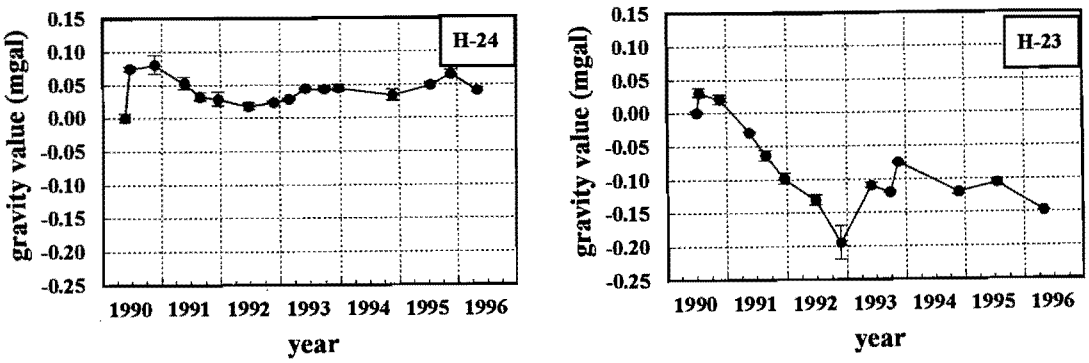



Fig. 3 Gravity changes in the reinjection(Left) and production(Right) zones of Hatchobaru field.

In Oguni field, we are repeating gravity measurements in an interval of about four months before development. We detected a relation between the gravity changes and shallow ground water flow. Such data obtained before the development will be useful after the development.

Recently, we started repeated gravity measurements in Yamakawa field. From only three times of measurements in an interval of about three months, we detected gravity increases and decreases in the reinjection zone. This field is near the coast. This case may show a different type of gravity change by development. We have a plan to continue gravity measurements in an interval of three months in the future.

In Hatchobaru field, we have shown that geothermal activities near the Power Station did not change before and after the development of Hatchobaru I plant( Yuhara et al., 1988 ). Repeated thermal measurements

with a new infrared apparatus were started recently. Geothermal manifestations are surface reflection of the undeground geothermal fluid flow system. Therefore, simultaneous measurements of thermal activity and gravity will give more effective information about the geothermal system.

## GRAVITY AND THERMAL MEASUREMENTS IN KUJU VOLCANO, CENTRAL KYUSHU

Kuju volcano began to erupt in October, 1995(Ehara, 1995). The second ash eruptions occurred in December, 1995. After that, no eruptions occurred until now (January, 1997). However, active crater activities still continue.

We started repeated thermal and gravity measurements around new craters just after the first eruption. As a result, we detected remarkable changes in thermal feature and gravity(Figs. 4 and 5). Very high level of heat discharge rate over 2000MWt have continued during two months after the first eruption. In this period, gravity around new craters decreased rapidly. After that, the heat discharge rate from new craters decreased rapidly. Accompanying with the decrease in the heat discharge rate from new craters, the rate of gravity decrease became smaller. Estimation of underground mass balance (mainly by water) based on the Gauss's theorem shows that the ground water recharge from the region around new craters is increasing after the eruption and about three months after, the underground water flow is gradually reaching to the equilibrium state. At

