THREE DIMENSIONAL MODELING OF GEOELECTRICAL STRUCTURE IN HIRAYU HOT SPRING

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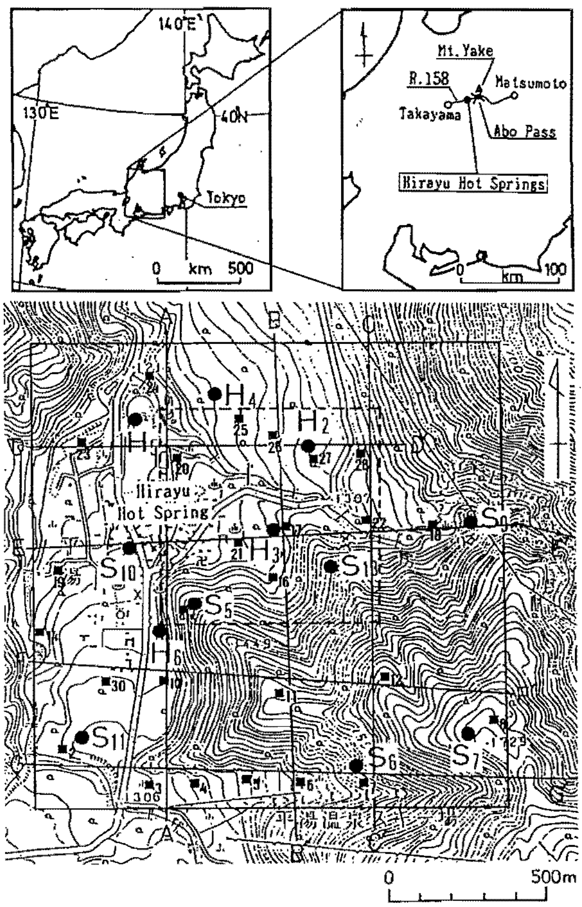
The purpose of this study is to develop the three dimensional resistivity modeling technique using finite element method for the magnetotelluric prospecting in geothermal areas, through the case study of Hirayu Hot Spring area (Fig.1). We reported some results in this study at the last meeting. However, the method discussed in the last year was insufficient for the accuracy. A major problem was to lead the significant error, when the large resistivity lateral change existed in a two dimensional structure. This problem was not entirely improved by only increasing the total number of element in the model. Therefore, we believed 8-noded isoparametric hexahedral element using the first order shape function was unadequate to obtain a good accuracy.

In the two dimensional modeling, it was made clear that the accuracy of modeling was remarkably improved using the second order shape function (Wakamatsu,1988). Therefore, we also tried to use 20-noded isoparametric hexahedral element, second order shape function, in the three dimensional modeling. The model using these elements has the advantage of not only improving the accuracy but also obtaining the good accuracy of differentiations, even when the model has large resistivity contrast. Moreover, it is possible to express topography and subsurface structure in reality because this element can represent a curved plane. The model using in this study has 10333 nodes and 2184 elements (13x14x12 [air part 4, earth part 8]). The computer memory was occupied about 65MB in this case. The Gauss-seidel iteration method requiring smallest computer memory was used to solve the grobal matrix of the model. The relative error of breaking off the iteration was less than 1x10E-04. The accuracy for the two dimensional model test, having resistivity contrast was 1:10, was indicated that maximum error was 5% in the E-polarization case and was 20% in the H-polarization case which is generally inaccurate.



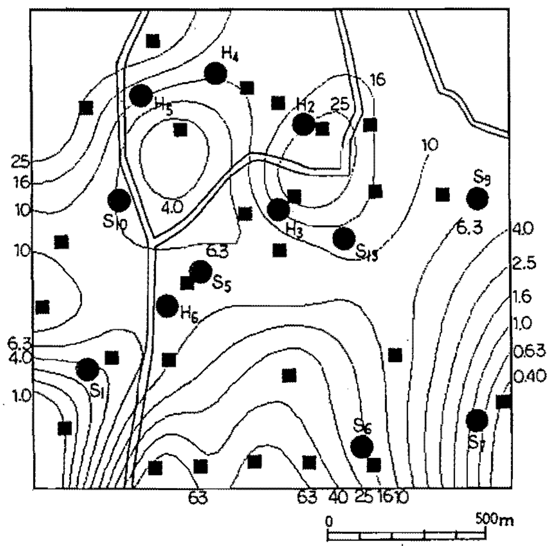


Fig.2 Distribution of apparent resistivity at 7.8Hz. Resistivity in ohm-m
●:Well ■:Survey site

Fig.1 Magnetotelluric survey site map of the Hirayu Hot Spring. ●:Well ■:Survey site
The square of solid line i the area of apparent resistivity map. The square of broken line is the area of the three dimensional analysis. Solid lines are the sections of the two dimensional analysis.

