

# HIGH SPATIAL RESOLUTION OF THE RESISTIVITY STRUCTURE REVEALED BY A DENSE NETWORK MT MEASUREMENT – A CASE STUDY IN THE MINAMIKAYABE AREA, HOKKAIDO, JAPAN

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**SUMMARY** – In 1988 we carried out a case study survey at Minamikayabe in the southern part of Hokkaido, Japan. This area is particularly interesting because of its geothermal potential. Seven control wells had been drilled prior to our operation, and also some other information has been available from other survey methods such as gravity, geology, geochemistry, DC resistivity and heat flow. Hence the area is an ideal site for a study of effectiveness of the MT method.

Analyses of the data derived from network MT measurements, which we undertook in the present case study, clearly show that dense network measurements could resolve a spatially fine resistivity structure. In order to attain a high spatial resolution of subsurface resistivity structure in a geothermal or a volcanic area, where the subsurface structure is extremely complicated, we show that a dense network MT measurement is indispensable.

## 1. INTRODUCTION

An intensive investigation, such as a gravity survey, a Schlumberger measurement, a geochemical survey, and a geological survey, as well as well drilling, was conducted in the Minamikayabe area, southern Hokkaido, as part of "Geothermal Development Promotion Survey" (New Energy and Industrial Technology Development Organization, 1988). Some geothermal developers were also interested in this area and conducted various kinds of surveys (personal communication). In particular, during the "Geothermal Development Promotion Survey" project, seven wells were drilled in the present survey area and two of them successfully produced geothermal fluid.

One defect of the MT method is a poor resolution in determining the subsurface resistivity structure, in particular in a complicated area such as the present geothermal area. In order to overcome this defect, we attempted a highly dense array measurement in the Minamikayabe area. We selected most of the sounding points around the two wells producing geothermal fluid. Special attention was paid to clarifying the direction along which the geothermal reservoir, indicated by the two wells, develops.

Here we report the results of our array MT measurement with special emphasis on the effectiveness of the highly dense array measurement, as is confirmed from the comparison with the results of other surveys.

## 2. OUTLINE OF MEASUREMENTS

As shown in Fig. 1, the present survey covers an area of about 9 km<sup>2</sup>. It is located in the Minamikayabe area, southern Hokkaido, Japan. The survey sites are distributed

rather irregularly as in usual MT sounding. In addition to such usual soundings, we measured the electric and magnetic field variations at closely spaced mesh points that were distributed as surrounding the wells MK-2 and MK-6. These are special wells from which geothermal fluid could be extracted. The mesh size is only 100 m. The total number of sounding points is 209, of which 161 points are mesh points and the other 48 points are located around the highly dense mesh.

The arrangement of mesh-points is shown in Fig. 2; the electric fields are measured successively from one point to its neighbors in the mesh survey area with an electrode separation of 100 m. In this study, electric-field measurement lines were arranged parallel and perpendicular to the coastline. The mesh area was selected so as to locate the successful geothermal wells MK-2 and MK-6 at nearly the center of the mesh, as shown in Fig. 1.

Most of the survey points are located east of Mt. Nakitsura, an extinct volcano bounded by the Ofuna River in the south and the Isoya River in the north. The area is covered extensively with material ejected from the volcano in the Quaternary Period (New Energy and Industrial Technology Development Organization, 1988).

At all the sounding points, the "High-Accuracy MT System" reported by Takasugi et al. (1989, 1992) were used to acquire tensor MT data for such a very wide frequency range as from 0.001 Hz to 20,000 Hz. Two reference points were established at the northeastern edge of the survey area during the whole survey period, so that the remote-reference data processing method (Gamble et al., 1979a, b) can be applied to the data obtained at all the survey sites.

### 3. COMPARISON WITH THE RESULTS OF OTHER SURVEYS

#### 3.1 Geologic Data

The survey area is underlain mostly by Neogene and Quaternary rocks (New Energy and Industrial Technology Development Organization, 1988). Outcrops of Pre-Tertiary basement rocks are not seen in the area. The Neogene zone comprises the Miocene Shiodomarigawa Formation (volcanic rocks and mud rocks) and the Pliocene Isoya Pyroclastic Rocks. The Quaternary zone is represented by Pleistocene volcanic rocks. Neogene intrusive rocks prevail in the east of the area.

