Analysis of the Network-MT data observed in the Chugoku and Shikoku Regions in Southwestern Japan

Y. Shi[1], M. Uyeshima[2], H. Murakami[3], I. Shiozaki[4], S. Yamaguchi[5] and Y. Usui[6]
[1]Earthquake Research Institute University of Tokyo, shiyj330@eri.u-tokyo.ac.jp
[2]Earthquake Research Institute University of Tokyo, uyeshima@eri.u-tokyo.ac.jp
[3]Faculty of Science, Kochi University, murakami@kochi-u.ac.jp
[4]Faculty of Engineering, Tottori University, shiozaki@tottori-u.ac.jp
[5]Faculty of Science, Osaka City University, yanchi@sci.osaka-cu.ac.jp
[6]Earthquake Research Institute University of Tokyo, yusui@eri.u-tokyo.ac.jp

SUMMARY

The geological structure of the Chugoku and Shikoku regions of Japan is complex, and there is no overall model of the electrical resistivity structure of this region. In this study, we present horizontal distribution maps of magnetotelluric(MT) response functions (apparent resistivity and phase) calculated using Network-MT data, which were collected from Nippon Telegraph and Telephone Corporation telephone lines in this region during the period between 1994 and 1995. In comparison to traditional MT methods, the Network-MT method employs long dipoles for measuring electric fields, resulting in higher signal-to-noise ratios and eliminating static shift effects. The analysis of high-confidence data yielded interesting results of out-of-quadrant impedance phases at some sites.

Keywords: Network-MT method, Magnetotelluric, Electrical resistivity structure, Chugoku and Shikoku SW Japan

INTRODUCTION

The Chugoku and Shikoku regions are located in the southwestern part of Japan. The Philippine Sea plate subducts towards the Eurasian plate at this region (Figure 1). The Median Tectonic Line of Japan also passes through the northern part of the Shikoku region. The geology of these regions is complex.

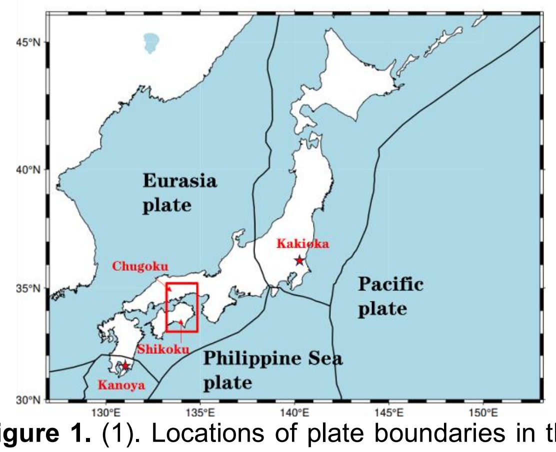

Figure 1. (1). Locations of plate boundaries in the Japan arc. (2). Red stars represent the Kanoya and Kakioka Magnetic Observatories. Kakioka's data and Kanoya's data are the local magnetic field and the remote reference magnetic field separately used in this study to calculate the impedance tensor. Plate boundary data from Bird, P. (2003)

Shiozaki et al. (1998) pointed out the possible existence of a conductive layer in the Chugoku region. Yamaguchi et al. (1999) concluded that the Shikoku region has a resistive area in the northern part of the region and high conductive area in the southern part. They also found a thin conductive layer on the subducting slab in the southern part of the median tectonic line. However, there is still no comprehensive electrical resistivity model covering the entire Chugoku and Shikoku regions.
Therefore, our ultimate goal is to determine the three-dimensional resistivity structure of the Chugoku and Shikoku regions using Network-MT data.

MTHODS

The Network-MT method is an electromagnetic exploration method that utilizes commercial telephone lines to measure voltage differences. Because the length of the measurement line is usually 10 to several tens of kilometers, we can measure relatively high signal-to-noise ratio data

using this method, and the Network-MT data is little affected by galvanic distortion (Uyeshima et al. 2007).
The method used in this study to calculate the impedance tensor for the Network-MT method is based on the approach described by Hata et al. (2012), which originates from Uyeshima et al. (2007).

First, according to

$$V(\omega) = V_x(\omega) \cdot H_x(\omega) + V_y(\omega) \cdot H_y(\omega) \qquad (1)$$

the response functions $V_x(\omega)$ and $V_y(\omega)$ between the horizontal magnetic fields $H_x(\omega)$ and $H_y(\omega)$ and the potential difference $V(\omega)$ were estimated, where ω denotes angular frequency.
Based on the equation (1), this study employed the BIRRP program (Chave and Thomson, 2003) to derive V_x and V_y from the time series data.

