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Subsurface Structure in Oita Hot Spring Area Inferred from Gravity Data, Eastern Kyushu, Japan

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ABSTRACT

The sustainability of hot springs in Japan has not been thoroughly explored. Only a few geochemical and geophysical surveys were conducted to interpret the subsurface structure of hot spring sites because of financial restrictions set by hot spring owners. This results in the depletion or drawdown of the hot spring water. For sustainable utilization of hot springs, it is important to understand the hydrothermal systems governing the hot spring activity. The hot spring area in the Oita plain, eastern Kyushu, Japan, contains many non-volcanic low-temperature hot spring wells. Some of them were formed by fluid extracted in the subduction of the Philippine Sea Plate. Such hot springs are rare in Japan; therefore, their hydrothermal system is not well known. Details of the subsurface structure are necessary to understand the hydrothermal system and to construct a hydrothermal model. This study outlines the shallow underground fault system and basement structure of the Oita hot spring area. Gravity surveys were conducted to understand the relationship between the low-temperature hydrothermal systems and the geophysical data of the area. Using data of dense gravity surveys of the Oita plain, we obtained a detailed Bouguer anomaly map and modelled the subsurface structure. Inversion analysis was performed using three-dimensional gravity analysis. The location and dip of the faults were clearly identified and the subsurface model was obtained. Based on our results and those of previous studies, a hot springs conceptual model of the hydrothermal system of the Oita plain hot springs was constructed.

1. INTRODUCTION

It is very important to understand hydrothermal systems of hot springs for sustainable utilization of this resource. Long-term use of valuable hot springs without understanding their hydrothermal systems can cause serious problems such as water depletion or changes in temperature. However, investigations such as geochemical and geophysical surveys are not usually conducted in Japan because of their high cost.

It is said that there are many non-volcanic hot springs in the Oita plain in eastern Kyushu (Figs. 1 and 2), but conceptual model has not been understood clearly. Also, the gravity data in this area has not been studied densely. Therefore, in my study, we conducted a dense gravity survey. And combining this data with previous studies, we tried to discuss conceptual model in Oita hot spring area.