A relatively conducting zone (50 ohm.m or less) is extensively found at the depth from 100 m to 600 m, or from 200 m above sea level to 300 m below sea level, as shown in Fig. 3. This zone seems to correspond to the Shiodomarigawa Formation because it is widely distributed at these levels. On the other hand, a resistive zone (100 ohm.m or more) is dominant below this formation. This indicates that intrusive rocks underlie the Shiodomarigawa Formation and basement rocks are probably situated at a deeper level.

At sea level and below, relatively resistive areas predominate in the west and south of the study area, including the sounding stations 24, 25, 26, 30, 31 and the dense measurement area (see Fig. 1). On the other hand, relatively conductive areas predominate in the north. This situation may be interpreted as follows. In the west and south, the Shiodomarigawa Formation is abundant in lava, and intrusive rocks and basement rocks are located at shallower levels. In the north, the northward inclined Shiodomarigawa Formation is thicker whereas it is rich in mud rocks in the north.

#### 3.2 Electrical Logging Data

Seven wells were drilled to a depth of 1,000 m or more in the field test area (New Energy and Industrial Technology Development Organization, 1988). The logging data for the two wells MK-2 and MK-6 can be compared with the resistivity distribution with depth derived from one-dimensional Bostick inversions of the MT data at nearby sounding points, as shown in Figs. 4 and 5.

The resistivity logging data for the MK-2 well and also for the MK-6 well agree with the results of Bostick inversion for the TE mode MT data at F05 and 108, respectively. Especially, the very conductive Shiodomarigawa Formation and the resistive intrusion are clearly seen at MK-6 and 108. On the other hand, the logging data at the MK-2 well show that the shallow part of intrusion is less resistive than in the MT results.

In the test area, three layers of different types have been recognized; the first relatively resistive layer near the surface consisting of Pleistocene volcanic rocks, the second conductive layer consisting of the Isoyagawa

Pyroclastic Rocks and the Shiodomarigawa Formation, and the third rather resistive layer consisting mostly of intrusive rocks and partly of the Shiodomarigawa Formation. Their resistivity values and boundary depths can be roughly estimated from the TE mode results of the MT analysis.

These figures imply that the resistive intrusive bodies under discussion can be detected by the MT analysis to a moderate degree of accuracy in the sense that the estimated resistivity for the TE mode reflects the value of the average of logging resistivity which fluctuates considerably with depth.

#### 3.3 Gravity Data

The resistivity distribution derived from the TE mode at 1,500 m below sea level is compared with the contour map of gravity data corrected for  $\rho = 2.3 \text{ g/cm}^3$  (New Energy and Industrial Technology Development Organization, 1988). The following gravity anomalies can be seen; a high gravity anomaly around the middle reaches of the Garo River, a low gravity anomaly around the lower reaches of the Isoya River, and a low gravity anomaly near Manjojiki. The elevation of resistivity basement derived from the depth contour for the resistivity of 200 ohm.m is compared with the gravity basement map (New Energy and Industrial Technology Development Organization, 1988).

A good correspondence can be seen between the resistivity and the gravity data, summarized as:

- (a) The upheaval of the resistivity basement in the southeast of the study area corresponds to the above-mentioned high gravity anomaly or the upheaval of the gravity basement therein.
- (b) The conductive area in the north of the test area corresponds to the area of low gravity anomaly.
- (c) The resistivity in the dense network area is rather high, and a narrow, relatively conductive zone runs across this resistive area in an almost north-south direction. This relatively resistive area corresponds to the area of high gravity anomaly caused by intrusive rocks.

#### 3.4 Mercury Concentration Data

In Fig. 6, the resistivity distribution at a depth of 1,500 m below sea level obtained from the TE mode data is compared with the distribution of mercury concentration (New Energy and Industrial Technology Development Organization, 1988). High mercury-concentration anomalies are seen around the spa of Isoya hot spring and Ofuna-Shimonoyu. The anomaly at the Isoya area extends further to the west. The high anomaly at the Isoya area also extends continuously southward from its east side to the dense network area.

