Densely-arranged Gravity Survey in Fukuoka City, Japan
-Relation between the Subsurface Structure and the Low Temperature Hydrothermal Systems of Fukuoka-

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DETAILED GRAVITY SURVEY IN FUKUOKA CITY, JAPAN: RELATION BETWEEN THE SUBSURFACE STRUCTURE AND THE LOW TEMPERATURE HYDROTHERMAL ACTIVITY

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SUMMARY – We have been conducting a gravity survey with a dense array of measurement points since 1996 to elucidate the detailed subsurface structure of Fukuoka City in Fukuoka Prefecture, Japan. The primary focus of the survey is to evaluate the location, strike and length of the Kego fault, which is one of the active faults in Fukuoka Prefecture. Fukuoka City was hit by an earthquake measuring 7.0 on the Richter scale on 20 March, 2005. The hypocenters of the main shock and the aftershocks exist in the offshore area of Fukuoka City and align with an extension of Kego fault. We measured gravity at 1259 points as of the end of April, 2006 using Scintrex CG-3 and CG-3M gravimeters. As a result, we detected some high gradient zones of Bouguer anomaly, one of which is caused by Kego fault. On the other hand, there are some low-to-moderate temperature hot springs in Fukuoka City. The temperatures of some hot springs in Yokote-Ijiri area, southern part of Fukuoka City, are relatively high (40 - 50°C) as compared with other hot springs in the city. As a result of the gravity survey, we conclude that one of the basement structures where the hot springs are concentrated is part of the Kego fault. We suspect there is a permeable fracture zone created by fault slips that acts as a path for hot water rising from the granite body to the surface in the centre of the hot springs area.

1. INTRODUCTION

Fukuoka City is the capitol of Fukuoka Prefecture, northern part of Kyushu Island, and the most populated city (1.4 million in 2006) in Kyushu (Figure 1). A large earthquake of M_{JMA} 7.0 hit the western off-shore submarine region of Fukuoka Prefecture on 20 March, 2005. After this main shock, many aftershocks, including the largest aftershock of M_{JMA} 5.8 on 20 April, 2005, have occurred in a zone, which extends in a direction of NW-SE for about 30 km (Figure 2) and aligns with an extension of Kego fault that is one of the active faults in Fukuoka Prefecture (Figure 3). The epicentre of the main shock, about 25 km northwest of Fukuoka City, is located in the northwestern part of the aftershock zone (Figure 2). The earthquake activity is low but still continues as of the end of September, 2006.

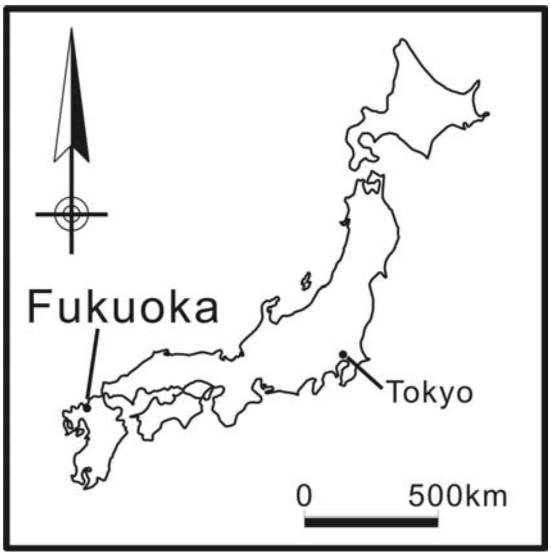

Figure 1 - Location of Fukuoka City.

We have been conducting a gravity survey with a dense array of stations since 1996, before the Fukuoka earthquakes, in order to elucidate in detail the subsurface structure of Fukuoka City. The primary focus of the survey is to evaluate the location, strike and length of Kego fault.

