Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Underground Structure Delineated from Gravity and AGG Data Analysis in the Hohi Geothermal Area, Central Kyushu, Japan

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Keywords: Gravity survey, Airborne Gravity Gradiometry, Hohi geothermal area, Hydrothermal system

ABSTRACT

An airborne gravity gradiometry (AGG) survey was conducted by the Japan Oil, Gas and Metals National Corporation (JOGMEC) in the Oguni area in 2017. The density structure modeling was conducted using the 4 components (A_{NE}, A_{UV}, B_{NE} and B_{UV}) of AGG data in western Hohi area, central Kyushu, Japan. The high-density (2400 – 2550 kg/m^3) areas were estimated below the middle and late Pleistocene volcanoes in the southern part of the study area at a depth of 0 to 2000 m below sea level. The low-density (2150 – 2300 kg/m^3) areas were estimated below the Oguni area and Shishimuta caldera at a depth of 700 to 2000 m. Most of hot springs and geothermal manifestations are located in the edge of these low-density area. Moreover, the depression structure was detected in the western side of Mt. Waita. Some hot springs are located on the edge of this structure. Two hydrothermal conceptual models were obtained based on the integration of the result of the density distributions and the above previous research results.

1. INTRODUCTION

Gravity and gravity gradiometry survey are used for an estimation of basement rock structures and fault distributions. In a geothermal prospect exploration, a distribution of faults and a fracture zone indicated by low deisity, which is one of the most important property in a geothermal reservoir, is usually detected by gravity survey. But most of geothermal prospect in Japan is located in and around the mountain area. The steep topography makes it difficult to conduct the gravity survey. To solve the above problem, an airborne gravity and gradiometry survey are used for the wide and inaccessible area. JOGMEC have conducted an AGG survey in the Kuju volcano and surrounding area since 2013.

The Hohi geothermal area is located in the central Kyushu, Japan (Fig. 1). Many geothermal fields, hot springs and the geothermal power plants (Otake, Hatchobaru and Takigami) are included in this area. Many geothermal explorations have been conducted in this area since 1960. The gravity data which is measured by many institute, company and university was recorded in some gravity database. Moreover, an airborne gravity gradiometry (AGG) survey was conducted by JOGMEC since 2013. The AGG data is able to estimate the shallow fracture zone (Nishijima, 2016).

A density structure inferred from an AGG data can delineate the detailed density structure in the shallow depth. However, it is difficult to detect the deep structure because of the attenuation of the signals of a gravity vertical derivative component. In order to get the detailed density structure including a deep structure, an inversion combined a gravity and AGG data should be needed. We focused on the Oguni area, western part of Hohi geothermal area, which is able to use the gravity and AGG data. This study tried to calculate the underground density structure by using the gravity and AGG data. This result is integrated with the previous research such as geological, geophysical and geochemical data on the GIS. Finally, the conceptual hydrothermal model is estimated by the integrated interpretation using GIS software.

2. GEOLOGICAL SETTING

The Hohi volcanic zone is a volcano-tectonic depression. The extension of this zone is 70 km long and 45 km width toward the E-W direction. The volcanic activity occurred from 5 Ma to present. This depression structure is covered by Yabakei (1.0 Ma), Imaichi (0.8-0.9 Ma), Yufugawa (0.5-0.7 Ma) and Aso (0.07-0.3 Ma) pyroclastic flow. The Shishimuta caldera is formed by the eruption about 1.0 Ma ago (Kamata, 1989).

Figure 2 shows a geological map of Hohi area (Geological Survey of Japan, 2015). The geological setting in this area comprises middle Pleistocene volcanic rocks (Hohi volcanic rock), Late Pleistocene volcanic rocks (Kuju volcanic rocks), and Alluvium sediments (Hoshizumi et al., 2015). The basement rock is the Cretaceous granitic rocks and metamorphic rocks. However, the depth of this basement rocks is very deep, because the surface is covered thickly by the lave, pyroclastic and andesite. Based on the drilling geology, Tamanyu (1985) estimated that the depth of this Cretaceous granite is 1.5–2.5 km.

