Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

THREE DIMENSIONAL MODELING OF GEOELECTRICAL STRUCTURE BASED ON MT AND TDEM DATA IN MORI GEOTHERMAL FIELD, HOKKAIDO, JAPAN

Tatsuya Kajiwara[1], Tohru Mogi[2], Elena Fomenko[3] and Sachio Ehara[4]
[1] JMC Geothermal Engineering Co., Ltd., 72 Sasamori, Ukai, Takizawa, Iwate 020-0172, Japan
[2] Graduate School of Science, Institute of Seismology and Volcanology, Hokkaido University, N10W8, Kita-ku, Sapporo, Japan
[3] Geoelectromagnetic Research Institute, Troitsk, Moscow Region, Russia
[4] Graduate School of Engineering, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka, Japan

Key Words: 3D modeling, MT, TDEM, Mori geothermal field

ABSTRACT

We applied a 3D modeling scheme for MT and TDEM data to the Mori geothermal field at Hokkaido, northern Japan to clarify the resistivity structure up to 3km depth. The three dimensional modeling scheme of MT and TDEM data based on the staggered grid approximation of the secondary electrical field (Fomenko et al., 1998) was extended to a model including topography by Fomenko et al.,(1999). We had made 3D resistivity model based on MT data . However, because of distributing low resistivity layer (about 5 ohm-m) at shallower depth, we were not able to identify the detailed resistivity structure at deeper part (more than 1km depth), even though using low frequency data, up to 0.001Hz. We expected TDEM survey and 3D modeling would overcome this problem, because the TDEM response seems to be more sensitive to a local structure at depth than MT. We obtained a 3D resistivity model up to 3km depth including topography, using 84 transient vertical magnetic responses obtained in the Mori. The resistivity structure of the Mori generally corresponds to the distribution of rock. A resistivity low of 5 to 10 ohm-m is distributed at the south-western part of the caldera located in the center of the Mori. This area was suggested as one of the up flow zones of geothermal fluid to Mori geothermal reservoir.

1. INTRODUCTION

The Mori geothermal field is a liquid-dominated geothermal field located at the Nigorikawa Basin in the north of Japan (Figure 1). In this field, the Mori geothermal power station (50MWe) has been in operation since 1982 by Hokkaido Electric Power Inc. where Dohnan Geothermal Energy Co., Ltd.(DGE), a subsidiary of Japan Metals and Chemicals Co., Ltd.(JMC), is steam supplier. The geology (shown in Figure 2) is mainly composed of vent fill, lake deposits and andesite intrusion in the funnel-shaped Nigorikawa Caldera which was formed about 12,000 years ago. Pre-tertiary basement (Kamiiso Group) consists of chert, pelite, limestone and crystal limestone, and the Neogene Ebiyagawa Formation which unconformably overlies the Kamiiso Group (e.g., Ando et al., 1992; Kurozumi and Doi, 1993,1995). The shape of the caldera has been confirmed by drilling and the three-dimensional gravity analysis (Kondo et al., 1993). The geothermal fluid flows through the caldera wall and the boundary of the andesite intrusion. The depth of the geothermal wells drilled recently reached more than 3km. We need information of the structure of the deep seated (at least up to 3km) geothermal reservoir. The purpose of this study is to identify the resistivity structure and to find a promising geothermal reservoir. We will present the result of 3D modeling and an interpretation of resistivity structure in comparison with geology and geothermal structure.

2. FIELD SURVEY

2.1 MT SURVEY

MT survey of frequency range from 0.001 to 10,000Hz was carried out in the Mori and surroundings (NEDO, 1991). Figure 3 shows the survey sites.