We discussed the resistivity structures in the Hirayu Hot Spring area by using magnetotelluric scalar apparent resistivity at the last meeting. However, this time, intrinsic apparent resistivity, which derived from solving the eigenstate formulation of tensor impedance, was used in this study. Fig.2 shows the apparent resistivity map at 7.8Hz and these apparent resistivity values are geometric means of two intrinsic values. This figure indicates the low resistivity zones extend from the center of Hirayu Hot Spring to the direction of east-southeast and to the direction of south-southwest.

Two dimensional analysis was made for seven lines from A-A' line to G-G' line as shown in Fig.1. The left figure of Fig.3 is the two dimensional model along B-B' line. This figure shows the low resistivity layers, less than 5 ohm-m, are existed in the second layer at site 26, 16 and 6. However, the low resistivity layer is not found at site 11. The resistivity value of the layer at site 16 is lower than that of site 26 and 17. The left figure of Fig.4 is the two dimensional model along E-E' line. This figure shows the low resistivity layers, less than 10 ohm-m, exist in the second or third layer at site 21 and 19 in the center of the Hirayu Hot Spring. Moreover, the low resistivity layer is found in the second layer at site 22 and in the third layer at site 18 and 31. The broken lines in Fig.3 and Fig.4 indicate the boundary of the low resistivity zone could not be determined by the ELF-MT method.

Three dimensional analysis was made for the area shown in Fig.1. Fig.5 shows the resistivity structure for about 900m level, 1000m level, 1100m level and 1200m level. This figure shows that the low resistivity zones extend to the 1000m-1100m level, and the high resistivity zones exist the first layer and the third layer (<900m level) except the center of Hirayu Hot Spring. The right figure of Fig.3 and Fig.4 show the resistivity structure along B-B' line and E-E' line. Comparing to the two dimensional model and three dimensional model, the low resistivity zones of the second layer are thicker than the two dimensional model and the resistivity value of the first layer is lager than that of the two dimensional model. The remarkable three dimensional effect is found in such a complicated resistivity structure as this area.

References

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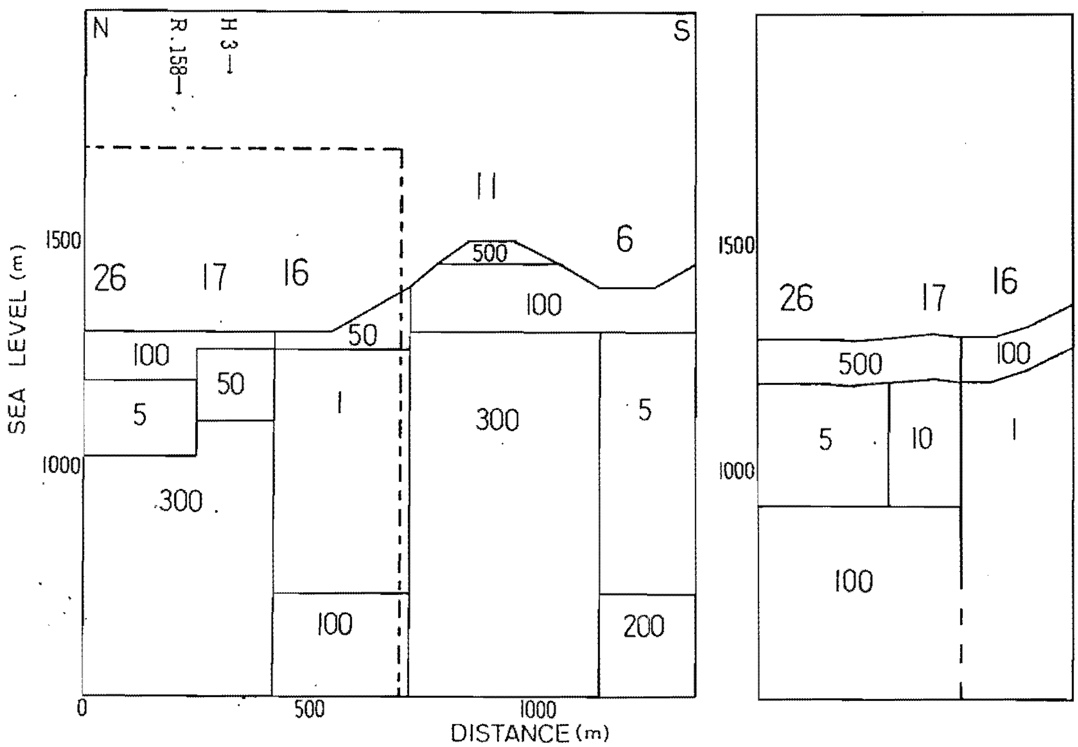

