PRECISE GRAVITY MONITORING WITH AN FG5 ABSOLUTE GRAVIMETER, AT THE YANAIZU-NISHIYAMA GEOTHERMAL FIELD

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SUMMARY – A Micro-g FG5 (S/N 217) absolute gravimeter was introduced and tested in 2002 to detect short-term gravity changes related to a suspension in production at the Yanaizu-Nishiyama geothermal field. The test confirmed that the FG5 absolute gravimeter is suitable for practical use in monitoring geothermal fields.

1. INTRODUCTION

Microgravity monitoring is recognized as a valuable tool for mapping the redistribution of subsurface mass that is associated with geothermal exploitation. Generally, microgravity monitoring involves the measurement of small changes in gravity over time, across a network of stations, with respect to a fixed base. Regional gravity variations can cause errors in the determination of the gravity "datum" against which any measured changes are referred. **A** combination of absolute and relative gravimetry provides a solution to this problem. It is useful to connect the array of observation stations with absolute gravity stations, to reduce **any** uncertainties caused by regional gravity variations.

An absolute gravimeter, the Micro-g FG5 (S/N 217), was introduced and tested in 2002 to detect short-term gravity changes related to a suspension-in production at the Yanaizu-Nishiyama geothermal field.

2. ABSOLUTE GRAVIMETERS

An absolute gravimeter observes the acceleration of gravity directly, by observing the free-fall of a reflective corner cube in a vacuum (Figure 1).

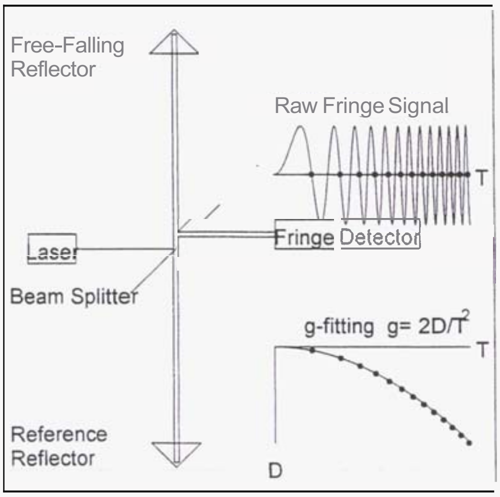

Figure 1 - FG5 free-fall gravimeter principle. Light is directed from a stabilized laser to a freely falling reflector and also to a reference reflector. The light is combined with the laser reference to produce optical interference fringes. The optical signal is directed to a photo-detector where the precise trajectory is sampled, resulting in multiple time and distance pairs. These data are then least squares fit to a parabolic trajectory, by a computer, to determine an absolute value for g. This method of measuring gravity is absolute because the determination is purely metrological and relies on standards of length and time (Micro-g. co., 2001).

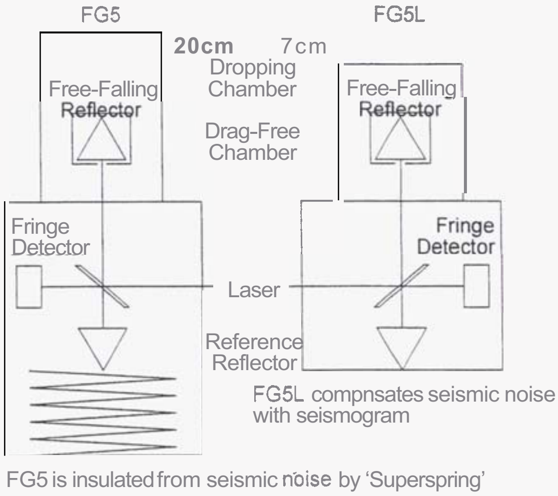

Figure 2 - Two absolute gravimeters: FG5 and FG5-L.

The FG5 absolute gravimeters have an estimated instrumental accuracy of 1-2 microGal (Sasagawa et al., 1995). A new miniaturized absolute gravimeter, the FG5L, has recently been released onto the market. It is much smaller and cheaper than the existing absolute gravimeters. It offers an attractive compromise between low price and precision in an instrument that is easy to use in the field, It was trialled (*SM* 3) in January 2001 and its suitability for geothermal fieldwork was investigated (Sugihara, 2001). Absolute gravimeters average many measurements (drops) to increase their precision. Therefore, we were interested to know how long it would take the FG5L to obtain sufficient measurements in order to produce an average result, accurate enough to be used for monitoring at the geothermal field.

Generally, one-day measurements output a gravity value with an error of about 10 microGal. However, the fluctuations in the daily values exceeded the daily estimated error. Therefore it was concluded that the FG5L was not suitable for monitoring the geothermal field (Sugihara, 200 1). Many of the subcomponents of the FG5L are compatible with the FG5, to provide an upgrade path to the FG5 (Figure 2). Therefore, the FG5 (S/N 217) was introduced in January 2002.