2.2 TDEM SURVEY

Previously, we have made a two-dimensional resistivity model based on MT data. However, because of the distribution of the low resistivity layer (about 5ohm-m) at shallower depth, we were not able to identify the detailed resistivity structure at deeper parts (more than 1km depth). Pellerin et al.(1996) evaluated four EM technique (MT, CSAMT, LOTEM, TEM) for use in geothermal exploration based on simple 3D numerical model. They suggested the methods, such as MT, which rely on electric field measurement, are superior to those where only magnetic field is measured, because of the presence of the electrical charge at the resistivity boundary. We consider, however, that the TDEM survey has better resolution than that of MT for a local structure at depth. We expected that 3D modeling using the TDEM data would overcome this problem.

The TDEM that we carried out here is similar to so called long offset TDEM but we used the B-field measurement and measured even in the near zone. The bipolar source, which ramp and off-time was 16 seconds was carried out at 84 sites as shown Figure 4. The transient vertical magnetic responses were obtained at each site. The spacing of the sites is about 200 to 500m.

3.THREE DIMENSIONAL MODELING

We used the three dimensional modeling scheme for MT and TDEM data based on the staggered grid approximation of the secondary electrical field (Fomenko et al., 1998, 1999). This scheme is possible to treat a model including topography.

3D grid model based on the MT data

The model has 6804 elements (18 (NS) x 18 (EW) x 21 (vertical), the upper 6 and lower 15 layers correspond to air and earth parts, respectively (Figure 3). Three layers were added as buffer layers, which were to reduce an influence of the boundary. We calculated the apparent resistivity at nine frequencies, which range from 1E-2 to 1E2 Hz, two frequencies per decade. The relative error of breaking off the iteration was less than 1x10E-6.

3D Grid Model based on the TDEM data

The model has 8280 elements (18 (NS) x 20 (EW) x 23 (vertical), the upper 7 and lower 16 layers correspond to air and earth parts, respectively (Figure 4). Three layers also were added as buffer layers to reduce an influence of the boundary. We calculate the vertical magnetic response at 91 frequencies, which range from 1E-5 to 1E4 Hz, 10 frequencies per decade. The relative error of breaking off the iteration was less than 1x10E-6. Transient vertical magnetic response of time domain was calculated by the Fourier transform. The total CPU time per one case was about 3 to 4 hours using the PC with Pentium-II 400MHz and 128MB memory.

According to electrical logs, vent fill and Ebiyagawa Formation indicate low resistivity; andesite intrusion, pelite and crystal limestone of Kamiiso Group indicate high resistivity; and chert and limestone indicate middle resistivity. Referring to these data, we made an initial three dimensional resistivity model.

At first we modified the model until we got a good fit with measured MT data. After that we modified the model until we got a good fit with measured TDEM data.

4.DISCUSSION

Figure 5,6 and 7 show the result of three dimensional modeling, examples of the sounding curve of MT and examples of the transient vertical magnetic response, respectively. The resistivity structure of Mori generally corresponds to the distribution of rock.

At 100m to 50m above the sea level, a layer of 20 to 50 ohm-m is widely distributed. However, the resistivity is 10 to 20 ohm-m in the northern part of the Nigorikawa basin where some hot springs are distributed. At 50m to -300m above the sea level, a resistivity low, 2 to 5 ohm-m is widely distributed, which corresponds to Ebiyagawa Formation and vent fill in Nigorikawa caldera. A resistivity high, 100 to 200 ohm-m is partially distributed, which corresponds to andesite intrusion which was detected as high density layer in the three dimensional gravity analysis (Kondo et al., 1993).

At -300m to -1100m above the sea level, resistivity varies from 5 to 200 ohm-m depending on the distribution of the rock. At less than -1500m above the sea level, the resistivity is 50 to 100 ohm-m in the northern part of the Nigorikawa basin and 20 to 50 ohm-m in the southern part. According to the numerical simulation of geothermal fluid flow (Sakagawa et al., 1994), the southern part of the Nigorikawa basin is a recharge zone of the Mori geothermal reservoir. Thus, this difference in resistivity suggests that the lower resistivity of southern part is related to the recharge zone of Mori geothermal reservoir. At less than -1750m above the sea level, a resistivity high 100 to 200 ohm-m is distributed in the caldera which corresponds to the andesite intrusion.