Fig.3 The left figure is two dimensional model and the right figure is three dimensional model along B-B' line. A chain line is the area of three dimensional model. Resistivity in ohm-m.

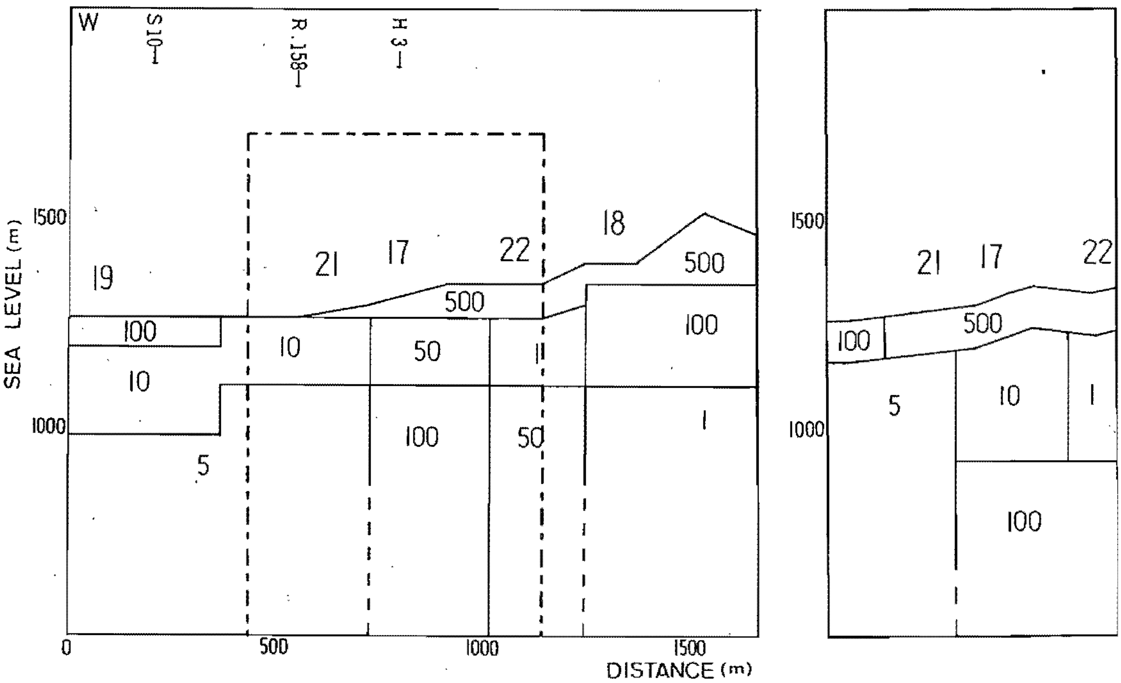

Fig.4 The left figure is two dimensional model and the right figure is three dimensional model along E-E' line. A chain line is the area of three dimensional model. Resistivity in ohm-m.