Low-to-moderate temperature hot springs occur in Fukuoka City. The temperatures of some hot springs in Yokote-Ijiri area, southern part of Fukuoka City (Figure 3), are relatively high (40 -

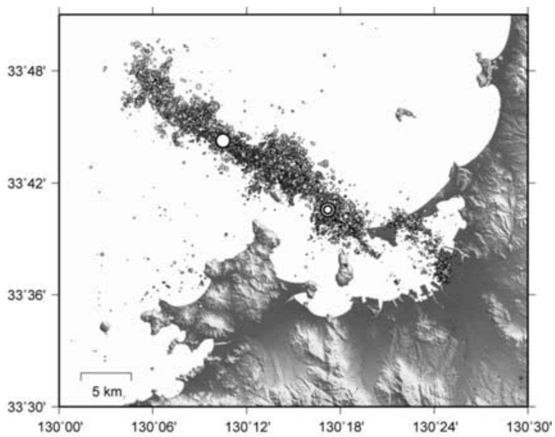

Figure 2 - Epicentres of the Fukuoka Earthquakes from 20 March 2005 to 27 September, 2006. An open circle and a double circle indicate the epicentres of the main shock (M_{JMA} 7.0 on 20 March, 2005) and the largest aftershock (M_{JMA} 5.8 on 20 April, 2005), respectively.