A resistivity low 5 to 10 ohm-m is distributed at the south-western part of the caldera. This area corresponds to the distribution of hydrothermal metamorphic minerals such as Ca-silicates (e.g. Garnet, Wollastonite, Actinolite, Clinopyroxene) which are concordant with the reservoir temperature of 200 to 260 degree C (Arai and Komatsu, 1997). Isotherm of 250 degree C is extremely shallow near N2-KX-3 (test well of New Energy and Industrial Technology Development Organization) which is included in this low resistivity area. Consequently, this low resistivity area suggests one of the up flow zones of geothermal fluid to Mori geothermal reservoir.

5.CONCLUSIONS

(1) We applied the three dimensional modeling scheme of MT and TDEM data (Fomenko et al, 1998, 1999) to the Mori geothermal field at Hokkaido. We obtained a three dimensional resistivity model up to 3km including topography, using MT data and 84 transient data of vertical magnetic response. (2) The resistivity structure of Mori field generally corresponds to the distribution of rock. (3) A resistivity low 5 to 10 ohm-m is distributed at the south-western part of the caldera. This area was suggested as one of the up flow zones of geothermal fluid to Mori geothermal reservoir.

ACKNOWLEDGMENT

The TDEM survey was carried out under the cooperative research with JMC Geothermal Engineering Co., Ltd., Central Institute of Electric Power Industry, Kyushu University and Kyoto University. The authors thank to the members of the Exploration Division of JMC Geothermal Engineering Co., Ltd. for their help and suggestions. The authors also thank JMC and DGE for their permission to publish this paper.

REFERENCES

Ando, S., Kurozumi, H. and Komatsu, R. (1992). Structure and Caldera-fill Deposits of Nigorikawa Caldera, *Abstr., 29th International Geological Congress*, Vol.2, pp.480.

Arai, F. and Komatsu, R. (1998). Hydrothermal Metamorphism in the Nigorikawa caldera, Hokkaido, Japan, *Proc. the 19th New Zealand Geothermal Workshop*, pp.397-402.

Fomenko E.Yu., Mogi T. (1998). 3D Modelling for high conductivity contrast structures, *XIV Workshop on EM induction in the Earth. Sinaia, Romania*, p.129.

Fomenko E. Yu., Kajiwara T., Mogi T. (1999). Three dimensional MT modeling for topography models and high resistivity contrast, *IUGG 22nd General Assembly, Birmingham*.

Kondo, T., Komatsu, R., Kurozumi, H. and Hanano, M. (1993). A three-dimensional gravity analysis at the Mori geothermal field, Hokkaido, Japan, *Proc. 88th Society of Exploration Geophysicists of Japan Conference*, pp.490-495 (in Japanese).

Kurozumi, H. and Doi, N. (1993). Inner structure of the Nigorikawa caldera, *Progr. and Abstr., Volcanological Society of Japan*, No.2, pp.14 (in Japanese)

Kurozumi, H. and Doi, N. (1995). Inner Structure of the Funnel-Shaped Nigorikawa Caldera Clarified by 3km Deep Geothermal Wells, Hokkaido, Japan, *IUGG 21st General Assembly, Boulder, Colorado*, B419.

New Energy Industrial Technology Development Organization (1991). *Geothermal Development Promotion Survey Report of Kaminoyu-Santai Area. [High accuracy magneto-telluric survey in Kaminoyu-Santai field, Hokkaido, Japan]* . (in Japanese).

Pellerin, L, Johnstone, J. M. and Hohmaan, G. W. (1996). A numerical evaluation of electromagnetic methods in geothermal exploration, *Geophysics*, Vol.61, pp.121-130.