3. PAST GRAVITY MEASUREMENTS

The Yanaizu-Nishiyama geothermal field is located in the western part of the Aizu district, northeast Japan. The production zone of the field is formed by the Chinoikezawa fault system and the Sarukurazawa fault system. The injection zone is in the Oizawa fault system (Figure 3). These three fault systems have NW-SE strikes and a steep dip to the NE (Nitta et al., 1995). The production wells produce a mixture of steam and water. The steam is separated and supplied to a 65 MWe power station. Commercial operation of power station began in May, 1995.

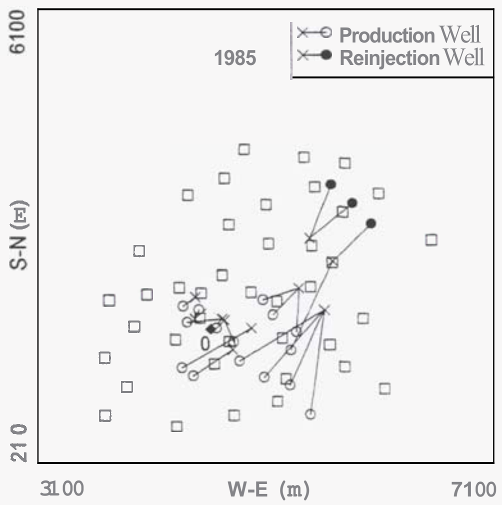

Figure 3 - Distribution of the gravity stations.

The gravity monitoring survey of the field began in September 1994. The survey area was originally about 15 km^2 and covered the production zone and the re-injection zone with 83 gravity stations. At these stations, gravity measurements and levelling were carried out every year until 1997. In 1997 the gravity network was expanded by the New Energy and Industrial Technology Development Organization (NEDO) to 138 stations, covering a 30 km' area. The intention was to develop optimal gravity survey methods and noise reduction techniques for geothermal reservoir monitoring (Takemura et al., 2000). Seasonal gravity measurements were carried out at these stations. In **1988** short-term gravity changes were detected; these were related to a suspension in production (NEDO, 1999). Additional gravity measurements at some of the stations were carried out between the seasonal gravity surveys, to appraise the short-term effects of suspension of production in 2000. From the results of eight seasonal and annual gravity surveys, the regional pattern of the gravity changes related to the suspension of production **in** 1998 was classified. No significant gravity changes were found when production was suspended this year, but a pattern of changes similar to those occurring in **1998** was found after re-starting production (NEDO, 200 1).

4. NEW GRAVITY MEASUREMENTS

In an effort to better understand the transient fluid **flow** associated with the changes related to the suspension in production, both the absolute and relative gravity measurements in and around the Yanaizu-Nishiyama geothermal field, since March 2002, were repeated.

All of the production wells were shut-in from March to April in 2002 to allow maintenance work on the Yanaizu-Nishiyama geothermal power plant. In March, the first survey was carried out before production was suspended.

Before making the measurements, an absolute gravity station (#0 in Figure 3) was constructed, consisting of a custom concrete pier with a thickness of 1 m, located **300** m south of the Yanaizu-Nishiyama power plant. A prefabricated shelter with an air conditioner was set on the pier. At the absolute gravity stations, the free-air gradient (**FAG**) was also measured, because the value provided by the absolute gravimeter is not referenced to the ground level. FAG measurements were taken with the Scintrex CG-3M gravimeter (S/N 385).

4.1. Relative Gravity Measurements

A Scintrex CG-3M gravimeter (S/N **385) was used** for the 2002 surveys, and the measurement procedure was similar to that described **by Ohta** *et al.* (2001). The CG-3M gravimeter was operated in cycling mode at night by the FG5 absolute gravimeter. Each day's measurements were tied to the local base (#1995). The gravity differences of the stations to the local base were determined (Figure 4). The gravity difference of the absolute station to the local base was also determined. Data reduction techniques similar to those described **by** Ohta *et al.* (2001) have yielded preliminary gravity values with an estimated uncertainty better than +- 10 microGal.

4.2. Absolute Gravity Measurements

A Windows-based software was designed to perform the acquisition and reprocessing of data obtained with the FG5. The default settings are to start a series of measurements ("project") immediately and to collect 48 sets of 100 drops per set every 30 minutes (at a 10 second drop interval).