When the results of the MT analysis are compared with the mercury concentration data, we note a good correspondence between the high mercury concentration anomaly around the spa of Isoya and the low resistivity

area detected through the MT survey. The spatial distribution of mercury concentration is supposed to be effective in detecting fracture-type reservoirs, because mercury gas tends to rise along fractures from the deep earth. In this connection, we may speculate that the north-south trending, relatively conductive area in the dense mesh-point measurement area, extends northward to the conductive area found east of the spa of Isoya at a depth of at least 1,500 m below sea level, as implied by the distribution of high mercury concentration mentioned above. This suggests the existence of fracture zones extending in the north-south direction in the above area.

#### 4. CONCLUDING REMARKS

Since the study area is close to the sea (the Uchiura Bay), we must pay much attention to the coast effect in interpreting the MT data. Practically we estimated the effect by making two-dimensional calculations. We then found that the tipper is affected considerably but the apparent resistivity estimates are less affected, particularly in the case of the TE mode. Since the resistivity was estimated mostly from the TE mode throughout this paper, it is likely that the results shown in this paper are not significantly affected by the sea effect.

The wells drilled in the study area have indicated that a possible geothermal reservoir exists in the southeast of Mt. Nakitsura (see Fig. 1) and the reservoir probably originates in the fractures developing in the intrusive rock formation. In detecting such a fine structure as the fracture zone in the intrusive rock, the conventional MT survey at scattered sites combined with the dense network survey turned out to be effective. From the coarse MT measurement, we could detect the relatively resistive intrusive rock formation, whereas the dense network survey clarified the existence of the relatively conductive fracture zone, 200–300 m wide, running in the north-south direction in the intrusive rock formation.

The electrical logging data and the gravity data support our claim that the intrusive rock formation could be detected by the MT measurements at rather scattered sites. The mercury concentration data also support the existence of the relatively conductive zone in the intrusive rock formation. It should be noted, however, that such a fine resistivity structure is unlikely to be derived with a coarse

MT measurement. It is the dense network MT measurement that is powerful enough to meet the requirement of resolving a fine structure, as indicated by the two-dimensional analyses. When a more practical three-dimensional analysis becomes popular in the future, a dense network MT measurement will turn out to be an effective tool for resistivity structural analysis.

#### 5. ACKNOWLEDGEMENTS

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#### 6. REFERENCES

- Gamble, T.D., Goubau, W.M. and Clarke, J. (1979a). Magnetotellurics with a remote magnetic reference. *Geophysics*, Vol. 44, 53–68.
- Gamble, T.D., Goubau, W.M. and Clarke J. (1979b). Error analysis for remote reference magnetotellurics. *Geophysics*, Vol. 44, 959–968.
- New Energy and Industrial Technology Development Organization (1988). Geothermal Development Promotion Survey Report of Minamikayabe Area, Report No. 13.
- Takasugi, S., Kawakami, N. and Muramatsu, S. (1989). Development of a "high accuracy MT" system and analysis of corresponding high-density MT measurements. Expanded Abstracts with Biographies 1989 Technical Program Vol. 1, 59th Annual International SEG Meeting, 175–178.
- Takasugi, S., Muramatsu, S., Yamaki, H. and Ikehata, T. (1992). Development of a High Accuracy MT system –system design and noise test–, *Butsuri-Tansa (Geophys. Explor.)*, Vol. 45, 190–203.