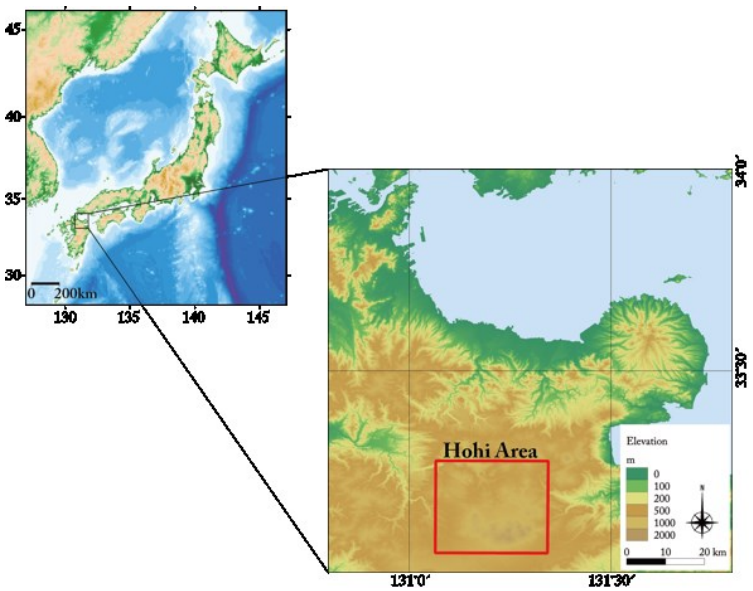


Fig. 1 Location of the Hohi area, central Kyushu, Japan.

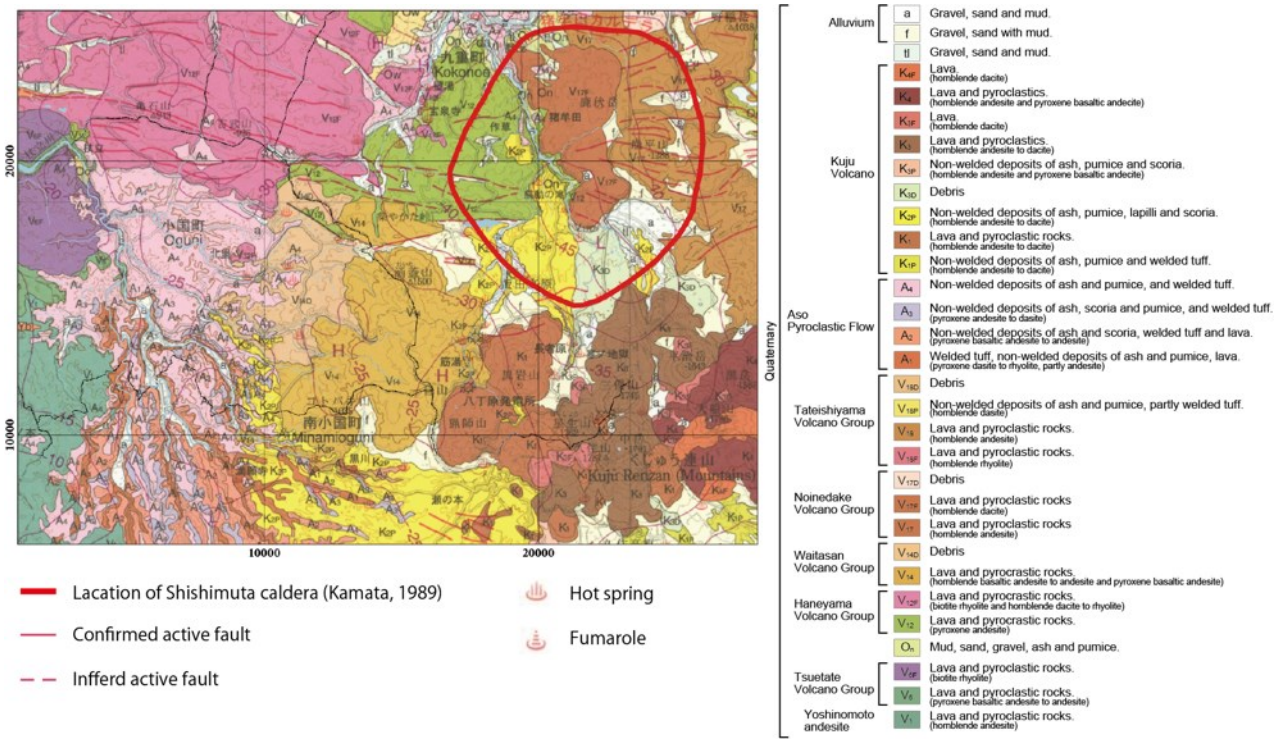


Fig. 2 Geological map of the study area modified from Hoshizumi et al., 2015.