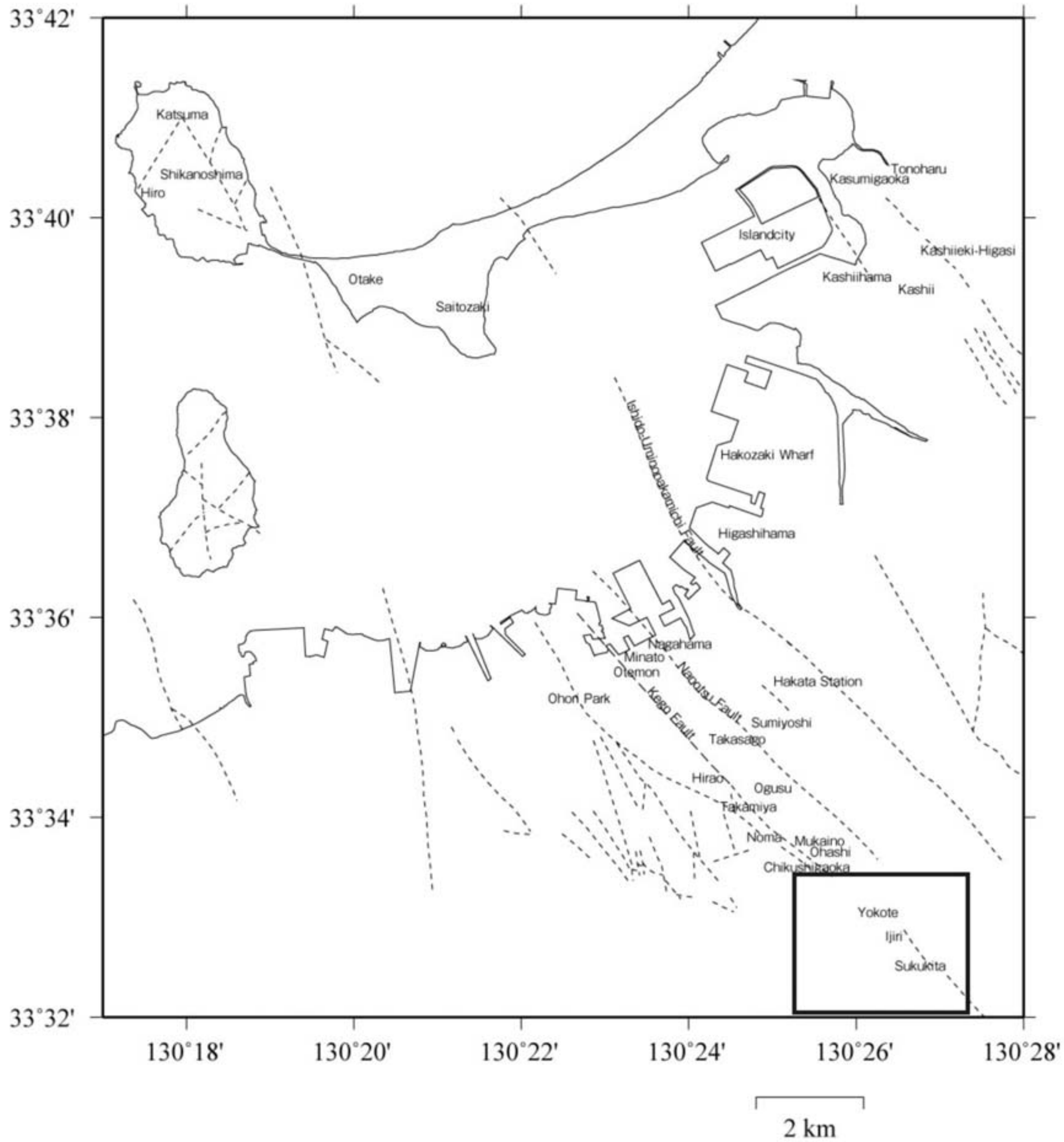

Figure 3 - Location of the faults (dashed lines; extracted from Karakida et al., 1994) with some place-names in the Fukuoka City area. A rectangle shows the location of Yokote-Ijiri area (the range of Figure 10).

50 °C) as compared with any other hot springs in the city although the nature of the heat source remains poorly defined (Karakida et al., 1994). They may be associated a subsurface structure, but insufficient data exist in the area. The secondary focus of the survey is to determine the subsurface structure of the Yokote-Ijiri area.

In this study, we show the result of the gravity survey at Fukuoka City and consider the subsurface structure of the hot springs in Yokote-Ijiri area.

2. GENERAL REMARKS ON GEOLOGY OF FUKUOKA CITY

In Fukuoka City and surroundings, Paleozoic Sangun metamorphic rocks, Cretaceous plutonic rocks, and Paleogene and Quaternary sedimentary rocks with some scattered Neogene sedimentary and basaltic rocks occur (Karakida et al., 1994) (Figure 4). The basement rock in the survey area is thought as Sawara Granite. Most of the Paleogene layers in the Fukuoka City area are coal-bearing, and there used to be many coal mines in this area (Karakida et al., 1994). There are many faults, which have the strike of mainly NW-SE (Figure 3). Kego fault is a left-lateral strike-slip fault with a strike of NNW-SSE. Trenching investigations on the Kego fault showed that the latest event occurred between 16,000 years B.P. and 10,000 years B.P. with an interval of about 15,500 years (Shimoyama et al., 2005). The existence of some other faults such as Nanotsu fault and Ishido-Uminonakamichi fault, which run parallel to the Kego fault, are inferred from geological data (Karakida et al., 1994; Figure 3).

3. HOT SPRINGS IN YOKOTE-IJIRI AREA

Low-to-moderate temperature hot springs occur in the Yokote-Ijiri area, a residential zone located in southern part of Fukuoka City (Figure 3). The history of these hot springs is relatively young. Ground water exploration using electrical resistivity methods was conducted in 1958, and a low resistivity layer beneath a high resistivity layer was detected. The high resistivity layer was thought to be a gravel bed in the basin of the Naka River, which acts as a ground water aquifer, but the reason of the low resistivity was not clarified (Yamashita et al., 1965).

A few years later, the first hot spring of 49 °C was developed. Matsushita et al. (1971) refined the resistivity data and showed that the low resistivity layer (less than 50 Ωm) under the high resistivity layer (more than 500 Ωm) formed a band, about 1200 m wide (E-W direction), which trends N-S (Figure 5). They explained that the