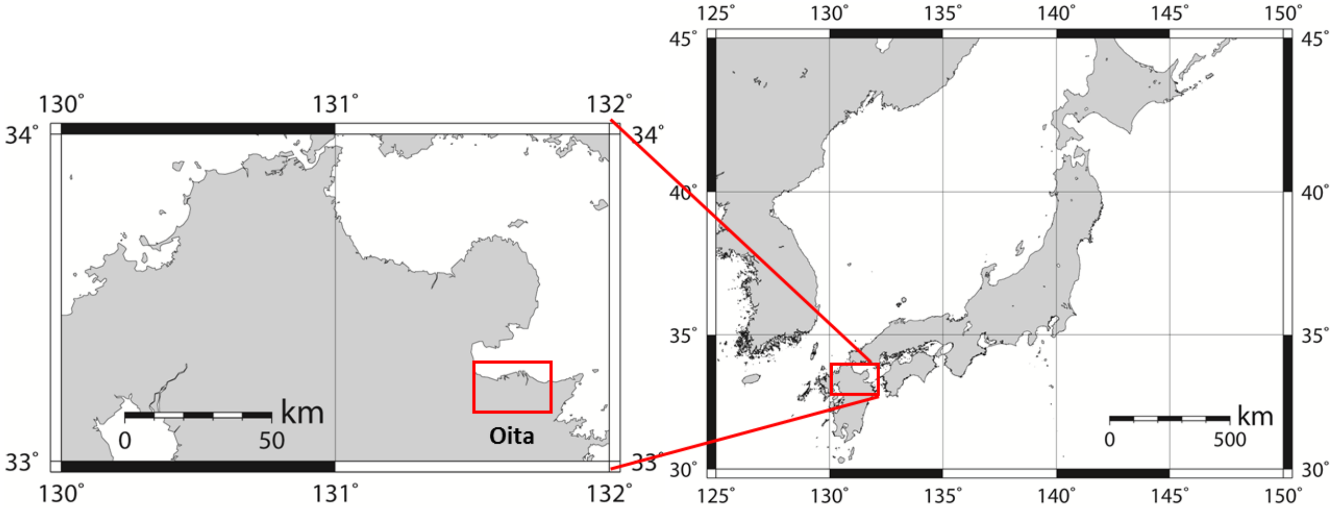

Figure 1: Location of the Oita hot spring area

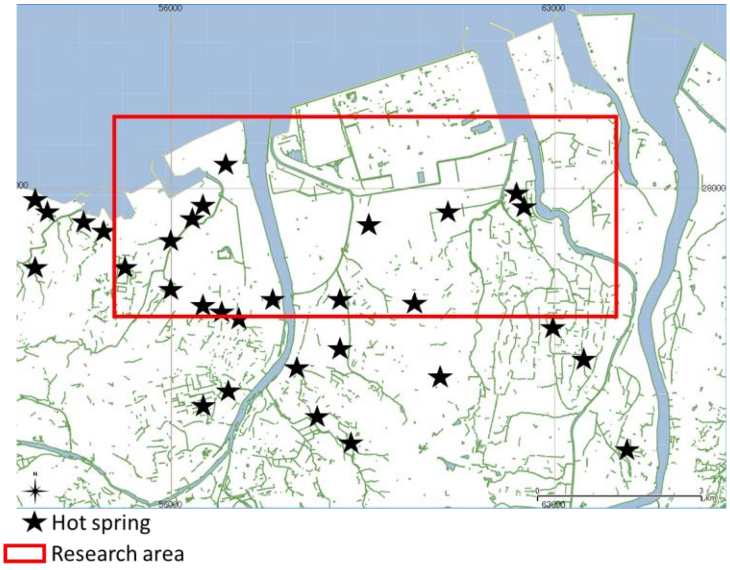

Figure 2: Location of hot springs in Oita city

2. GEOLOGY

The stratigraphy of the Oita plain, from oldest to youngest, consists of Holocene and Middle Pleistocene sedimentary rock which includes marine animals, volcanic rocks, and reclaimed land. There are Alluvium along the river and Sekinan Group and Oita Group in the north-east hill area. Red dashed line shows presumed fault reported by Chida et al. (2003) and it is assumed to be active fault. The geological map of Oita City is shown in Fig. 3.

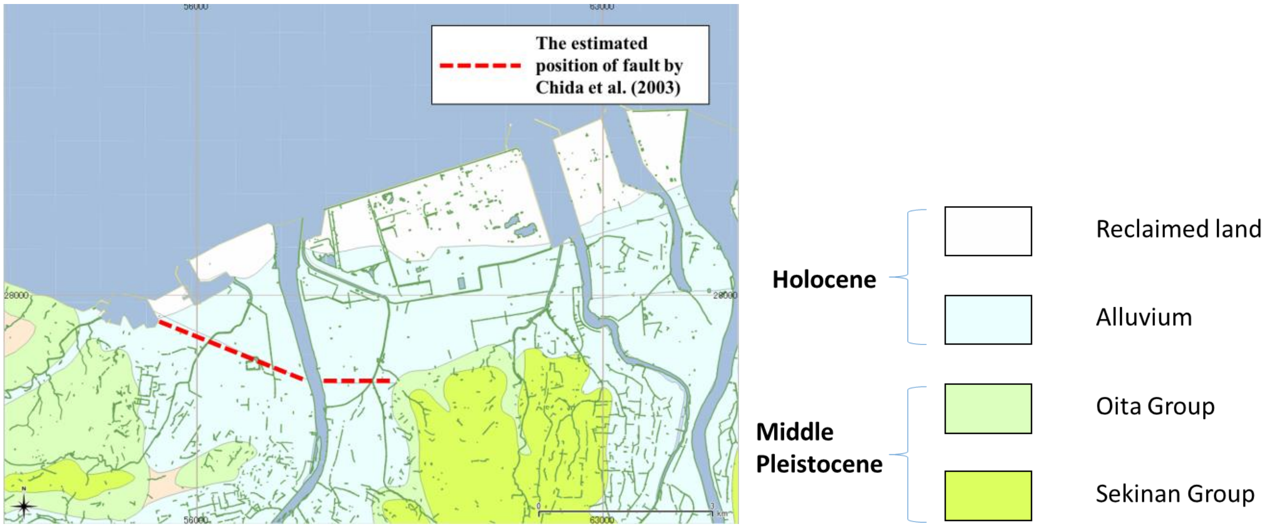

Figure 3: Geological map of the study area (Geological Survey of Japan, 1997)