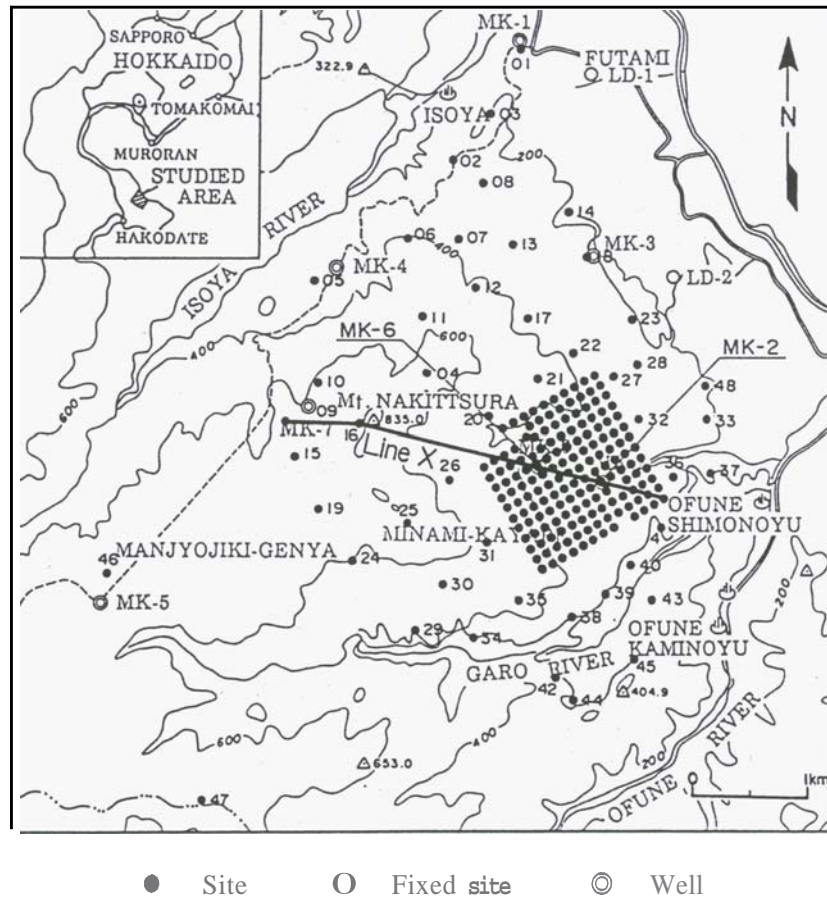


Figure 1– Location of the case study area; the Minamikayabe area, southern Hokkaido, Japan. Solid dots represent MT sounding sites. Open circles, LD-1 and LD-2, indicate the locations of fixed remote-reference points. Double circles, **MK-1**, **MK-2**, **MK-3**, **MK-4**, **MK-5**, **MK-6**, and **MK-7**, indicate the wells drilled for geothermal exploration. An east-west running solid line is a traverse line for which cross-sectional view of the structure will be presented later.

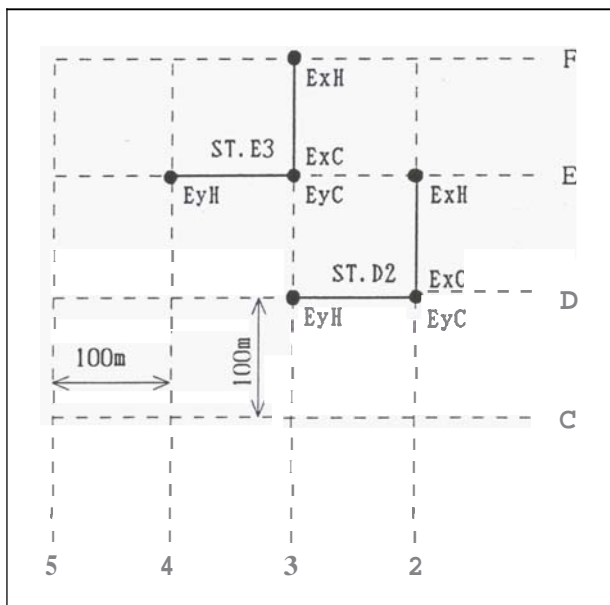


Figure 2– Arrangement of electrode points for electric field measurements in the dense network area.