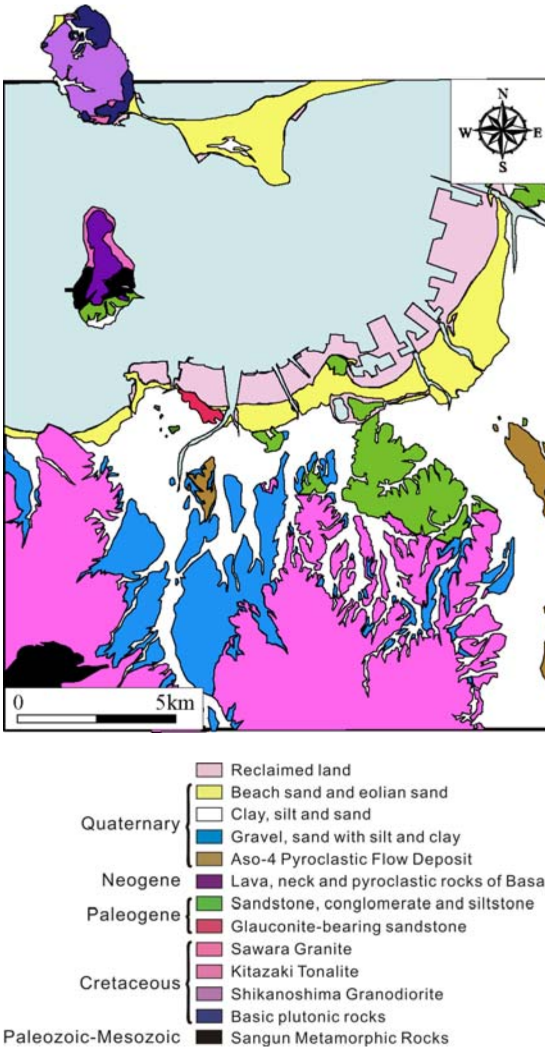

Figure 4 - Geological map of the Fukuoka City area (after Karakida et al., 1994).

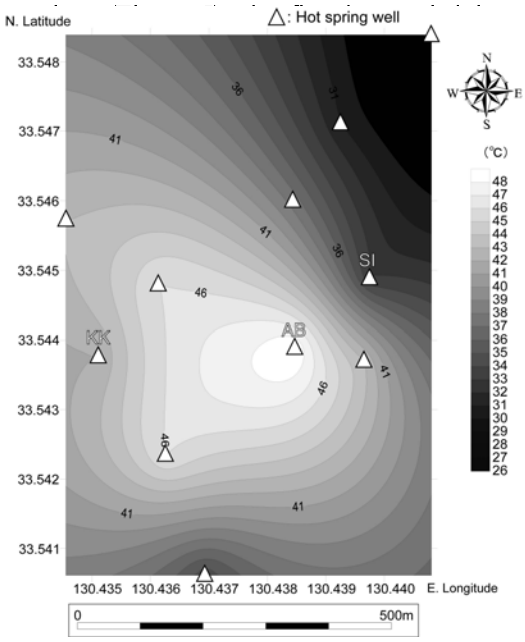

Figure 6 - Temperature distribution of the hot springs in Yokote-Ijiri area listed by Matsushita et al. (1971).

4. GRAVITY SURVEY

We measured gravity at 1259 stations as of the end of April, 2006 using Scintrex CG-3 and CG-3M gravimeters. The station interval was set as about 20 - 1000 m, but they were arranged more densely along the Kego fault (Figure 8). The measurements were processed with height correction, drift correction, tidal correction, free-air correction, Bouguer correction and terrain correction to obtain a Bouguer anomaly map. We used a computer program "GOTIC2" (Matsumoto et al., 2001) for the tidal correction and the method by Katsura et al. (1987) for the terrain correction. We determined the Bouguer density of 2.47 g/cm^3 for this area by using the F-H correlation that includes not only the measured values from this study, but also the reprocessed values found from a more extensive study of Fukuoka city published by Geological Survey of Japan (2000), using the optimization method proposed by Murata (1990).

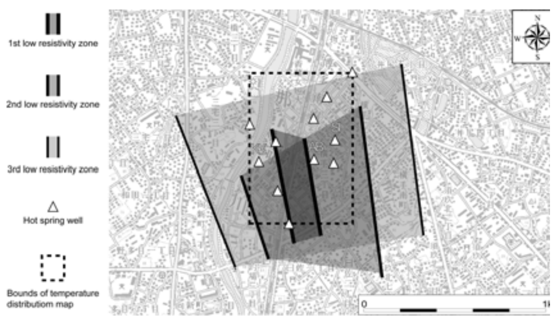

Figure 5 - Low resistivity bands in Yokote-Ijiri area detected by electrical resistivity method (Matsushita et al., 1971). A broken rectangle indicates the range of Figure 6.