3. GRAVITY SURVEY

We carried out a gravity survey in Oita City from 2014 to May 2016, and obtained measurements at 514 points using a Scintrex CG-3+ gravity meter (Fig. 4). The gravity base station was established near Oita station. The gravity survey was designed to identify subsurface structure such as faults and cracks under the hot springs area. The coordinates of the measurement points (latitude, longitude and elevation) were determined during the survey using GPS and the network real time kinematic (n-RTK) method (Fig. 5). Using this measurement system takes a few minutes to complete each measurement. The gravity measurement points (Fig. 6) are located densely.

Figure 4: Scintrex CG-3+ gravimeter

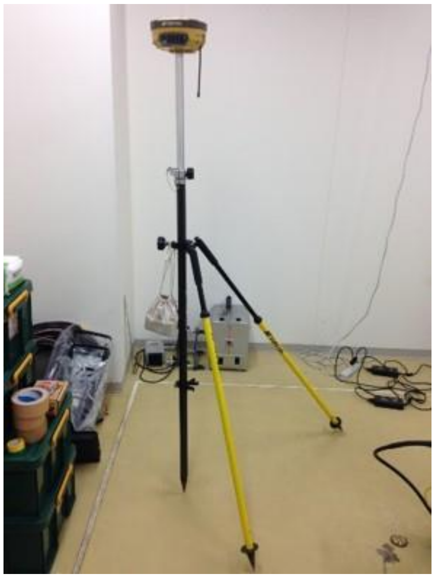

Figure 5: n-RTK measuring instrument

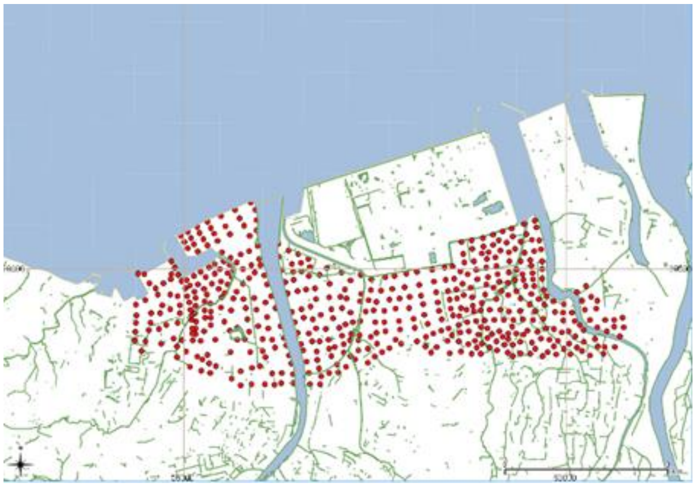

Figure 6: Gravity survey measurement points

4. BOUGUER ANOMALY

Gravity corrections were performed on the gravity data. We used a density of 2.45g/m^3, determined using the ABIC minimization method (Murata, 1990). To account for the effect of the topography, a terrain correction program using a 50-m mesh digital elevation map (Nishijima, 2009) was used. The gravity anomaly that remained after the corrections were applied is the Bouguer anomaly (Fig. 7). It shows that the Bouguer anomaly difference is about 20mgal and this anomaly decreases toward the northwest. This trend could be caused by the deep structure. To focus on the shallower structure, we removed this trend using the second order polynomial trend (Fig. 8), leaving the trend as shown in Fig. 9.

The basement of the study area falls north-westwards (Fig. 8). The steep slope of the residual Bouguer anomaly (Fig. 9) lies along the northwest–southeast direction (Fig. 9, upper left). The steep slope of Bouguer anomaly might reflect the underground structural gap like a fault; this fault and associated cracks can be interpreted as the path and the reservoir of the hot spring water in the Oita hot spring area. And this steep slope is corresponded to presumed fault (Chida et al., 2003).