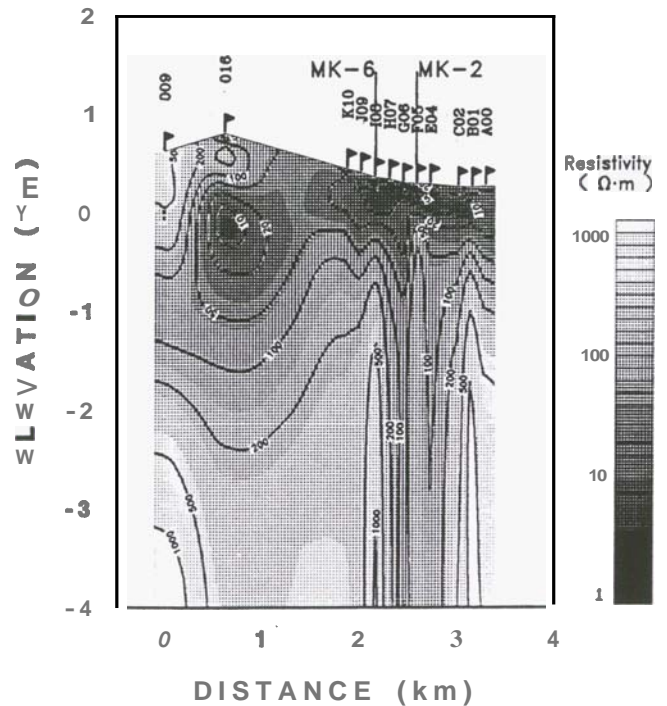


Figure 3– A cross-sectional view, derived from Bostick inversion, along the east-west traverse line running through the two wells, MK-6 and MK-2 (see Fig. 1).