3. GRAVITY DATA ANALYSIS

3.1 Gravity data

This study processed gravity data comprising 2914 stations (Shichi and Yamamoto, 2001; Honda et al., 2012; Geological Survey of Japan, 2013) to make a complete Bouguer anomaly map, and covering an area of approximately 526 km^2 (Fig. 3). The gravity data was reduced in order to obtaion the Bouguer anomaly, applying the necessary corrections, such as free-air, Bouguer, and terrain conditions. An assumed density of 2350 kg/m^3 was determined by an objective Bayesian approach (Murata, 1993) and CVUR (comparison of variance of upward-continuation residual) method (Komazawa, 1995) For the Bouguer and terrain corrections. Terrain corrections were calculated using the 50-m mesh digital elevation map of the Geographical Survey Institute (GSI) of Japan. The complete Bouguer anomaly was interpolated to a 100-m grid using the minimum curvature method (Smith and Wessel, 1990). Figure 3 depicts the Bouguer anomaly map. The Bouguer anomalies were all negative, ranging from -35 mgal to 0 mgal, decreasing toward the eastern region of the mapped area. In addition, a low Bouguer anomaly can be seen in the northeastern area, which is

called “Shishimuta caldera” (Kamata, 1989). Kuju volcano is located southern edge of the Shishimuta caldera. In addition, many hot springs and geothermal manifestations are located around Mt. Waita. JOGMEC conducted the airborne gravity gradiometry survey at Oguni area in 2017. In order to delineate the detailed density structure using the gravity and AGG data, we focused on the Oguni area (Fig. 4).

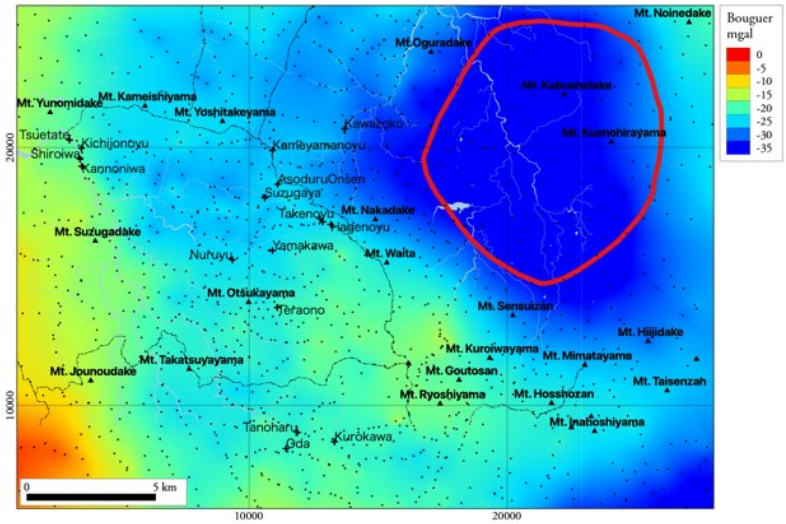


Fig. 3 Bouguer anomaly in Hohi area with an assumed density of 2350 kg/m^3.

The complete Bouguer anomaly (Fig. 4 left) includes the effect of regional trend caused by the deep, large structure. Because The aim of this study is to reveal the shallow density structure including shape of the basement rock, the regional anomaly was removed using the planar trend (Fig. 4 right) which is considered to represent the deep, granitic structure.

Fig. 4 right shows two low Bouguer anomaly in the center and eastern part of this area. In comparison with Fig. 3, the eastern low anomaly agrees with the location of the Shishimuta caldera. Many hot springs (Tsuetate, Kichijounoyu, Shiroiwa, Kannoriiwa, Kameyamanoyu, Asozuru, Suzugaya, Yamakawa, Nuruyu) are located the edge of the low anomaly in the Oguni area. there is a possibility of existing a depression structure like an old caldera. However, it is difficult to find a geological evidence. because this area is covered by the quaternary pyroclastic flow of Aso volcano.

