GEOTHERMAL HEAT SOURCE ASSESSMENT USING ELECTROMAGNETIC PROSPECTING

Tohru Mogi*, Susumu Nishimura**, ikuo Katsura**, Koichi Suzuki***, Djedi S. Widarto****

*Dept. of Mining, Kyushu Univ., Fukuoka 812, Japan
**Dept. of Geology and Mineralogy, Kyoto Univ., Kyoto 606-01, Japan
***Central Res. Inst. Electric Power Ind., Abtko, Chiba 270 11, Japan
****R&D Ctr. for Geotechnology, Indonesian Inst. of Sciences, Bandung 40135, Indonesia

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Abstract

We have carried out combined surveys composed of the CSMT and the long offset TDEM prospecting at two geothermal areas, the Kuju-Iwouyama and the Waita area, attempting to delineate a heat source type of area. The depth of investigation of TDEM depends on the intensity of source moment, the offset between the transmitter and receivers, dynamic range of the receiver and also noise level of the receiver site. If we choose reasonable condition of these factor, we may investigate about the heat source, such as a magma chamber or hot rock, which may situate at the depth of 5 to 10km. The CSMT method was used to investigate the shallower part. of the resistivity structure that was sometimes incorrectly determined by the TUEM.

Based on these results, we have delineated relation between the sites of heat source and the geothermal reservoir in these area. And we pointed out, that development of the reservoir depends on age of heat source.

1. Introduction

It is important for a geothermal reservoir modelling to consider the site, scale arid temperature of heat source as well. The amount of heat from the source governs the life of the geothermal reservoir. The heat source (magma or hot rock) of a geothermal area is usually considered situating at depths of several to 10 km. The long offset TDEM is convenient to survey at those depths. We have carried out the TDEM prospecting at some Japanese geothermal areas around a volcano showing various ages of activity to delineate the heat source type of these area.

An electric bipole source was used as a transmitting station of the survey that locates at 4 to 8 km distance from the receiver sites. The receiver of the magnetic field was used with the fluxgate magnetometer. Since the fluxgate measured magnetic field, dynamic range of transient response is relatively smaller and it can be obtained until later time. On the other hand, the fluxgate cannot be observed at the very early stage of response and the resistivity structure of the shallower depth is sometimes incorrectly determined. The CSMT data was used to determine the shallower part.

2. Depth of investigation

Depth of investigation of the electromagnetic method is sometimes estimated by using the skin depth (frequency domain) or diffusion depth (time domain) of EM wave for conductive medium. Practically, the depth of investigation of EM method using artificial EM source is influenced by many factors such as momerit of source, distance between source and receiver, dynamic rangc of receiver, noise level of the receiver and resistivity difference of layers. Spies (1989) proposed a simple formula to calculate the depth of investigation. Fig.1 shows the response curves of the vertical magnetic component(hz) for the two-layer case. This shows that influence of lower layer appears at time that diffusion depth coincides with depth of lower boundary of upper layer, except for the far zone case. From this point, the depth of investigation can be defined as the diffusion depth when the response reaches the noise level. It. requires longer time to detect the lower layer for the far zone case. Fig.2 shows the depth of investigation with the distance between transmitter and receiver for various noise level. The depth of investigation does not depend on the layer resistivity, since intensity of hz does riot depend on the resistivity of the layer. Layer resistivity control the length of response time *so* that it must be observed the transient response for long time on the low resistivity layer.

3. Kuju-Iwouyama area

The Kuju-Iwouyama area, distributing many active fumaroles, hot springs and wide alteration zones, is the crater of the Hosshou volcano in the central part of the Kuju volcano group, central Kyushu, southwest Japan. Eharaet al. (1981) estimated that the maximum fumarole