Sakagawa, Y., Takahashi, M., Hanano, M., Ishido, T. and Demboya, N. (1994). Numerical simulation of the Mori geothermal field, Japan, *Proc. 19th Workshop on Geothermal Reservoir Engineering, Stanford University*, pp.171-178.

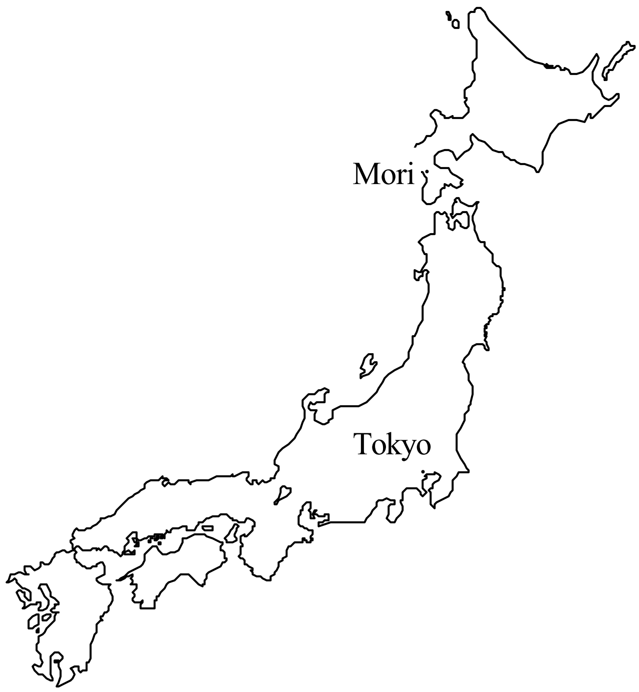

Figure 1 Location of the Mori geothermal field

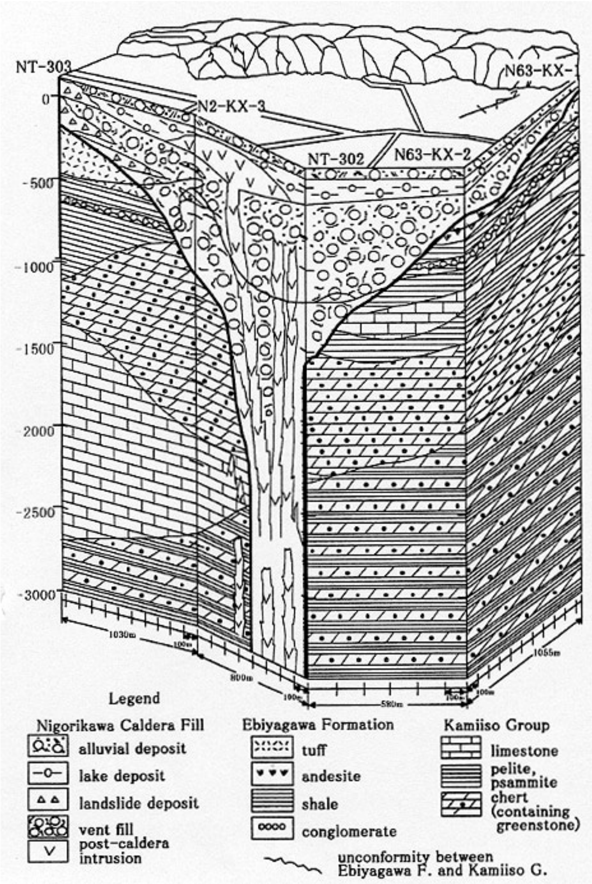

Figure 2 Schematic geological structure of the Mori geothermal field(modified from Kurozumi and Doi, 1993)