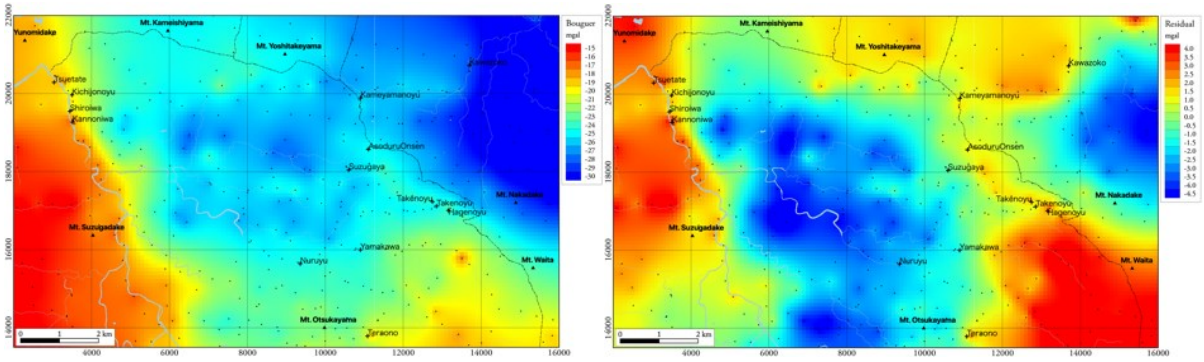


Fig. 4 Bouguer anomaly of Oguni area (left) and the residual Bouguer anomaly removed the regional anomaly (right).

4. AIRBORNE GRAVITY GRADIOMETRY DATA ANALYSIS

An airborne gravity gradiometry survey was conducted by JOGMEC in the Kuju volcano (2013) and Oguni area (2017), Oita and Kumamoto prefecture, Japan. The measurement and data reduction were operated by CGG aviation. The interval of measurement line is 250 m. The flight was kept the altitude as 120 m along the topography. The obtained data was reduced, applying the necessary corrections, such as tie-line, micro leveling, terrain conditions, and so on. For the Bouguer and terrain corrections, an assumed density of 2300 kg/m^3 was applied. AGG (A_{NE}, A_{UV}, B_{NE} and B_{UV}) data is consist of two pare of NE and UV components (Fig. 5). The CGG aviation provides AGG data and FTG data (G_{EE}, G_{NE}, G_{ND}, G_{NN}, G_{ND}, and G_{DD}) modeled from AGG data.