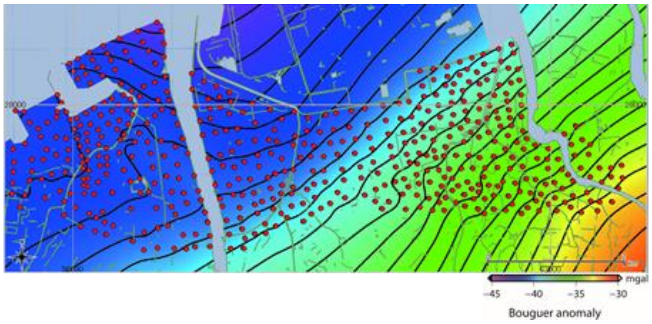

Figure 7: Bouguer anomaly with an assumed density of 2.45g/cm^3

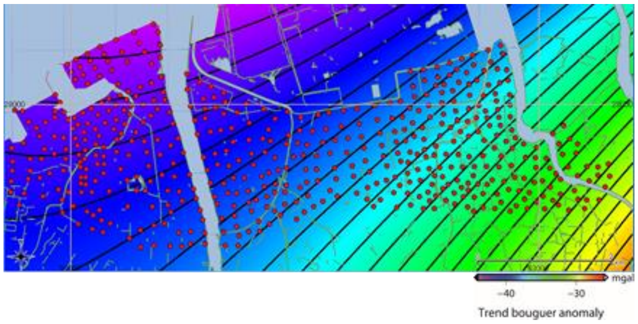

Figure 8: Regional trend of the Bouguer anomaly

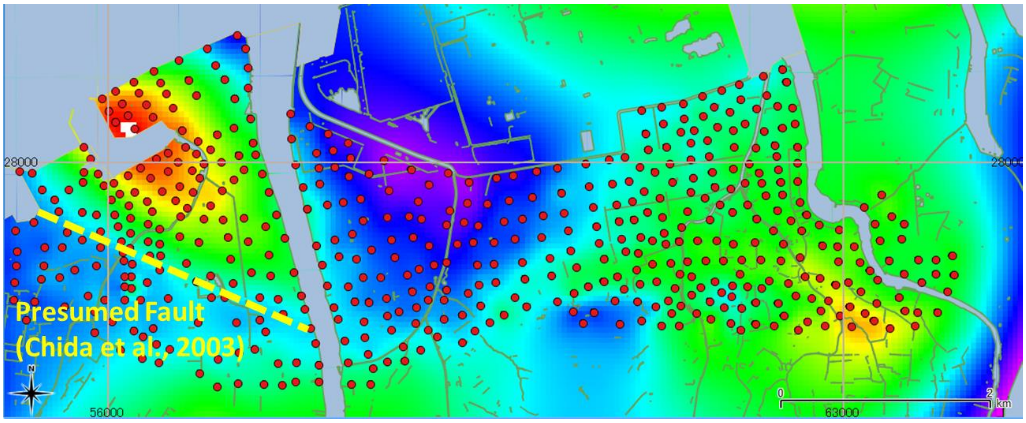

Figure 9: Residual Bouguer anomaly in the study site

5. THREE-DIMENSIONAL GRAVITY BASEMENT ANALYSIS

The three-dimensional gravity analysis was performed using Nishijima's method (2009) to calculate the depth of the gravity basement. In this method, it is necessary to estimate the density contrast between the surface and the basement layers. Based on the geological map and stratigraphic column (MEXT, 2016), we concluded that the survey area is part of the Sekinan group. The average density of the Sekinan group is 2.3 g/cm^3 and that of the Oita group and alluvium is 2.0–2.1 g/cm^3 (MEXT, 2016). Therefore, a density contrast of −0.2 g/cm^3 was assigned to all the prismatic cells of our three dimensional (3D) model. The result of the 3D gravity analysis is shown in Fig. 10.