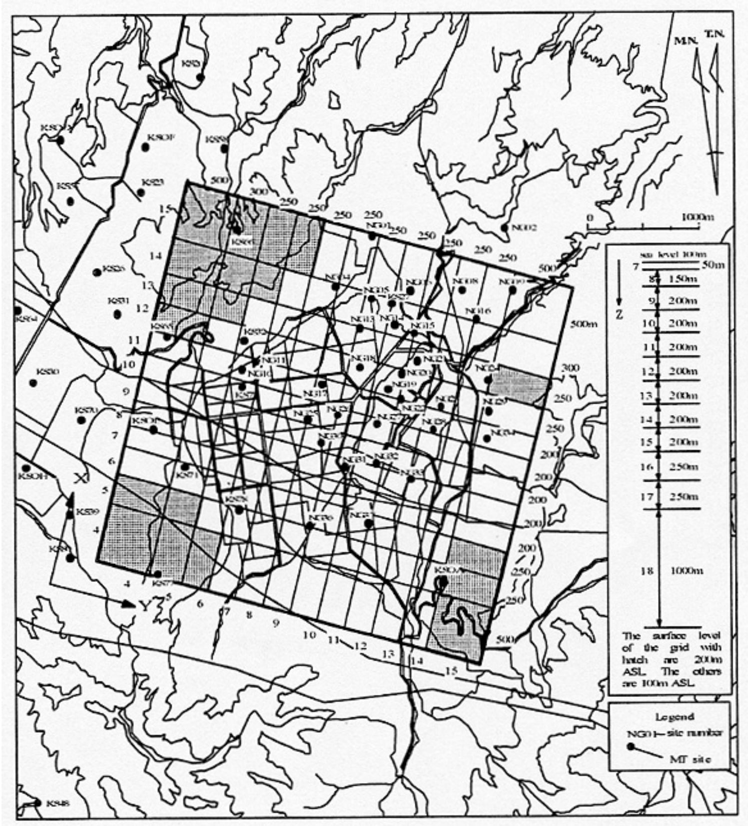

Figure 3 MT survey site map and the area of the three dimensional modeling of the Mori geothermal field