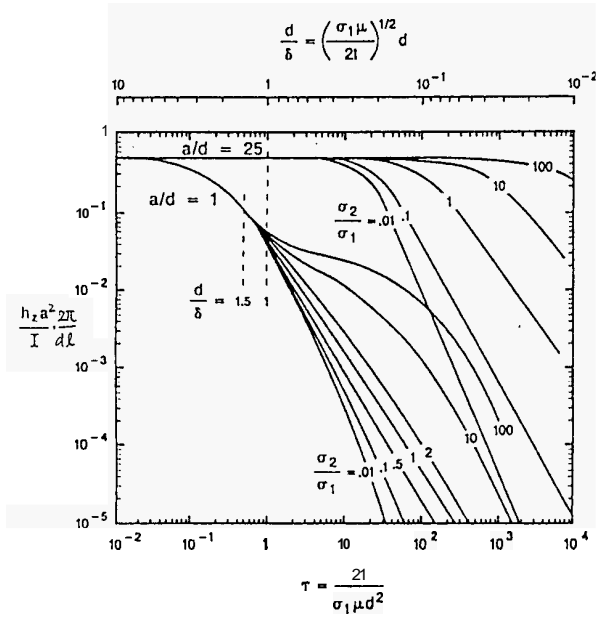


Fig.1.Transient response curve of vertical component of magnetic field (after Spies(1989)). a:source-receiver separation, d:upper layer thickness, dl:grounded wire source length.

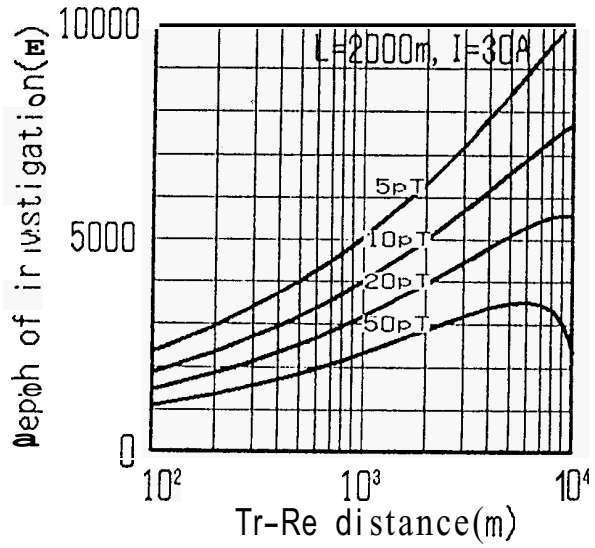


Fig.2.The depth of investigation versus transmitter-receiver distance with some noise levels (5pT to 50pT).

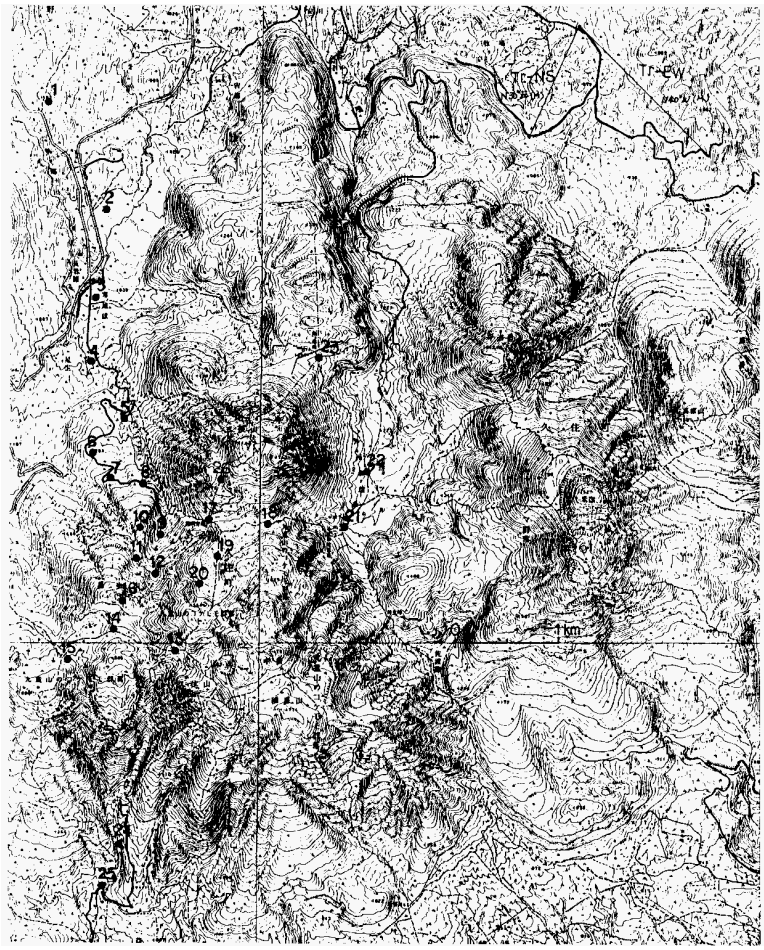


Fig.3.Transmitting lines and receiving sites in the Kuju-Iwouyama area.

temperature is more than 300°C and total heat discharge from the area amounts to 99.2MW and total water discharge amounts to 65.2kg/s. Prominent geothermal areas (e.g.Hatchobaru) and hot springs are distributed around the volcano.