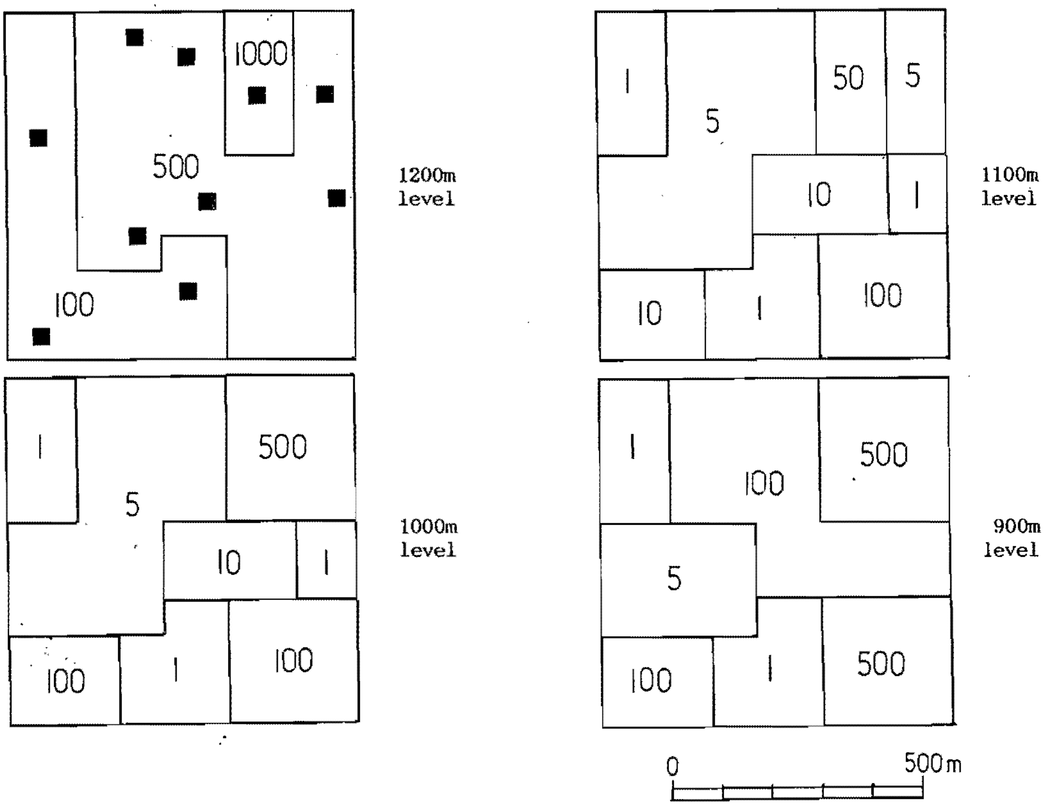

Fig.5 The resistivity structure for 900m,1000m,1100m and 1200m level. Resistivity in ohm-m.

GEOTHERMAL EXPLORATION BY THE MISE-À-LA-MASSE METHOD

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The mise-à-la-masse survey was carried out in 1983 at Hatchobaru geothermal field using HT-8 exploratory well which is located near the present geothermal reservoir of 55 MW power station. The HT-8 well is directional and cased to the TD of 1276 m.

If the geothermal reservoir is charged electrically by the use of well casing pipe, the shape of the equipotential lines will reflect the geometry of the reservoir and be expected to yield some informations on the strike, dip of the fault and the electrical resistivities of the formations in the surveyed area. The residual maps derived from the data processing clearly indicated the four promising zones including the present geothermal reservoir. It was found that the mise-à-la-masse measurements used in this survey showed the sharply contoured residual anomalies because of the high contrast in true resistivities among the surrounding rocks, hydrothermally altered zones and geothermal fluids. It was concluded that the distribution of low resistivity zones and the lateral changes of the geothermal reservoir could be directly determined by the mise-à-la-masse measurement in a geothermal area, because the anomalous area shows a good agreement with the low resistivity layer determined by the DC (Schlumberger) resistivity method.

Potential anomalies with regard to a regional effect are determined by the data processings and their possible causes are simulated from the three-dimensional (3D) modeling by the numerical calculation of the finite difference method (FDM).

PROCEDURES OF DATA PROCESSING

Potential difference anomalies with regard to a regional effect are computed by the data processings, and their possible causes are investigated according to the flowdiagram shown in Figure 1. The actual voltage V measured at each station are transformed into the apparent resistivity using the geometric factor and compared with the theoretical value in order to get a residual anomaly at each station.