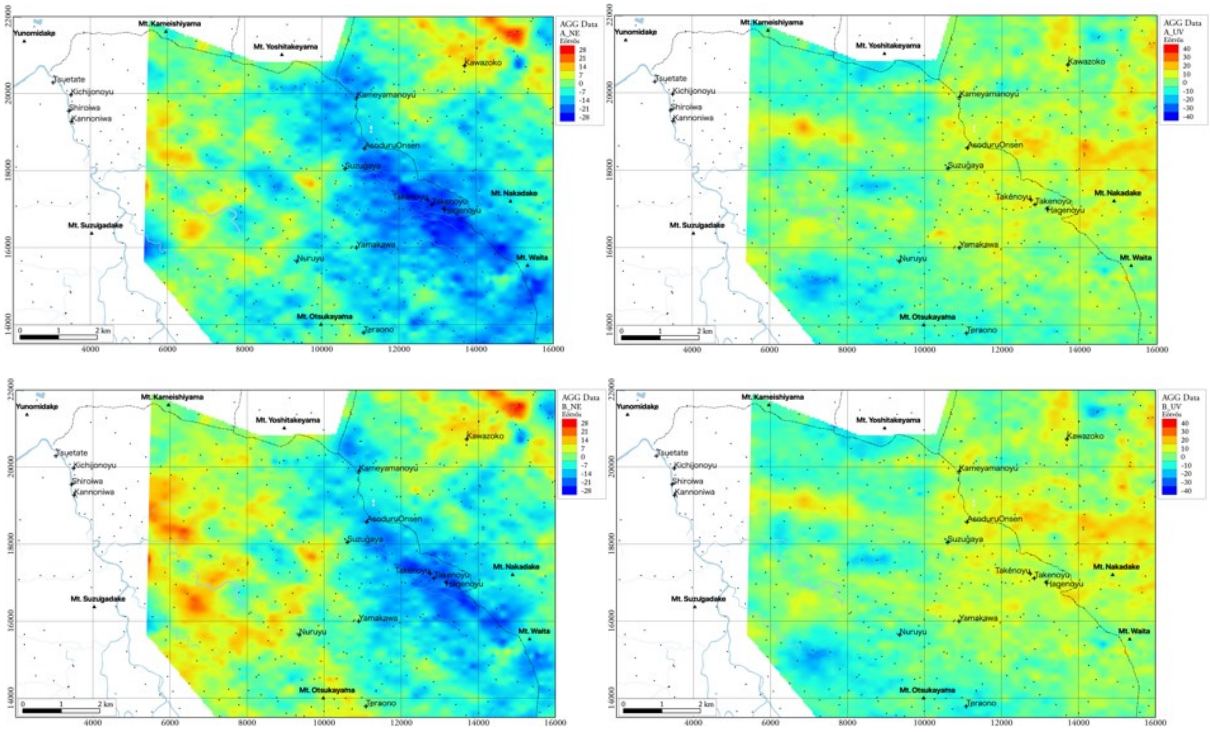


Fig. 5 Airborne gravity gradiometry data with an assumed density of 2300 kg/m^3.

In order to estimate the underground structure easily, the following shape index (Cevallos et al., 2013) was adopted (Fig. 6).

$$ShapeIndex(SI) = \frac{2}{\pi} tan^{-1}\left(\frac{-G_{DD}}{\sqrt{(G_{NN} - G_{EE})^2 + 4G_{NE}{}^2}}\right) = \frac{2}{\pi} tan^{-1}\left(\frac{-G_{DD}}{\sqrt{2G_{UV}{}^2 + 4G_{NE}{}^2}}\right)$$

A Dome structure is located below and southeastern part of Mt. Waita. In addition, a ridge structure toward the northwestern direction can be seen from Mt. Waita to Mt. Yoshitakeyama. This ridge structure divides two bowl structure. The eastern bowl structure is corresponding to the western edge of the Shishimuta caldera. Some hot springs (Takenoyu, Hagenoyu, Kawazoko) and Sugawara geothermal power plant are located in the western edge of this bowl structure. The wester bowl structure indicates an unknown depression structure. Many hot springs in Oguni area such as Kameyamanoyu, Suzugaya, Yamakawa, Nuruyu are located in this depression structure.

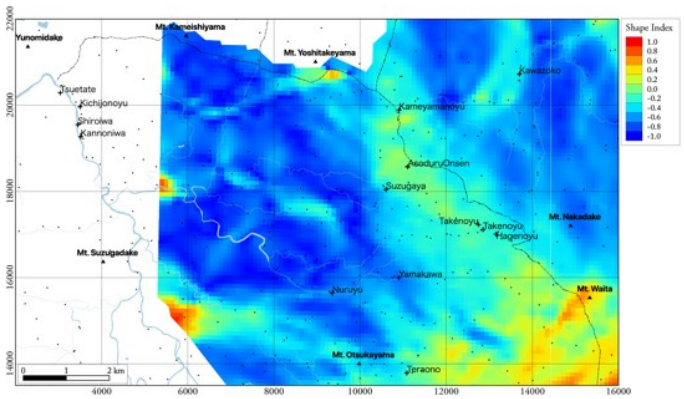


Fig. 6 Shape index of AGG data.

5. THREE-DIMENSIONAL DENSITY STRUCTURE MODELING

The underground density structure is estimated by the gravity and AGG data inversion using VOXI Earth modeling on Geosoft Oasis montaj. This result is integrated with the other geological, geophysical and geochemical data on the GIS software. Finally, the conceptual hydrothermal model is estimated by the integrated interpretation using GIS software. The high-density (2400 – 2550 kg/m^3) areas were estimated below the middle and late Pleistocene volcanoes in the southern part of the study area at a depth of 0 to 2000 m below sea level. These high-density areas correspond to the distributions of the older Hohi volcanic rocks. Moreover, the depression structure was detected in the western side of Mt. Waita. Some hot springs (Yamakawa, Asozuru, Nuruyu and Tsuetate) are located on the edge of this structure.