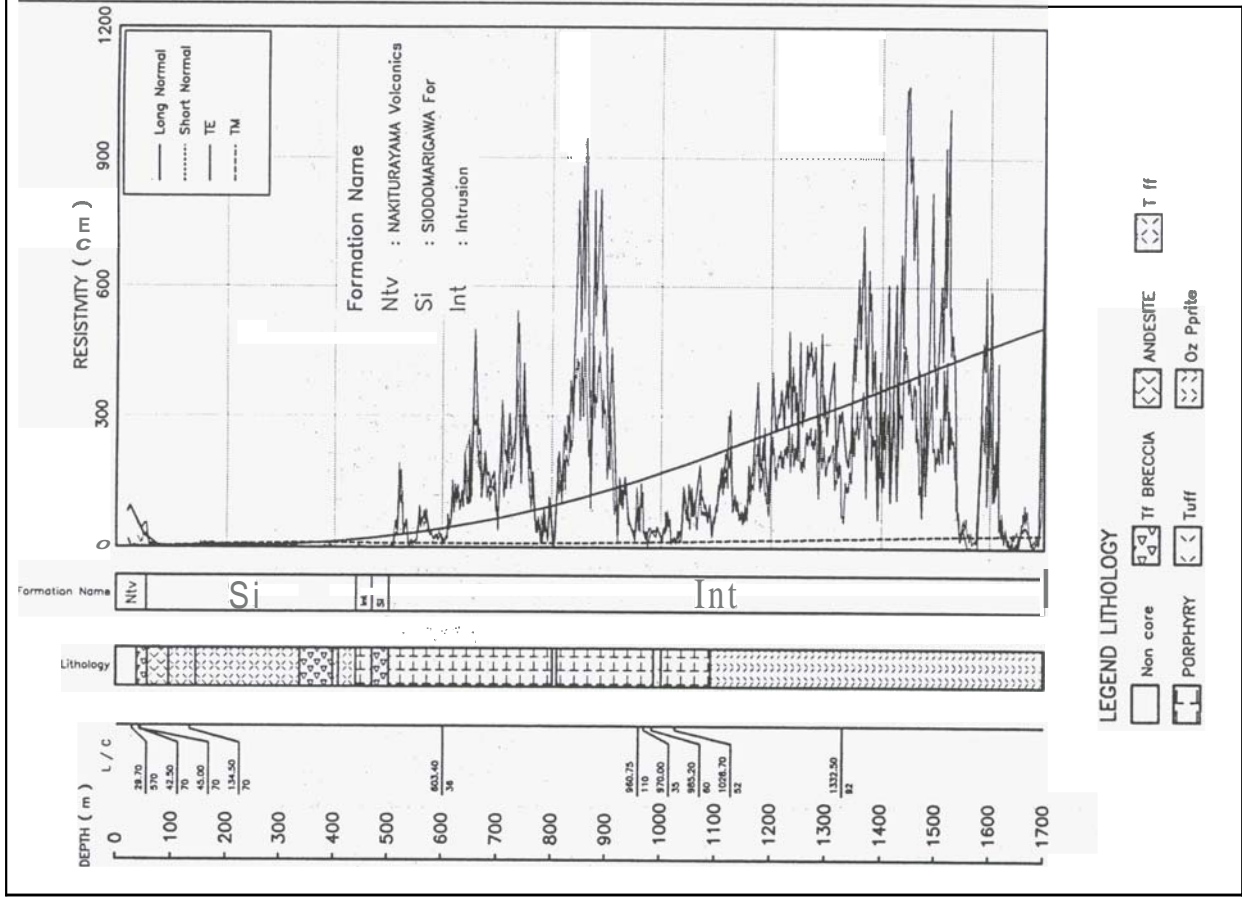


Figure 5- Logging data for the MK-6 well and the resistivity distribution with depth derived from one-dimensional Bostick inversion of the TE- and TM-mode data at the nearby sounding site, I08.