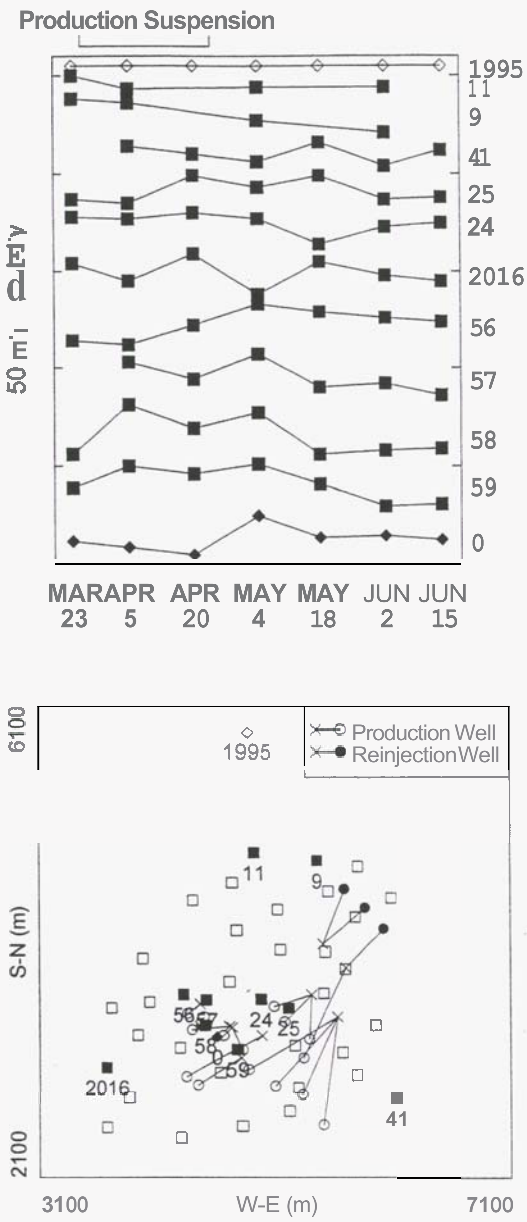

Figure 4 - Gravity changes versus time (upper) and location of the stations (lower).

Figure 5 shows plots of measured gravity values (set values) during the 4th survey between 0932 May 1 to 2151 May 5, 2002 (UT). A drilling pad was being built near the station in the daytime, therefore absolute gravity measurements were made only during the night. The "set value" is the weighted mean of 100-drop values, excluding abnormal values beyond 3-sigma of every "set". After a pause of 13 minutes, the next "set" starts.

Figure 5 shows the set values after corrections for the solid earth tide, the pole tide, the ocean tide and the barometric effect. At each survey an absolute gravity value was inferred from averaging all the set values (Figure 5).

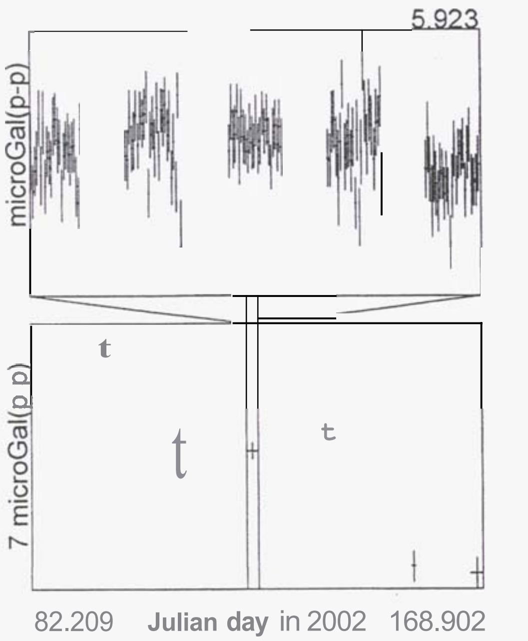

Figure 5 - Plot of absolute gravity measurements: Set values of the 4th survey (upper) and gravity changes during the seven surveys (lower).

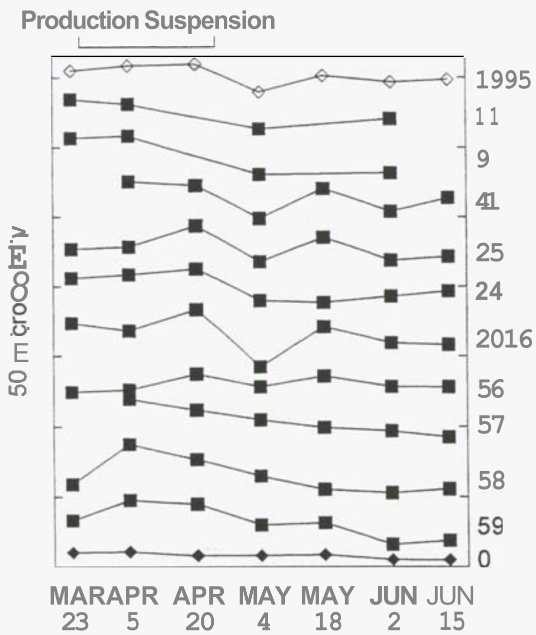

Figure 6 - Temporal gravity differences to the absolute reference.

5. CONCLUSIONS

By combining the absolute measurements (Figure 5) and the relative measurements (Figure 4), the temporal gravity differences to the absolute reference (Figure 6) can be determined.

Definite conclusions as to whether or not the expected short-term gravity changes have been detected from this set of data cannot be drawn yet because the 2002 surveys are still underway.

However, the successful performance of the FG5 absolute gravimeter has been proved.

6, ACKNOWLEDGMENTS

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