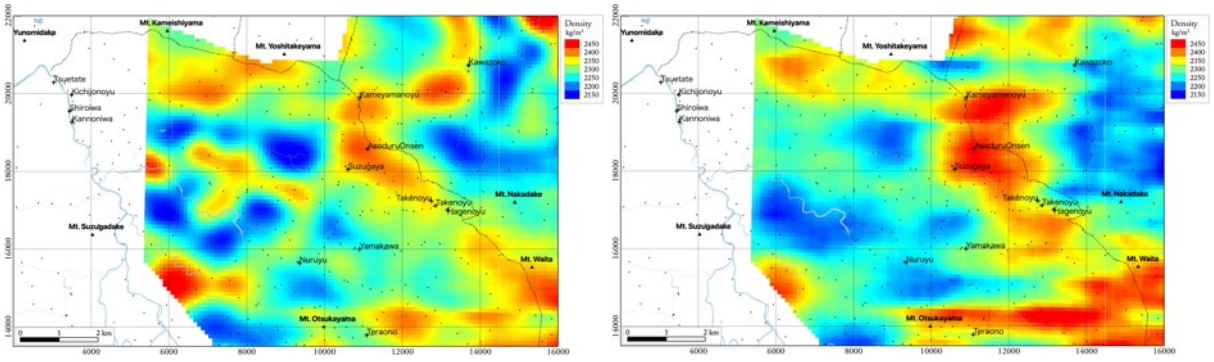


Fig. 7 Density distribution inffered from the three-dimensional AGG inversion. The elevation is -250 m a.s.l. (left) and -1000 m a.s.l. (right) respectively.

Ishido (1985) detected the negative anomaly of spontaneous potential at the northan part of Mt. Waita, Nuruyu hot spring and Shishimuta area. These negative anomaly indicates the recharge area of surface meteoric water. On the other hand, a pare of positive and negative anomaly is detected at the northwestern side of Mt. Waita. These anomaly indicate the up flow of the deep geothermal water.

Kawamura (1985) estimated the heat flow based on the bore hole temperature in Hohi geothermal area. The high heat flow area more than 420 mW/m^2 is located in the Takenoyu fault and the surrounding area. This area is corresponding to the western edge of the Shishimuta caldera. In addition, other high heat flow area is correspoding to the eastern edge of western depression structure.

Two hydrothermal conceptual models were obtained based on the integration of the result of the density distributions and the above previous research results (Fig. 8). Because there is no previous research about the up flow area in Tsuetate hot spring area, it is difficult to disscuss the origin of Tsuetate hot spring. However, the chemical components of the hot spting water indicates there is another hydrothermal system around the Tsuetate hot spring area. Fig. 8 left shows previous research interpretation of hydrothermal system. The deep geothermal water is up-flowing at the northwesten part of Mt. Waita, then flows lateraly towards each hot spring through the NW or EW direction faults.

Fig. 8 right shows the conceptual hydrothermal system considering the result of the gravity and AGG analysis. The relationship between the location of hot springs and depression structures indicates the existing two different hydrothermal systems in each depression structures. In the next step, the numerical simulation based on the these conceptual model should be needed in order to evaluate the potential of the geothermal resources.

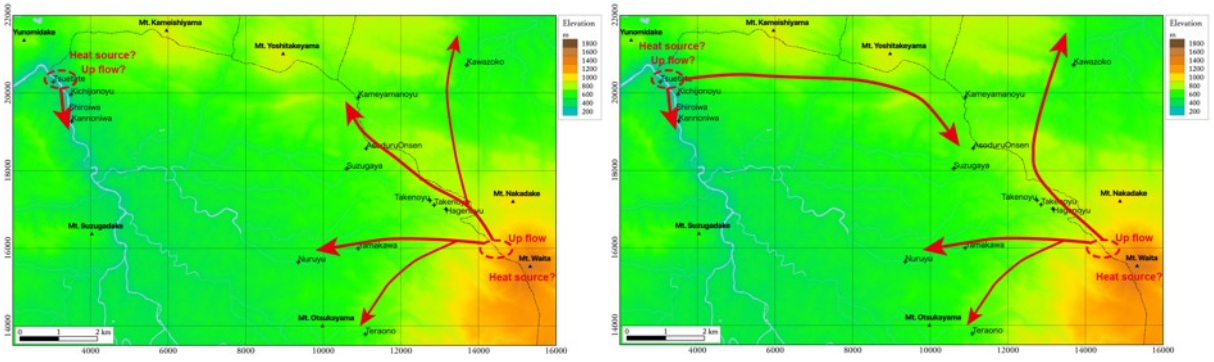


Fig. 8 Conceptual model (left): previous research interpretation of hydrothermal system. (right): hydrothermal system considered the result of the gravity and AGG analysis.