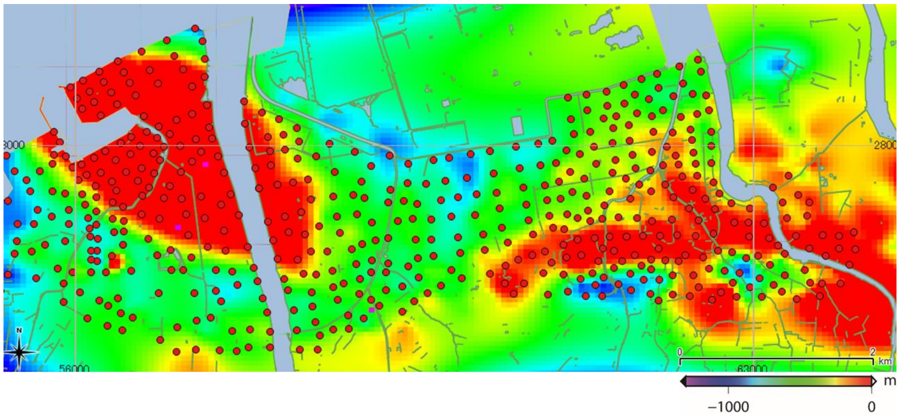

Figure 10: Depth to basement based on gravity model

The uplifts of the gravity basement in the northwest and southeast parts of the map (Fig. 10) correspond to the location of the high residual Bouguer anomaly zone in Fig. 9. The depression of the gravity basement reaches 1300 m. To understand the relationship between the basement data and the hot spring, we overlaid the hot spring distribution data onto Fig. 10.

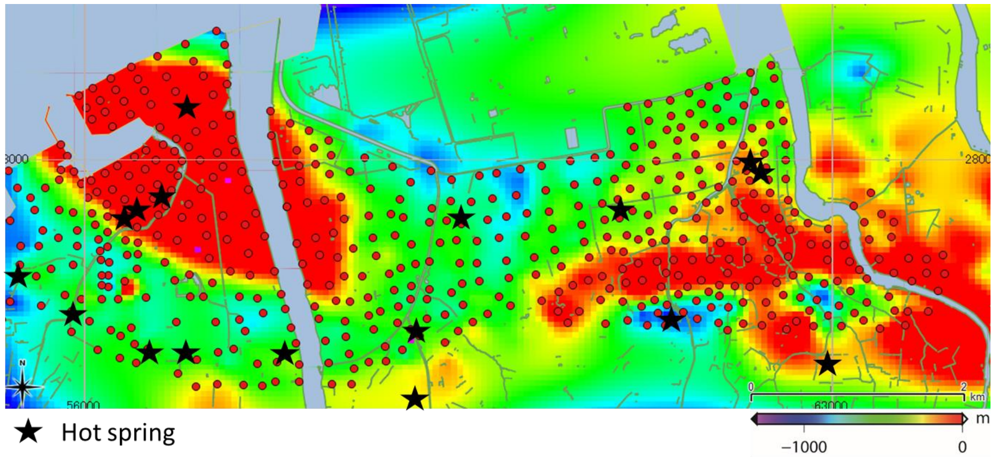

Figure 11: Modelled depth to basement with hot spring data

Fig. 11 shows good agreement between the low basement area and the distribution of the hot springs. We assume that the hot spring water comes out from the edge of high basement point (at the north-west part of this map) through the presumed fault. The hot spring water flows to the low basement area.

6. DISCUSSION

There are no volcanoes in the Oita hot spring region; hence, two types of underground heat transfer mechanisms were considered: conduction from inside the deep earth and convection of underground fluid. In general, heat transfer of underground water is more efficient than heat transfer inside rocks; therefore, hot springs exist in areas that have a high geothermal gradient. According to Fig. 12, there are three areas in the study region that have a high geothermal gradient, and one of these areas is located in the presumed fault. Thus, it is likely that this fault is related to the path of the hot spring flow.