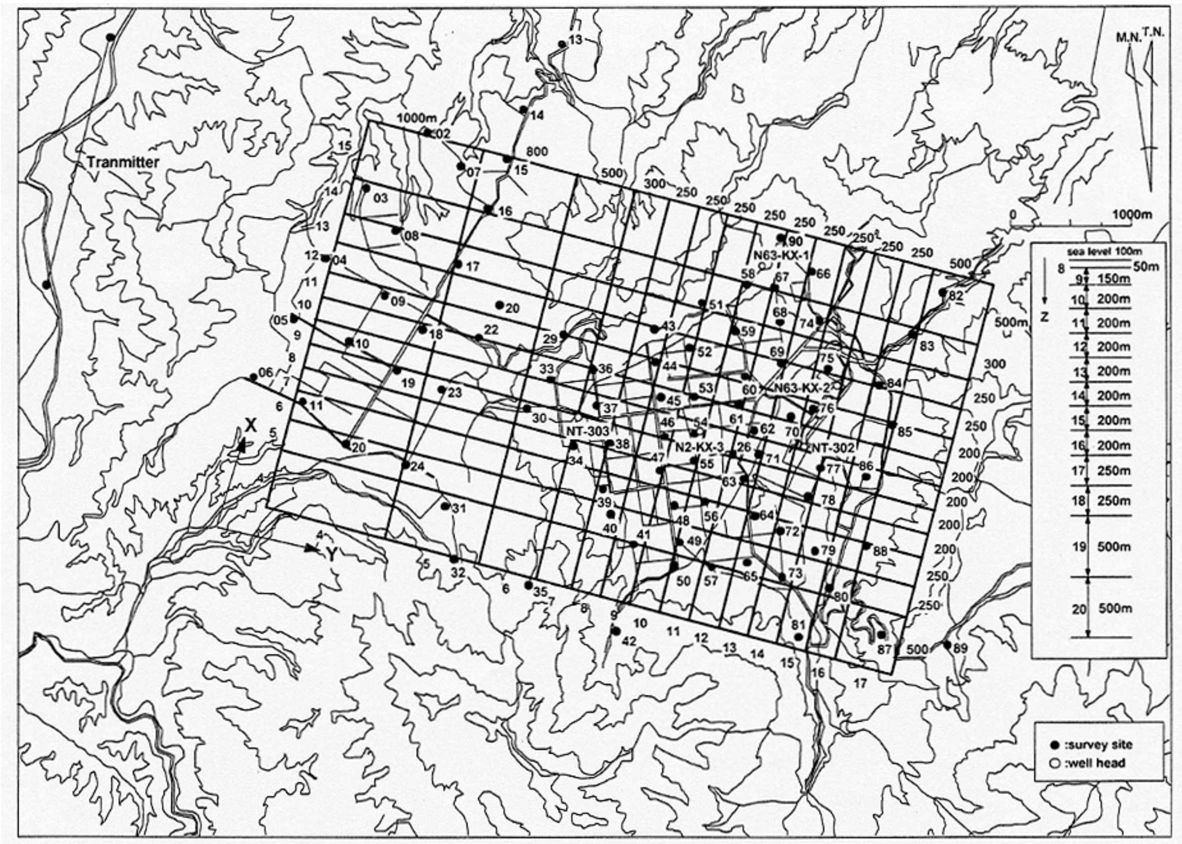

Figure 4 TDEM survey site map and the area of the three dimensional modeling of the Mori geothermal field