6. CONCLUSION

The underground density structure is estimated by using the gravity and AGG data. Two low Bouguer anomaly are detected in the center (Oguni area) and eastern part (Shishimuta caldera) of study area. The eastern low anomaly agrees with the location of the Shishimuta caldera. Many hot springs are located the edge of the low anomaly in the Oguni area. The possibility of existing a depression structure like an old caldera is estimated from the Bouguer anomaly. The underground density structure is estimated by the AGG data inversion using VOXI Earth modeling on Geosoft Oasis montaj. This density structure is integrated with the previous research such as geological, geophysical and geochemical data on the GIS. Finally, the conceptual hydrothermal model is estimated by the integrated interpretation using GIS software. Two hydrothermal conceptual models were obtained based on the integration of the result of the density distributions and the above previous research results. In order to evaluate the geothermal resouces, the numerical simulation based on the these conceptual model should be needed.

ACKNOWLEDGEMENT

The authors gratefully acknowledge providing and allowing use of the AGG data to the Japan Oil, Gas and Metals National Corporation (JOGMEC) .

REFERENCES

Cevallos, C., Kovac, P. and Lowe, S.: Application of curvatures to airborne gravity gradient data in oil exploration, Geophysics, 78, (2013), G81-G88.

Geological Survey of Japan, AIST, 2013. Gravity Database of Japan, DVD Edition. Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology.

Geosoft Inc., "VOXI Earth Modeling", 2018, http://www.geosoft.com/products/voxi-earth-modelling/ (accessed May 1, 2019).

Hoshizumi, H., Saito, M., Mizuno, K., Miyazaki, K., Toshimitsu, S., Matsumoto, A., Ohno, T. and Miyakawa, A.: Geology Map of Japan 1:200,000, Oita (2nd Edition), Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, (2015).

JOGMEC., "Report of survey on the potential of geothermal resources", 2013, pp.9-20.

Kamata, H.: Shishimuta Caldera, the Buried Source of the Yabakei Pyroclastic flow in the Hohi Volcanic Zone, Japan, *Bulletin of Volcanology*, **51**, (1989), 41-50.

Komazawa, M.: Gravimetric Analysis of Aso Volcano and It's Interpretation, *Journal of the Geodetic Society of Japan*, **41**, (1995), 17-45.

Honda, R., Sawada, A., Furuse, N., Kudo, T., Tanaka, T., Hiramatsu, Y.: Release of Gravity Database of the Kanazawa University, *Journal of the Geodetic Society of Japan*, **58**, (2012), 153-160.

Ishido, T.: Self-potential Anomalies in the Hohi Geothermal Area, *Report of Geological Survey Japan*, **264**, (1985), 337-349, (in Japanese with English Abstract).

Kawamura, M.: On Thermal Structure of the Geothermal Field in Mt. Waita Area, Central Kyushu, Japan, *Report of Geological Survey Japan*, **264**, (1985), 353-382, (in Japanese with English Abstract).

Murata, Y.: Estimation of optimum average surficial density from gravity data: An objective Bayesian Approach. *Journal of Geophysical Research*. **98**, (1993), 12097. doi:10.1029/93JB00192.

Nishijima, N.: Density Structure Inferred from Airborne Gravity Gradiometry Survey Data in the Western Part of Kirishima Volcano, *Butsuri-Tansa*, **69**, (2016), 29-39, (in Japanese with English Abstract).

Shichi, R. and Yamamoto, A. (Representatives of the Gravity Research Group in Southwest Japan): Gravity Database of Southwest Japan (CD-ROM), Bulletin of Nagoya University Musium, Special Report, No. 9, (2001).

Smith, W.H.F., Wessel, P.: Gridding with continuous curvature splines in tension, *Geophysics*, **55**, (1990), 293–305.

Tamanyu, S.: Stratigraphy and Geologic Structures of the Hohi Geothermal Area, Based Mainly on the Bore Hole Data, *Report of Geological Survey Japan*, **264**, (1985), 115-142, (in Japanese with English Abstract).