Quaternaryvolcanic rocksare thick aridwidely distributed in this area and arc underlined by Tertiaryvolcanic rockandpre-Tertiarygranitic or gneissic basement rock. The thickness of the quaternary volcanic rock is 1 or 2 km at this area. Recent volcanic activity began about 300,000 years ago and the main activity ceased 50,000 years ago in this area. Ages of the Hossyou lava is estimated 0.07Ma by the fission track dating (Watanabe et al.,1987). However, the remaining magma is still active and latest (phreatic) eruption occurred in the 17th century.

Fig.3 shows locationof measuring sites and the transmittingline that set approximately 2 kmin length. Apparent resistivities were obtained at 12 frequencies from 8700 to 4.2 Hz using the CSMT method. We have been using an analogue complex phase detector(Mogi et al.1990) to obtain agood quality data in this noisy band. These apparent resistivitieswere considered reflecting to the resistivitydistribution of up to 1 or 2 kmdeep. The 'I'DEM receiver system was composed of the flux-gate magnetometer, the clock and the portable computer (PC). The flux-gate magnetometer have high sensitivity of 1mV/pT and good high frequency characteristics that working for up to 100Hz (Shimoizumi et al.1991) was used for data acquisition. A transient magnetic field record was composed of 4000 data sampled at 4ms interval. The data were monitored and recorded using the PC in the observedsite. High accuracy clocks, withdrift of less than 1ms per day, were usedto synchronize the transmitter and receiver system. The TDEM data were sorted to good data (high signal to noise ratio) and then stacked. The instrumental response was corrccted by the deconvolution technique. To construct resistivitymodels that composed ofthe CSMT and TDEM data, a one-dimensional (layer structure) joint inversion technique applying Marquardt's non-linear least-squares method was used.

A resistivity model of N-S section across the Kuju-Iwouyama area is shown in Fig.4. Fumaroles were distributed around site 9 and 12. The 10 to 30 ohm-m zone was appeared in the shallower part of these site, however, the low resistivity zone (<10 ohm-m) existed in the deeper part (<2000-3000m). In most of other site, thc resistivity of the deeper part was more than 30 or 100 ohm-m that refer to the resistivity of basement, rock. The low resistivity in the basement rock just beneath the fumarole zone is considered an upflow zone of geothermal fluid from a heat source. This low resistivity zone is also recognized in the resistivity model obtained by MT survey (Mogi and Nakama, 1993). Ehara et al.(1988) observed many microearthquakes occurring in this zone up to 1.5km deep. They interpreted that the thermal fluid supplied from the deep magma was convected and mixed with surface water in this zone. Relatively low resistivity zones (10-30 ohm-m) elongating to the deeper part were seen at site 3 and 24. Hot springs are distributed at these sites and probably fracture zones are expected.

5.Waita volcano area

The Waita volcano and the Takenoyu geothermal area are situated at western part of the Hohi gcothernial area that is one of the most prominent volcanic geothermal features in Kyushu, southwest Japan. The studied area is in and around the Waitavolcano. Local distribution of volcanic rocks and geological structures in the studied area, as simplified from Matsumoto (1983), is depicted in Fig.5. Plio-Pleistocene volcanic rocks predominate in this area. The basement is placed by pre-Tertiary rocks, primarily Cretaceous granite and schist. They are absent as outcrops in the subsurface but found in drill holes about 2km deep. Activity ages of the Waita volcano were estimated as 0.31Ma (fission track ages) (Watanabc et a1.1987) or 0.34-0.47 (K-Ar ages) (Kamata, 1985). Any geothermal manifestation such as fumarole or hot spring was not seen in the volcano, except weak alteration zone. The prominent geothermal area, Takcnoyu geothermal area, is developed at the western foot of the volcano.