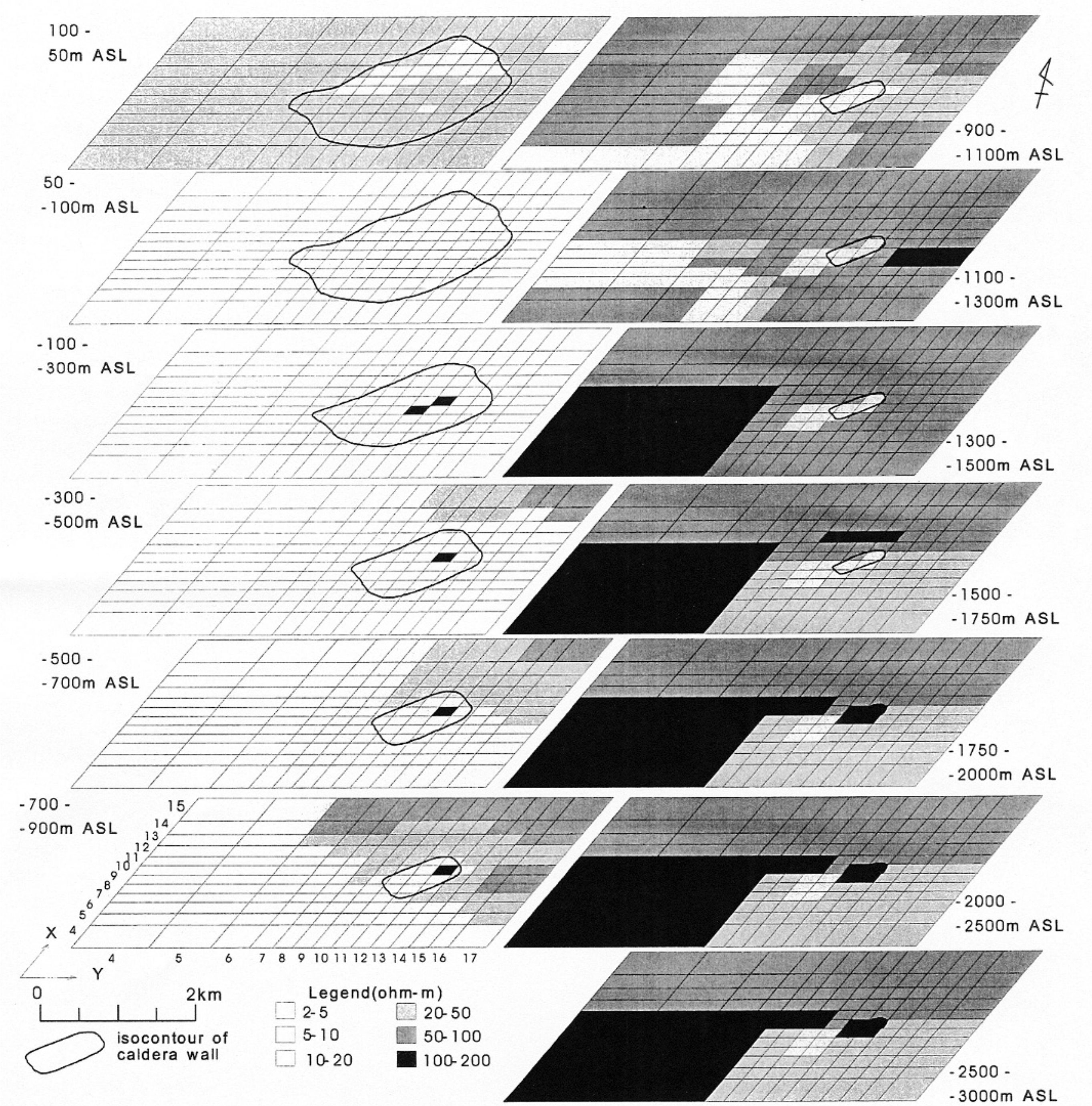

Figure 5 Result of the three dimensional modeling

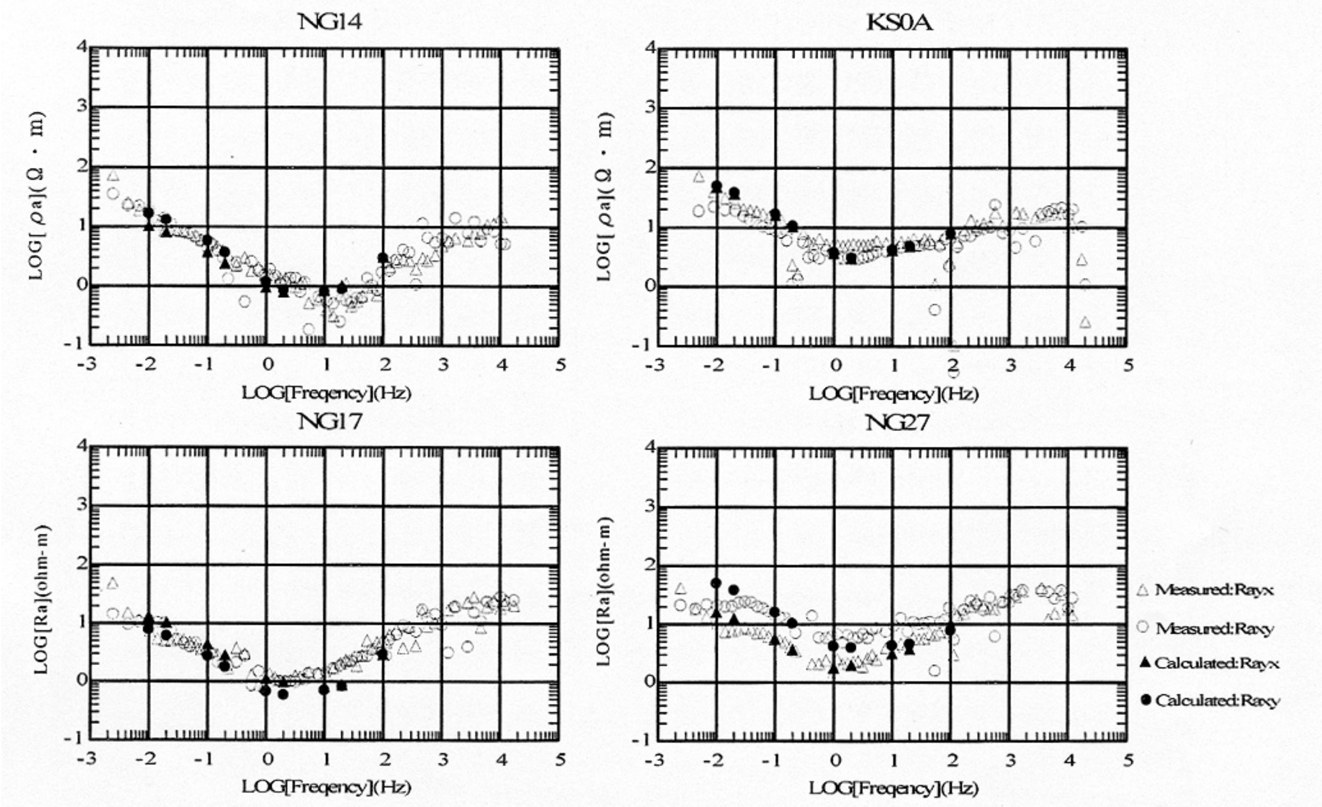

Figure 6 Examples of fitting between measured and calculated