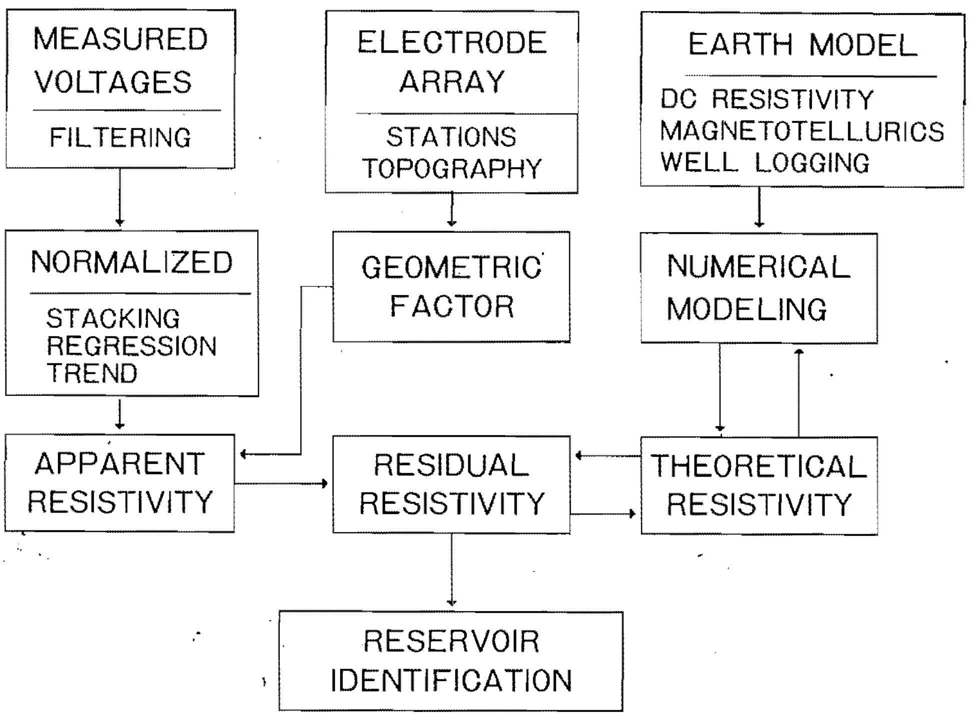

Figure 1. Data processing for the mise-à-la-masse measurement.

COMPARISON WITH SCHLUMBERGER SURVEY

Figure 2 shows the apparent resistivity map obtained by the mise-à-la-masse method. The distribution of true low resistivity determined from the resistivity inversion of Schlumberger VES curves is shown in Figure 3. Both resistivity contour maps show good agreement. Therefore, the mise-à-la-masse method can be used for determining areas of anomalously low resistivity instead of DC resistivity and/or MT survey which are indicative of potential geothermal reservoir beneath the thick resistive volcanic rocks that cover the Hatchobaru geothermal field.

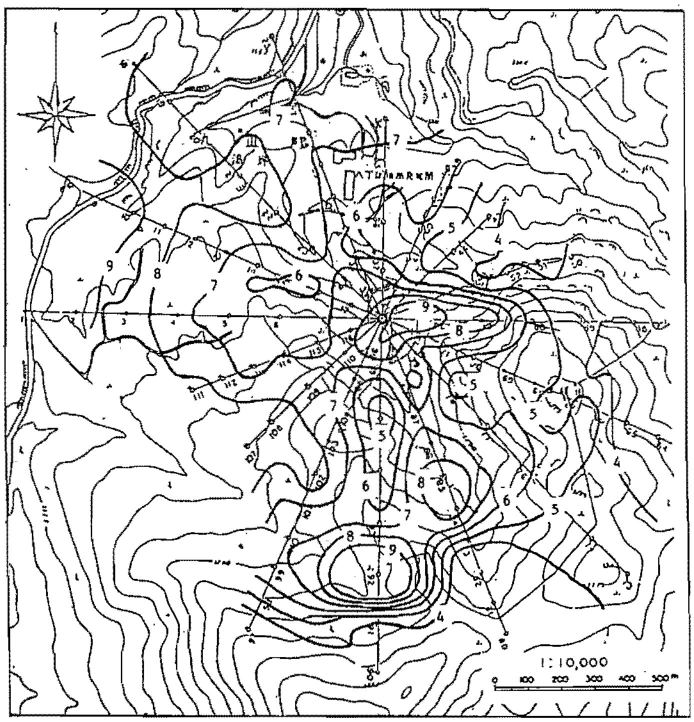

Figure 2. Apparent resistivity contour map determined by the mise-à-la-masse method (unit: ohm-m).