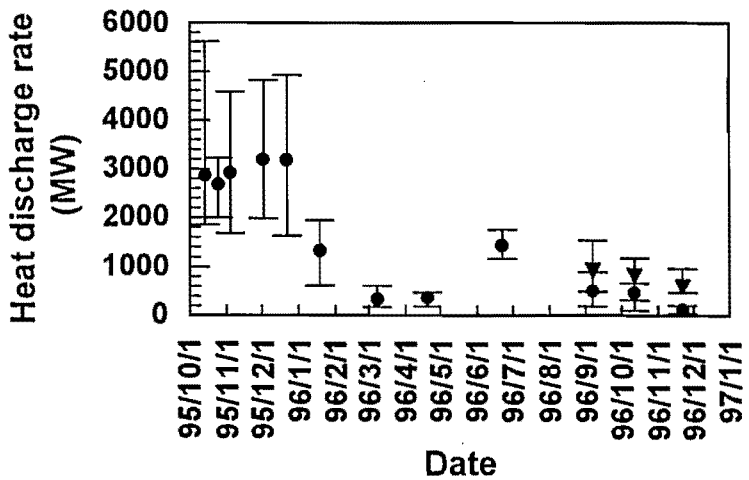



Fig. 4 Changes in heat discharge rates from new craters and existing fumarolic areas in Kuju volcano after the 1995 eruption. ●:from the new crater d(the most active new crater), ▲:from the all new craters and existing fumarolic areas.

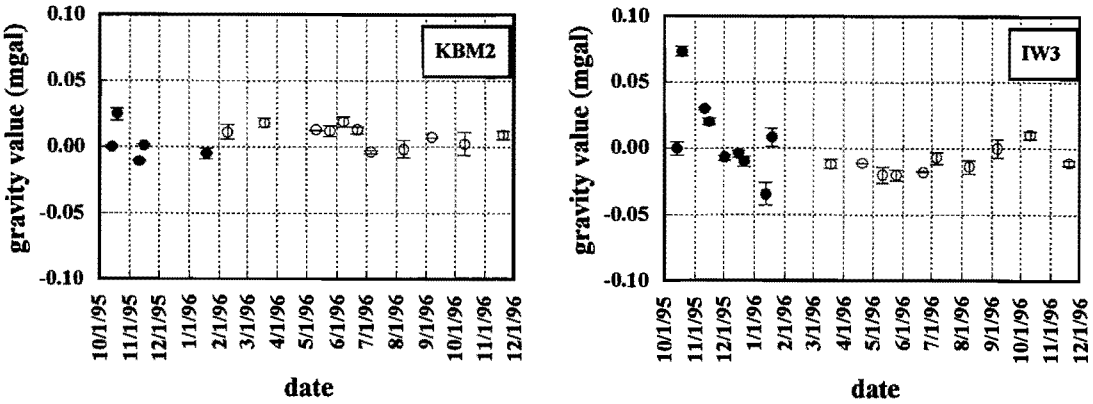



Fig. 5 Changes in gravity at two stations of Kuju volcano.
Left: distant from new craters, Right: near new craters.

present, most of scientists consider that the 1995 eruption of Kuju volcano is essentially phreatic, although some small magmatic intrusion may exist beneath the new crater zone. The 1995 eruptive activity is analogous to thermal fluid production in the geothermal field. The phreatic eruption may be compared to the thermal fluid production without reinjection. The frequently repeated thermal and gravity measurements in Kuju volcano after the eruption will give new insights to monitoring of the underground fluid flow in geothermal fields.

## CONCLUSION

Repeated thermal and gravity measurements in geothermal fields and erupting volcanoes are very promising methods to monitor the underground fluid flow. From the pattern of gravity changes, we can infer the formation of new equilibrium state of the underground fluid flow system. If we can obtain a new equilibrium state of underground flow after the development in a field, we can continue production of thermal fluids harmonizing with the environment. In this case, geothermal energy is sustainable energy. However, we may not obtain a new equilibrium state of underground fluid flow somewhere. In this case, we must cut down the production of thermal fluids to utilize geothermal energy for a long time.

REFERENCES

Ehara, S. (1995). 1995 Eruption of Kuju volcano, central Kyushu, Japan, Bull. Volcanol. Soc. Japan, Vol. 40, 425-427(in Japanese).

Japan Geothrmal Energy Association(1996). Annual Report on Geothermal Energy Development in Japan-1996-, 1-91(in Japanese).

Yuhara, K., Ehara, S., Kuboguchi, M. and Fujimitsu, Y. (1988). Proceedings of Int. Symp. on Geothermal Energy, 1988, Kumamoto and Beppu, 565-566.