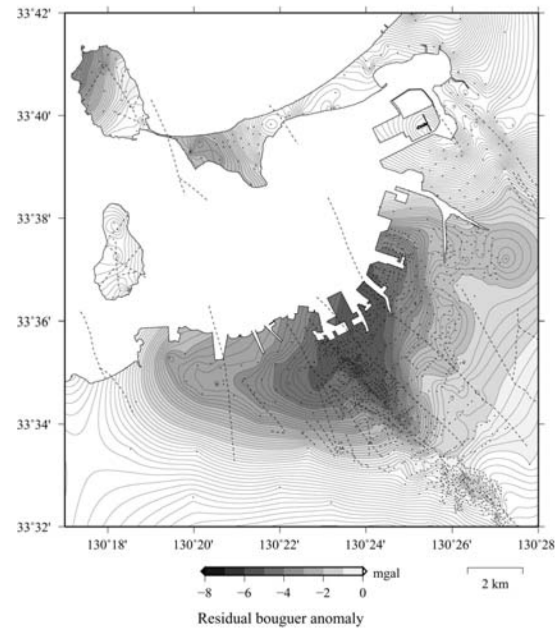

Figure 9 - Regidual Bouguer anomaly map of the Fukuoka City area (Bouguer density: 2.47 g/cm^3).

Figure 9 indicates the residual Bouguer anomaly map of the Fukuoka City area. In this map, the gravitational basement, which has a high density and affects the Bouguer anomaly, consists of Sangun metamorphic rocks and Cretaceous plutonic rocks (Sawara Granite, etc).

There is an inverted triangular low anomaly at the centre of Figure 9. This low anomaly corresponds to the Tenjin depression that was inferred from the bore data obtained from civil engineering and construction related investigations. The basement depression is covered by thick Quaternary sediments (Karakida et al., 1994). The inverted triangular low anomaly forms a sharp edge on the southwestern side, where the gravity difference of up to about 1.8 mgal is observed. The sharp edge extends from Otemon to Mukaino (see Figure 3) along the inferred position of Kego fault; the edge is especially clear between Otemon and Noma. There is another low anomaly, which shows the gravity difference up to 1.2 mgal, in Yokote-Ijiri area with weak continuity between the two low anomalies from Mukaino to Yokote.

The eastern side of the inverted triangular low anomaly in Figure 9 also forms a high gradient zone that extends in a N-S direction. However, the strikes of Nanotsu fault and Ishido-Uminonakamichi fault indicated by Karakida et al. (1994) are discordant with the direction of this high gradient zone.

5. DISCUSSION

In order to reveal the minute subsurface structure of Yokote-Ijiri area, we calculated the distribution