The exploration methodand dataprocessing are similar to the case of the Kuju-Iwouyama described in the previous section. The resistivity structure along two sections across the Waita volcano are shown in Fig.6 and 7. Very low resistivity layers (<10 ohm-a) were seen in the shallower part (<1000m deep) of Takenoyu geothermal area (site No.38, 39, 40) at the foot of the Waita volcanoas shown in Fig.6. This zone is considered ageothermal water reservoir. This zone reached to the surface at the central part of the geothermal zone where many fumaroles and hot springs are distributed. This low resistivity zone continued to the summit of the Waita volcano. Although resistivity of the deeper part is more than 30 ohm-m at the geothermal area and the west site of the volcano, low resistivity zone (10-30 ohm-m) continue to the deep at the south and south-east side of the volcano (site No.20, 21, 22, 16) as shown in Fig.7. From these result, we consider that the magmatic fluid come up to the shallower

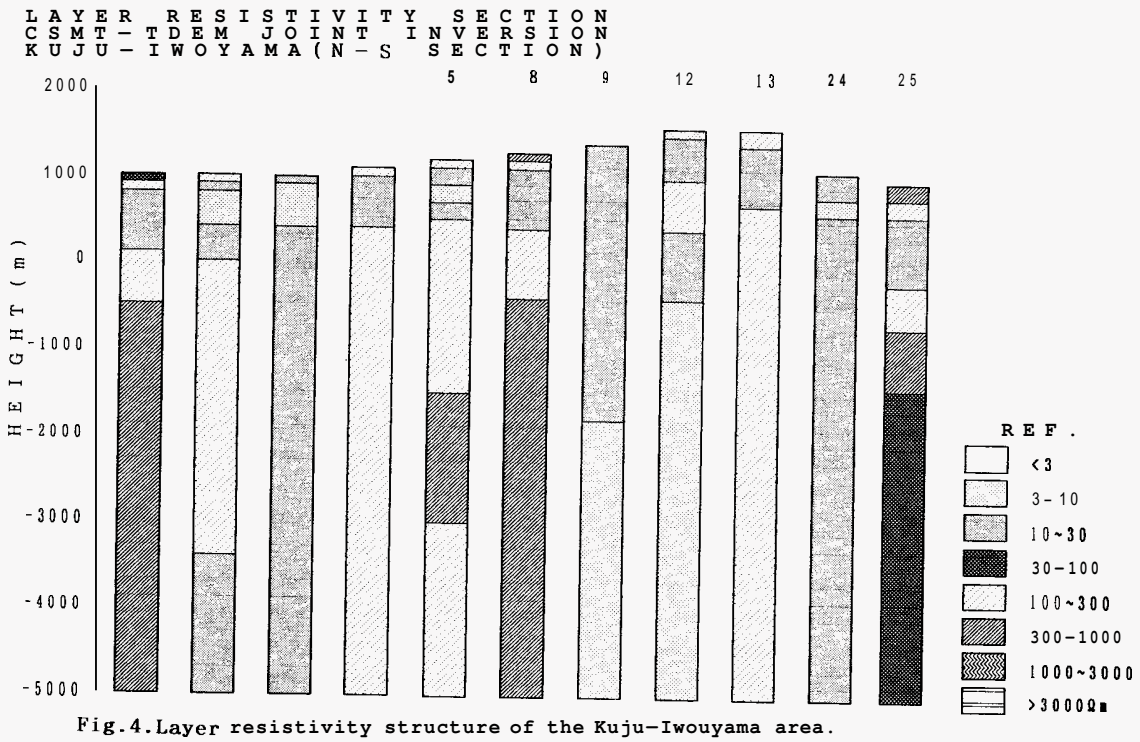


Fig.4. Layer resistivity structure of the Kuju-Iwouyama area.