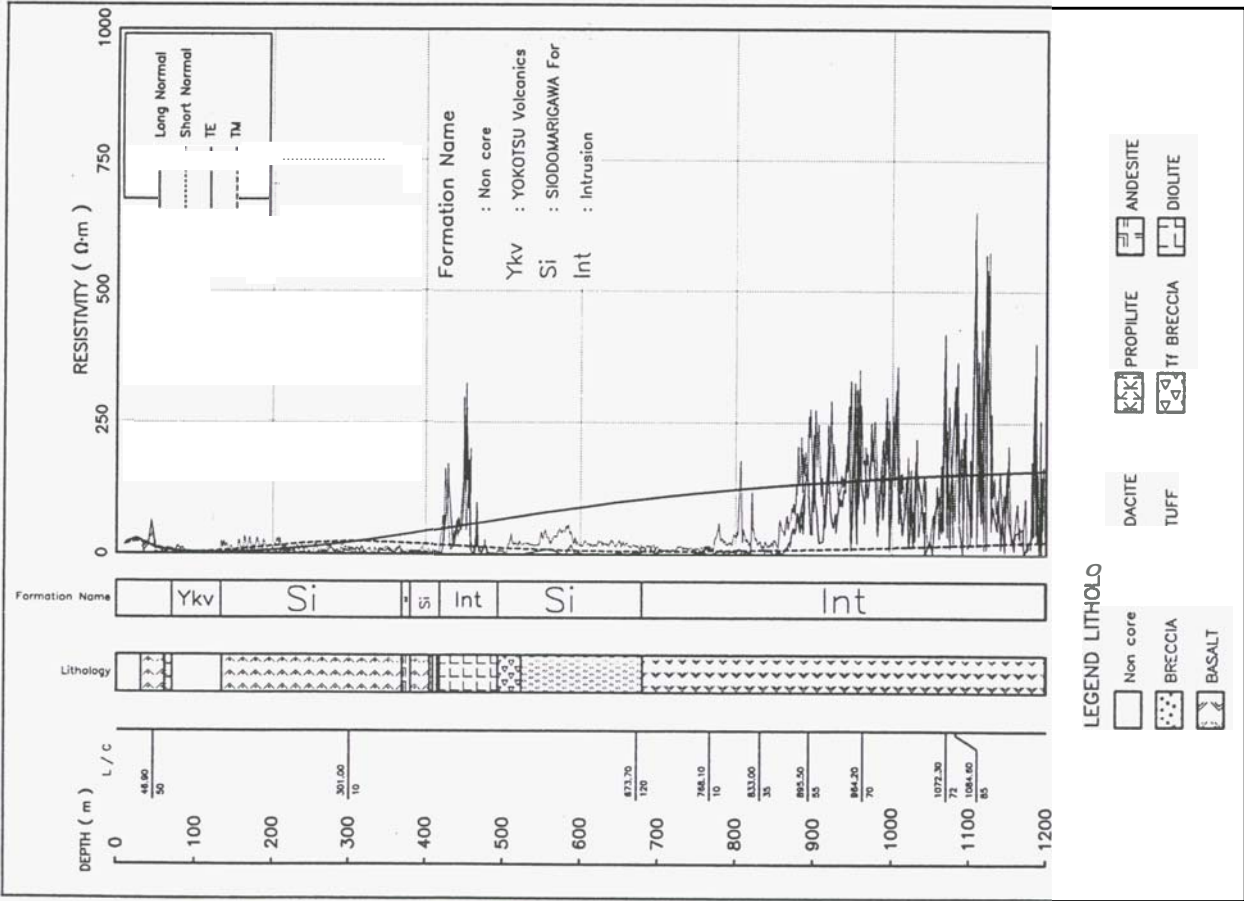


Figure 4- Logging data for the MK-2 well and the resistivity distribution with depth derived from one-dimensional Bostick inversion of the TE- and TM-mode data at the nearby sounding site, F05.

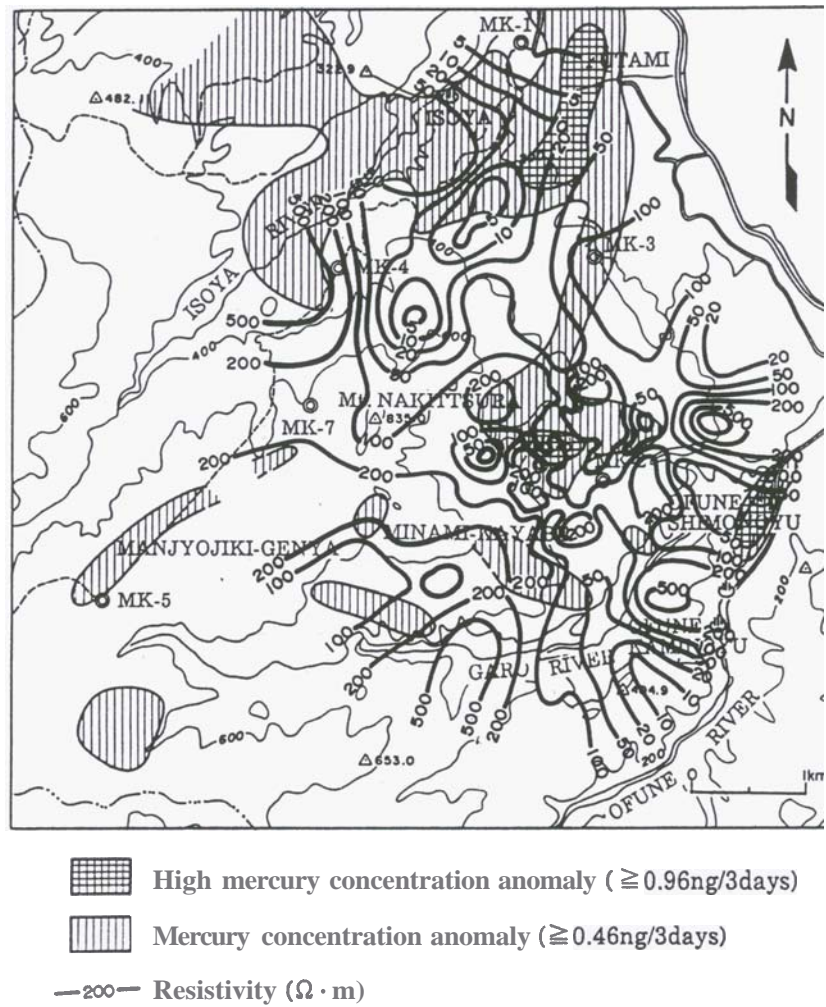


Figure 6- Comparison between the resistivity distribution, derived from the Bostick inversion for the TE-mode data at a depth of 1,500 m below sea level, and the distribution of Mercury concentration (New Energy and Industrial Technology Development Organization, 1988).