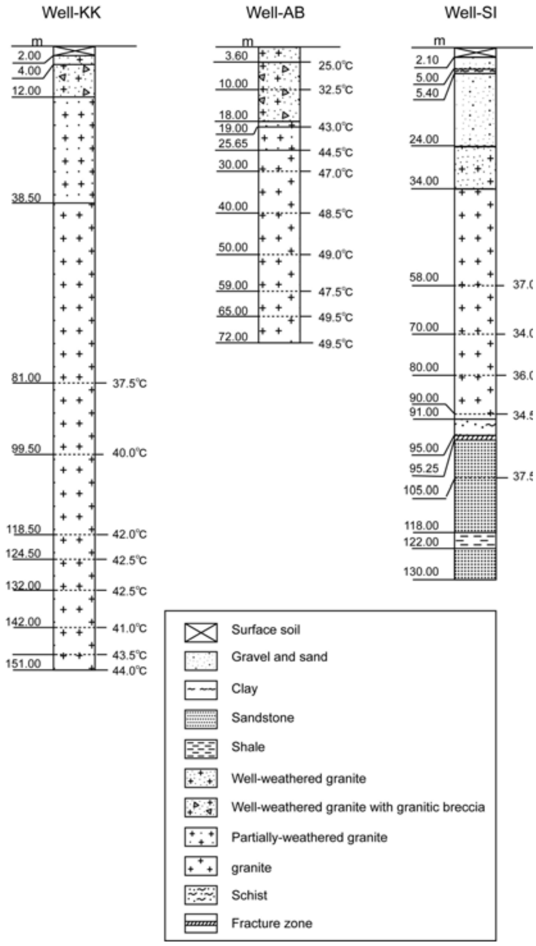

Figure 7 - Columnar sections of three wells in Yokote-Ijiri area (Matsushita et al., 1971).

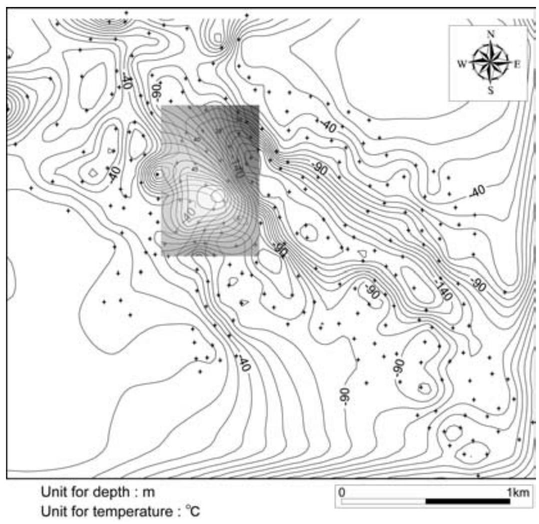

Figure 10 - Basement depth distribution in Yokote-Ijiri area analysed by using the method of Cordell and Henderson (1968) and the hot spring temperature distribution (contour lines in a small rectangle) overlapped on the basement depth distribution.

of the depth to the top of the gravitational basement by using the gravity data of this study.

As mentioned previously, we think that heavier Sawara granite forms the gravity basement, and lighter Paleogene and Quaternary sediments overlie the basement. Therefore, we conducted the two-dimensional analysis on a vertical section through the hot spring area with a two-layer model at first to decide the density difference between the basement and the sediments. In this analysis, the depth data of the boundary between the granite and the sediments indicated on the three columnar sections (Figure 7) were used as the control points, and as a result, the value of 0.5 g/cm^3 best explains the Bouguer anomaly in cross section. Next, we conducted a three-dimensional analysis by using the method of Cordell and Henderson (1968) to obtain the distribution of the depth to the top of the basement. The result of the analysis shows two continuous offsets in level of the basement (Figure 10). These offsets trend NW-SE and form a crank-shaped long ditch in the basement.

Figure 10 also indicates that the higher temperature wells are concentrated at the southwestern offset where the southwestern basement is shallower than the northeastern basement. The Kego fault here is a west-dipping reverse fault with a left-lateral component of slip (Shimoyama et al., 1999), and the sharp edge of the gravity offset along the Kego fault extends to the low anomaly in the Yokote-Ijiri area (Figure 9). Therefore, we interpret that the basement offset where the hot springs are concentrated is part of the Kego fault. A three-dimensional analysis is required to determine if this is a reverse fault or not.

According to Figures 6 and 7, Well-AB is located in the hottest part of the hot spring area, adjacent to the steep slope of the basement (Figure 10). We believe that a fracture zone created by movement along the Kego fault provides permeability near Well-AB, which acts as a path of hot water from the deep side of the granite body.

6. CONCLUSIONS

We have been conducting a gravity survey with a dense array of stations (1259 points as of the end of April, 2006) since 1996 in order to determine the detailed subsurface structure of Fukuoka City. As a result, we detected some high gradient zones of Bouguer anomaly, one of which is caused by Kego fault. We conclude that the hot springs in Yokote-Ijiri area coincide with a basement offset related to the Kego fault. It seems likely that the permeability controlling the movement of hot water is associated with fracturing created by the past activities of the fault.

7. ACKNOWLEDGMENTS

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