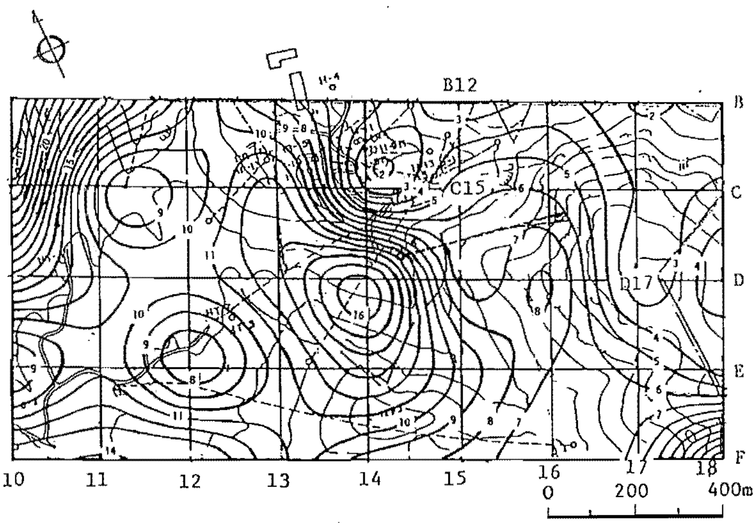

Figure 3. True resistivity contour map determined by the resistivity inversion of Schlumberger resistivity sounding data.

INTERPRETATION

Figure 4 shows the contour map of residual anomalies derived from the data processing. The mise-à-la-masse method indicated anomalously potential zones including the present production zone in the northeast part of the area. It is noted that the present production zone shows a largest anomaly of -0.4 mV/A in the survey.

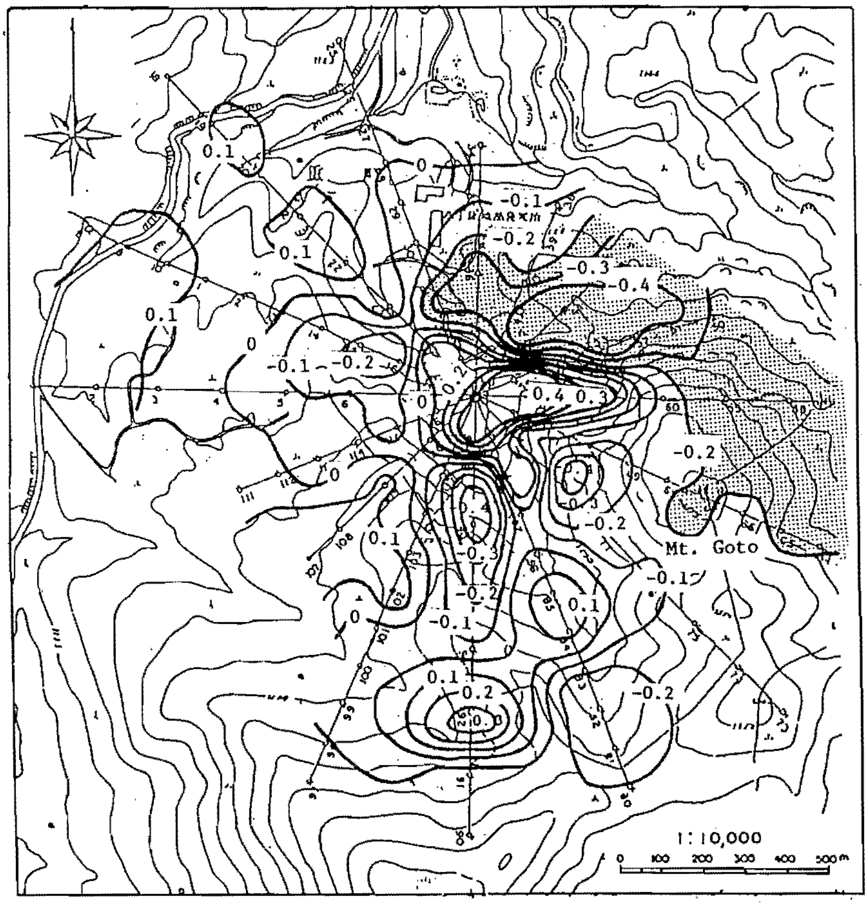

Figure 4. Residual potential anomalies by the mise-a-la-masse survey in Hatchobaru geothermal area using HT-8 well casing.

The zone of north-eastern part corresponds to the known geothermal area where supplies steam to the 55 MW geothermal power plant in Hatchobaru area. The other zone of north-western part is also confirmed that the reservoir temperature is high, 240°C. The south-eastern part near Mt. Goto was not developed yet, but the zone is the most promising for further geothermal development in Hatchobaru geothermal area.