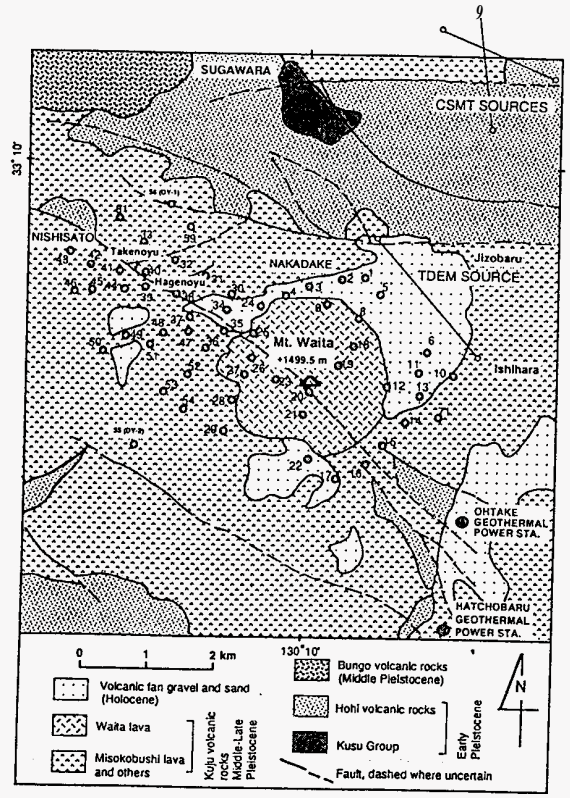


Fig.5. Transmitting lines, receiver sites and distribution of volcanic rock in the Waitavolcanoarea.

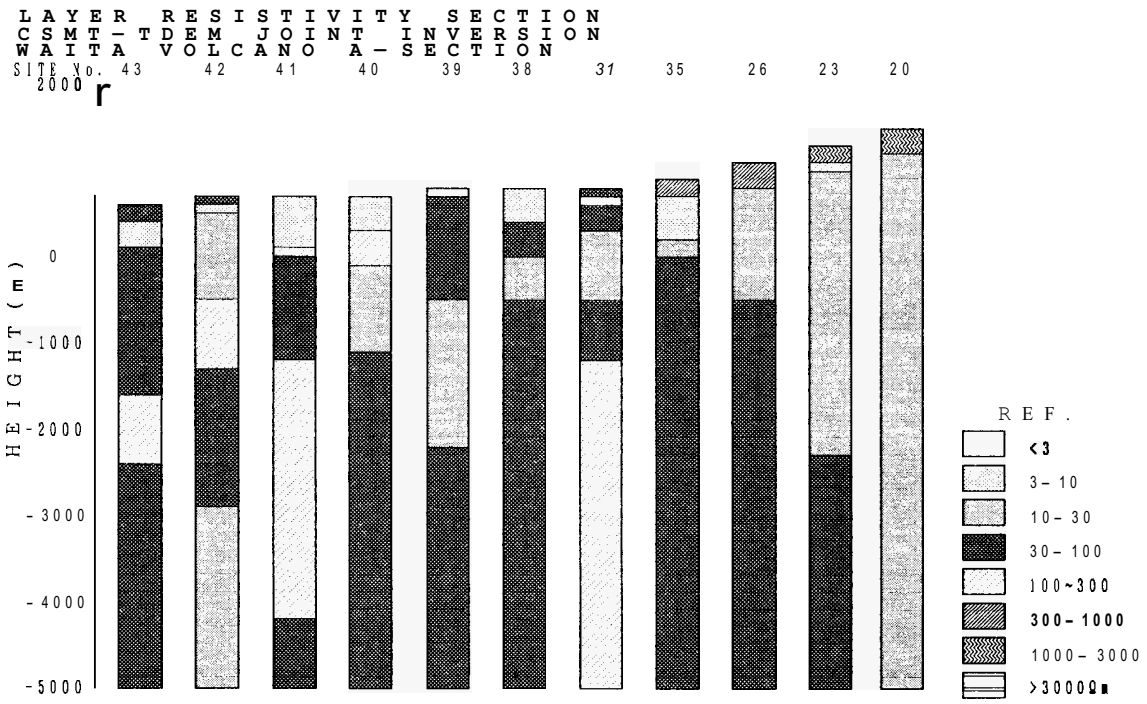


Fig.6.Layer resistivity structure at the Takenoyu geothermal area and the west side of the Waita volcano.