curve of the apparent resistivity and phase

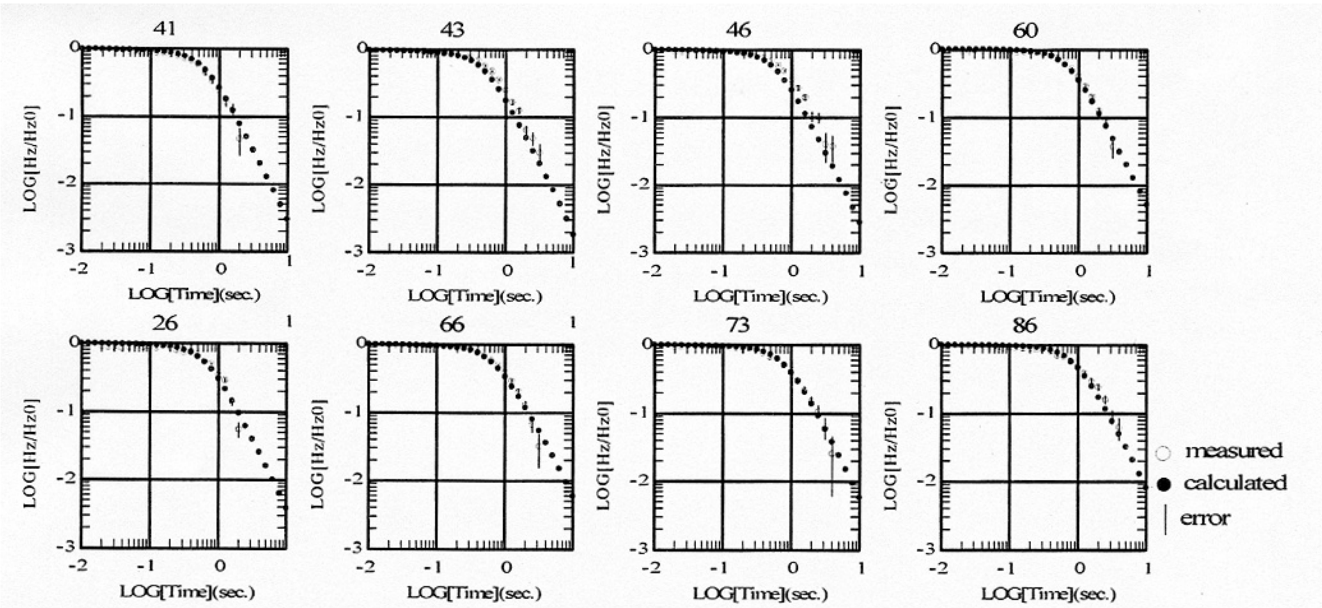

Figure 7 Examples of fitting between measured and calculated curve of the transient vertical magnetic response