Then, the impedance tensors Z_{xx}, Z_{xy}, Z_{yx}, Z_{yy} were estimated by combining sets of V_x and V_y, taking into account electrode positions within a triangle defined by two observation baselines (Figure 2). The impedance tensors are obtained from equation, as follows

$$\begin{pmatrix} Z_{xj} \\ Z_{yj} \end{pmatrix} = \begin{pmatrix} -x_1 & -y_1 \\ -x_2 & -y_2 \end{pmatrix}^{-1} \begin{pmatrix} V_{1j} \\ V_{2j} \end{pmatrix} \qquad (2)$$

The subscript "j" denotes either "x" or "y". Subscripts "1" and "2" refer to the two dipoles forming the triangle, with coordinates (x_1, y_1) and (x_2, y_2) representing the vertices of the triangle, as illustrated in Figure 2.

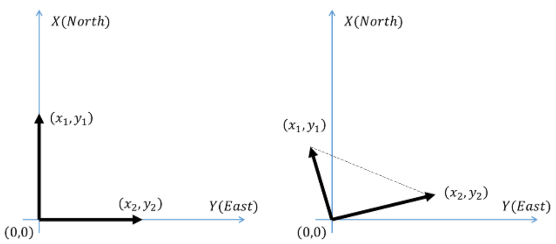

Figure 2. Schematic coordinate systems of (a) conventional MT and (b) network-MT for obtaining the impedance after Hata et al (2012).

RESULTS

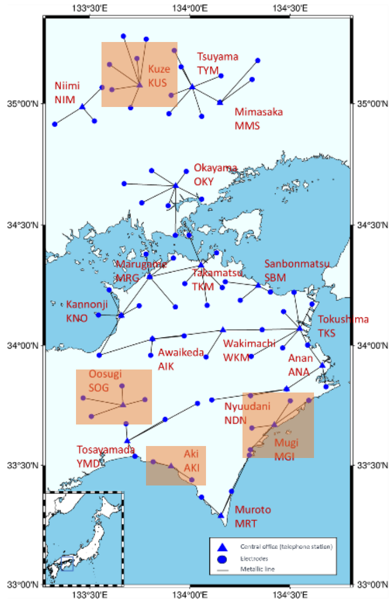

Figure 3. Spatial distribution of Network-MT observation sites. (1). The upper part of the image shows the Chugoku region, and the lower part shows the Shikoku region. (2). The orange squares are where the out-of-quadrant impedance phases were observed.

The data used in this study were collected from 1994 to 1995, with an average observation period of 90 days and a sampling interval of 10 seconds. There are five networks in the Chugoku region and 14 networks in the Shikoku region. Their electrode positions are shown in Figure 3.
We used Kakioka magnetic data as the local magnetic field and Kanoya magnetic data as the remote reference magnetic field (see Figure 1). The sampling interval of the geomagnetic data available for the period 1994-1995 was 1 minute, so the analysis of the electric field data was also performed with a 1-minute sampling interval .

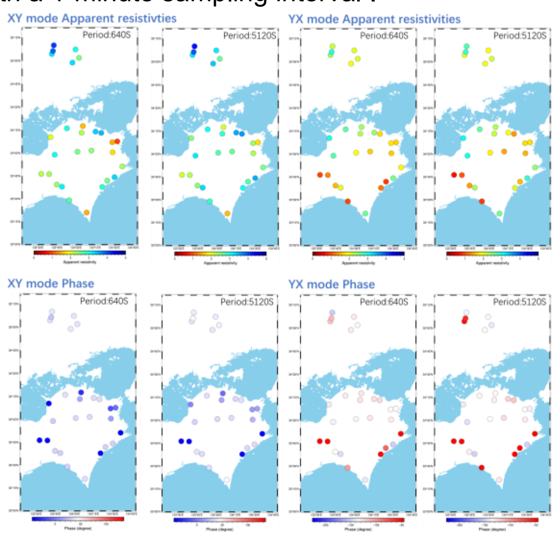

Figure 4 Apparent resistivity and phase maps for xy mode and yx mode at 640s and 5120s, respectively.

As shown in Figure 4, for the XY mode, the apparent resistivity of the Tokushima network relatively low and increases with period, from a few tens of ohm-meters to about 500 ohm-meter, and the rest of the area is generally in the range of 500 to 2000 ohm-meter. For the YX mode, the overall apparent resistivity is lower than that of the XY mode. Apparent resistivity in the Chugoku and the northern part of the Shikoku is about a few hundred ohm-meters, whereas that in the southern part of the Shikoku and the eastern part of the Shikoku is about a few tens of ohm-meters.
Data at Okayama area need to be analyzed more carefully because the electromagnetic field coherence is as low as 0.01 probably due to the leakage current from the nearby DC trains.
Normally, the phases for the off-diagonal components of the impedance tensor, XY and YX, are expected to lie in the first quadrant (0° < phs. < 90°) and the third quadrant (–90° < phs. < –180°), respectively.

It is worth noting that at the AKI, KUS, and MGI sites (Figure 3), we observed the YX component phase lying outside the third quadrant at the long-periods segments. This phenomenon referred to as out-of-quadrant impedance phases (POQ) (Figure 5 shows the example of the AKI site). Furthermore, at OSG, we observed instances where the XY component of the phase was in the third quadrant while the YX component was in the first quadrant.