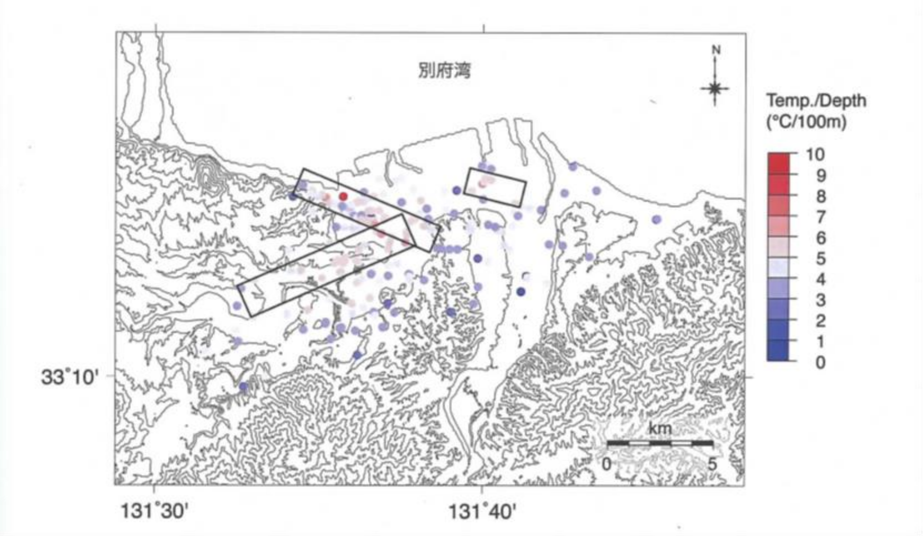

Figure 12: Geothermal gradient in the study region (MEXT, 2016)

Here, we compare the chemical composition of the Oita hot spring area. Hot springs with similar chemical components (Fig. 13) lie along the presumed faults shown in Fig. 13, indicating a fracture that carries the hot water from the deep underground source along the presumed fault.

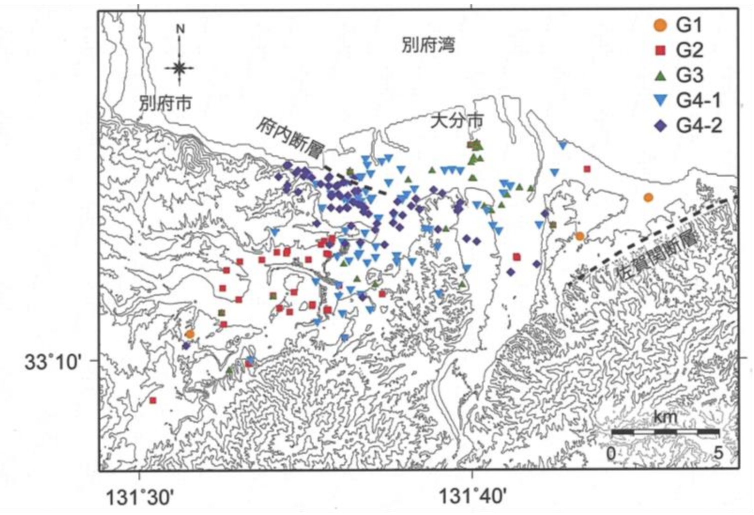

Figure 13: Distribution of chemical compositions of the hot springs in the study area (MEXT, 2016)

Ohsawa (1996) classified the hot spring water in the Oita plain into three types: (1) seawater origin, (2) sea sedimentary rock origin, (3) volcanic rock origin.

In my study area, the origin of hot spring water was estimated to be seawater based on the B/Cl method (Ohsawa, 1996). This can be clearly seen from Fig. 3. The seawater penetrates through porous alluvium and is heated by the high geothermal gradient and then stored underground.

According to Amita (2005), the Li, B, and Cl ratios show that the water originates from the Philippine Sea Plate. Amita (2005) concluded that the Oita hot spring water is a mixture of underground water from a shallow layer and water extracted from the Philippine Sea Plate.

Integrating the results from previous studies and our gravity survey, we constructed a conceptual model of the Oita hot spring area (Fig. 14). Its direction is northwest–southeast along the fault.

There are two heat sources. One is the high geothermal gradient and the other is the water extracted from the Philippine Sea Plate. The latter heat source constantly provides fluid from the Philippine Sea Plate, which includes various chemical compositions (Li, B, Cl).

The meteoric water comes from the shallow and deep ground-water aquifer. The shallow groundwater flows along the basement that falls north-westwards. The deep water is heated by the high geothermal gradient, and mixed with the extracted fluid that rises from the deep. Sea water penetrates from the north-western area, which consists of highly porous alluvium. The deep groundwater, sea water, and the extracted fluid from the plate rises through the presumed fault. This composes the reservoir of the Oita hot spring area.