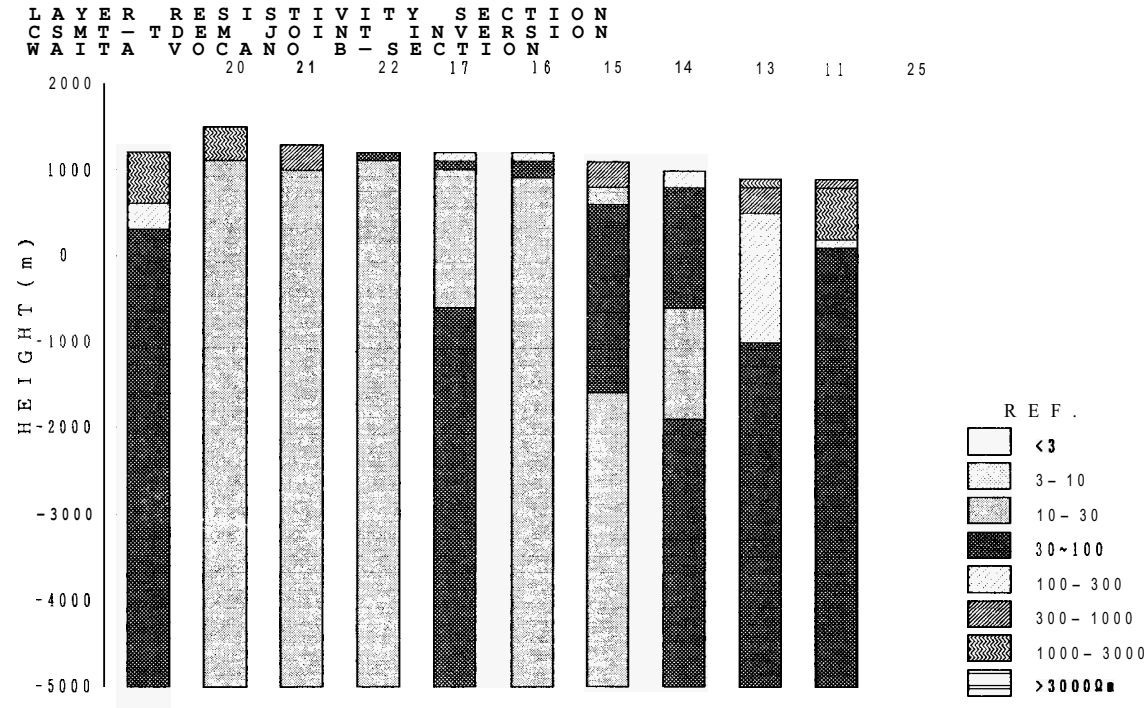


Fig.7.Layer resistivity structure at the south and east side of the Waita volcano.

part at the south-east side of summit, then it mixed with ground water and the reservoir was formed at the shallower part. The low resistivity does not continue to the surface at the volcano. This result explain that no geothermal manifestation is seen in the surface of volcano.

5. Discussion

We described the resistivity structure obtained from joint analysis of CSMT and TDEM data in two geothermal areas. The first field, Kuju-Iwouyama, is an example of relatively new volcano, but it has already ceased main eruption. The remaining magma is still aclive in this volcano and power of upflow is strong enough to appear fumaroles just above the upflow zone. The upflow zone was recognized as the low resistivity zone beneath the fumarole zone. Magma chamber, probably exist at deeper part of upflow zone, has not, detected in this study. Since a large amount of fluid is supplied, the upflow zone itself forms a reservoir to extract energy sufficient to generate electric power. Ehara and Mogi(1989) estimated that 10MW electricity generates for 30 years by extracting energy from the reservoir of the Kuju-Iwouyama.

On the other hand, the second field, the Waita volcano, is an example of relatively old volcano. The remaining magma probably has mostly cooled and solidified. Power of upflow rather weak and any geothermal manifestation is not seen in the volcano. The fluid coming from magma is mixed with meteoric water at the shallower part of the volcano. The geothermal water flows horizontally Lo the foot of volcano and forms reservoir. This would be typical geothermal reservoir developed around a volcano. Howevcr, sometimes it is not clear the source of heat and magmatic chemical components. This result indicate clearly the heat source of the geothermal area developed at the foot of the Waita volcano. Usually, such horizontal flow probably occurs along a fracture zone associated with a fault. Actually, it seems that fumaroles and hot springs in the Takenoyu geothermal field lines along the Takenoyu-Sujiyu fault. The Takenoyu-Sujiyu fault may govern the flows and an extent of the reservoir.

Based on the resistivity structure obtained fromthe CSMT-TDEM combined survey, we have been able to discuss about the heat source of the geothermal reservoir depending on the ages of volcanoes.

6. Conclusion

We showed that the TDEM method is useful for Investigating deeper part up to 5 or 10 km deep of a geothermal area if reasonable survey design is applied. Diminishing the noise level is essential to increase the depth of investigation.

Investigating the deeper part of geothermal area surrounding t.o a volcano is useful to discuss a process of developing the geothermal reservoir and to determine a target of geothermal energy development.

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