COMPARISON WITH THE OTHER DATA

Figure 5 shows the detailed map of the residual potentials around the present production zone. From this result, it was confirmed that HT-8 well was drilled within the more resistive zone compared with the surrounding formations, then the well was unproduced. It was found that the almost all of production wells are located in the region marked and the contour lines of the residual potentials are elongated in the north-west to south-east direction. This direction coincide with the strike of Komatsuike sub-fault (dashed line) determined by the MT and DC resistivity surveys, that is considered to be the geothermal reservoir in Hatchobaru geothermal field.

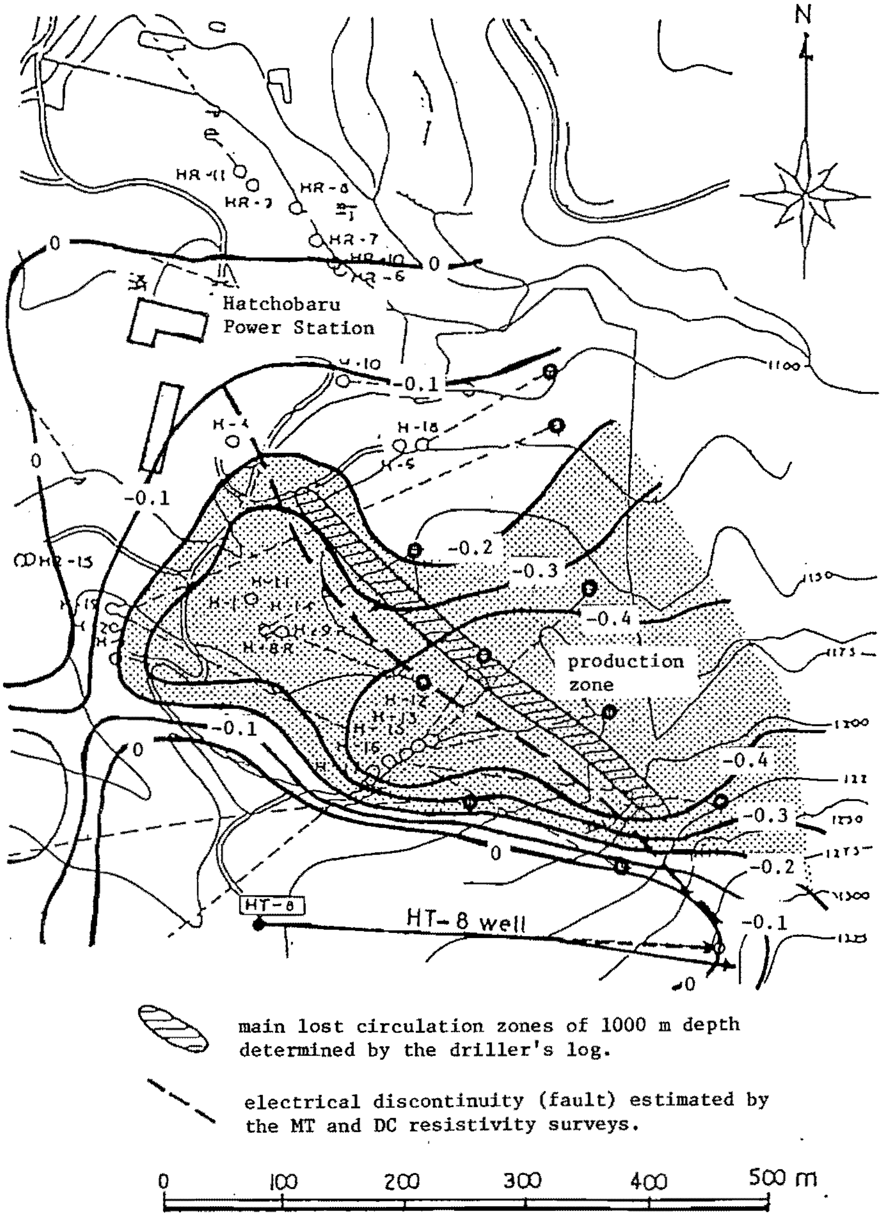

Figure 5. Residual potential contour map over the present production zone in Hatchobaru geothermal field with the other exploration data.

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