This reservoir is located in a high position; therefore, the water from the reservoir will flow into a lower position. As shown in Fig. 11, the hot spring water flows through the deeper basement depth area, producing hot springs along its route.

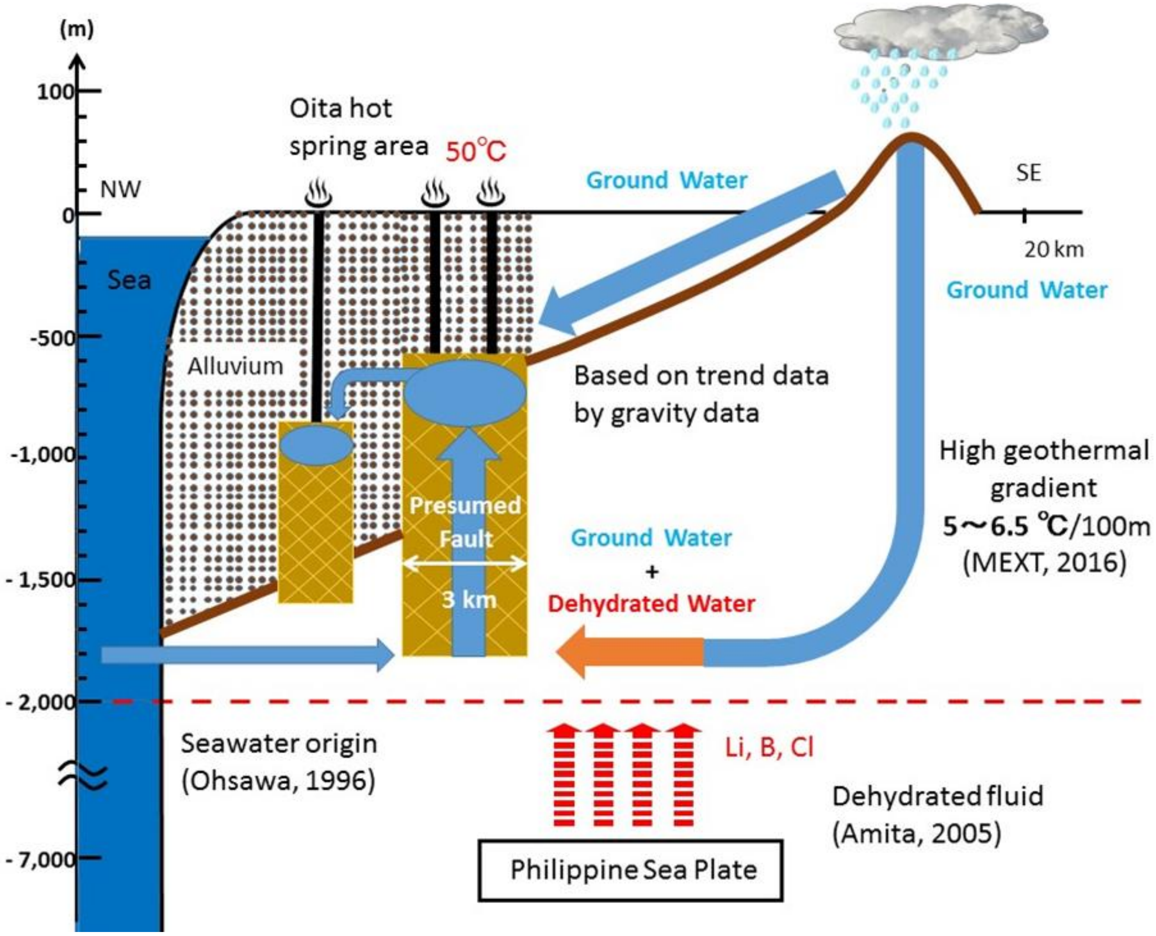

Figure 14: Conceptual model of hydrothermal system in the Oita hot spring area

7. SUMMARY

As a result of dense gravity measurements, we can clear the location of the fault and the basement structure in Oita hot spring area. Also, we can estimate the conceptual model in Oita hot spring area by combining the result of this gravity survey and other previous studies. But this model was estimated by using only the results of our gravity measurement, so the gravity survey in a southeast area is needed to understand larger area.

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