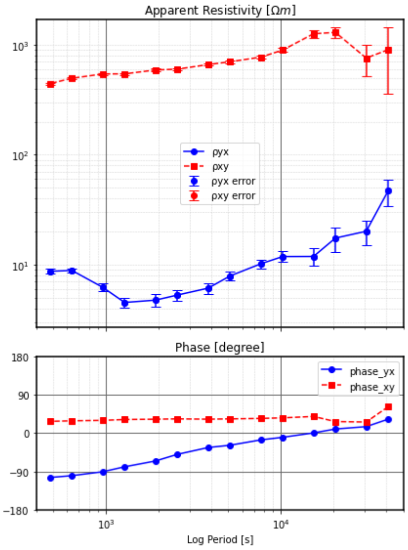

Figure 5. Apparent resistivity and phase curves of AKI

Discussion

Anomalous apparent resistivity and phase were observed especially at sites near the coast.
Okayama's station experiences significant artificial noise, primarily from the influence of DC trains. To mitigate this noise, we calculated data differences between two baselines to reduce common artificial noise at central stations. Additionally, we used only nighttime data for estimating the response functions. However, neither of these methods yielded satisfactory results. Therefore, future work may explore more sophisticated noise reduction techniques tailored specifically for high-frequency artificial noise. For instance, we are currently experimenting with the Multiple Remote Reference (MRR) method (Ritter 1998). We will keep exploring other methods for noise reduction.
The POQ phenomenon has been explained as an electrically anisotropic property (e.g. Pek 2009), galvanic distortion (e.g. Lilley&Weaver 2010) or the presence of 3D conductors (e.g. Ichihara et al. 2013), among others. The POQ in this study may be attributed to the complexity of electrical structures.

Conclusions

1. We obtained horizontal distribution maps of apparent resistivity and phase.
2. In the AKI, KUS, MGI, and OSG sites out-of-quadrant impedance phases were observed.
3. The discussion on noise reduction for Okayama has ruled out some less effective methods in the current study.

Acknowledgments

We gratefully acknowledge the support of the Nippon Telegraph and Telephone Corporation for their assistance with network-magnetotelluric observations. We also thank the Kakioka and Kanoya Magnetic Observatories for providing magnetic data. Special thanks to Chave and Thomson for providing the BIRRP code, which enabled smooth data processing. Lastly, we extend our appreciation to all the researchers who provided guidance and advice for this study.

Reference

Pek, J., & Spichak, V. V. (2009). Effects of electrical anisotropy upon magnetotelluric data: modelling and experiments. *Modern methods of electromagnetic data measurement, processing and interpretation. Librokom Publ, Moscow*, 110-135.

Bird, P. (2003). An updated digital model of plate boundaries. *Geochemistry, Geophysics, Geosystems*, *4*(3).

Chave, A. D., & Thomson, D. J. (2003). A bounded influence regression estimator based on the statistics of the hat matrix. *Journal of the Royal Statistical Society Series C: Applied Statistics*, 52(3), 307-322.

Hata, M., Oshiman, N., Yoshimura, R., Tanaka, Y., & Uyeshima, M. (2012). Fluid upwelling beneath arc volcanoes above the subducting Philippine Sea Plate: Evidence from regional electrical resistivity structure. *Journal of Geophysical Research: Solid Earth*, 117(B7).

Ichihara, H., Mogi, T., & Yamaya, Y. (2013). Three-dimensional resistivity modelling of a seismogenic area in an oblique subduction zone in the western Kurile arc: constraints from anomalous magnetotelluric phases. *Tectonophysics*, *603*, 114-122.

Lilley, F. E. M., & Weaver, J. T. (2010). Phases greater than 90 in MT data: Analysis using dimensionality tools. *Journal of applied geophysics*, *70*(1), 9-16.

Ritter, O., Junge, A., & Dawes, G. J. (1998). New equipment and processing for magnetotelluric remote reference observations. *Geophysical Journal International*, 132(3), 535-548.

Shiozaki, I., Nishigaki, T., Yamaguchi, T., Murakami, H., Oshiman, N., Uyeshima, M., Yamaguchi, S., Utada, H., Nishida, R., Sumitomo, N. (1998). A Report on Network MT Investigations in the Chugoku District, Southwestern Honshu, Japan. *Bulletin of the Earthquake Research Institute, University of Tokyo*, 73(3-4), 319-344.

Uyeshima, M. (2007). EM monitoring of crustal processes including the use of the Network-MT observations. *Surveys in Geophysics*, *28*, 199-237.

Yamaguchi, S., Kobayashi, Y., Oshiman, N., Tanimoto, K., Murakami, H., Shiozaki, I., ... & Sumitomo, N. (1999). Preliminary report on regional resistivity variation inferred from the Network MT investigation in the Shikoku district, southwestern Japan. *Earth, planets and space*, *51*(3), 193-203.