An approach for the three-dimensional interpretation of MT data distorted by the sea- and static effects

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SUMMARY

Three-dimensional (3D) magnetotelluric (MT) surveys were performed from 2004 to 2006 in Jeju Island to figure out any possible structure or potential anomaly related with remnant deep geothermal resources. To solve the old question that both the induction vectors and 3D inversion results have indicated the existence of a conductive anomaly in central parts of the island, 3D inversion incorporating the static shift was applied with the sea-effect-corrected MT data. The sea-effect was excluded from the Jeju MT dataset by an iterative correction method. The method repeats correction of sea effect by putting 3D forward models both including and excluding the surrounding sea effect as the components of the tensor distorted by the sea effect and then inverting the sea-effect-corrected responses. 3D inversion in this study dealt with the static shifts as inversion parameters. Reconstructed images using the MT dataset with sea-effect correction showed the conductive anomaly in a similar depth to previous works and RMS misfits converged to a lower value than those of inversion using non-corrected MT dataset. There can be big possibility of the isolated conductive anomaly under the Jeju Isalnd. Further investigations are needed to see if it is from a fracture containing saline water or from features related to old volcanic activities.

Keywords: magnetotelluric, sea-effect, static shift, 3D interpretation, Jeju Island

INTRODUCTION

MT method is a well-known tool for investigating various kinds of geological structures. Recently, it has been widely used in exploring the renewable energy such as geothermal resources. Korea Institute of Geoscience and Mineral Resources (KIGAM) of Korea and National Institute of Advanced Industrial Science and Technology (AIST) of Japan performed MT and audio-frequency MT (AMT) surveys at mid-mountain area of Jeju, the largest volcanic island in Korea. MT data with wide band and good quality were acquired, however, suffered from severe sea- and static effects (Lee et al., 2009). A new technique of an iterative sea-effect correction has been suggested (Yang et al., 2010). This study conducted the method for getting the sea-effect-corrected MT dataset. Control of the static shifts in MT inversion can be done by employing the static effect as variable (Sasaki, 2004). We inverted MT dataset with and without sea-effect correction to verify the feasibility of sea-effect correction technique for the real MT data and to get more reliable subsurface structures beneath the Jeju.

JEJU ISLAND

Jeju Island is the largest island located at South Sea of Korea, oval in shape, and is 31 km and 73 km along its minor and major axes, respectively. Mt. Halla, 1,950 m high above sea level, rises at the center of the island with a great mass of volcanic rock. It is a dormant volcano now, however the history says that the last volcanic activity was in 1007 A. D. Surrounding sea is getting deeper from the boundaries and reaches a flat 100 m deep. Geological structure of Jeju has mainly four-layer system; Quaternary basaltic lava, Plistoene consolidated sedimentary rocks (SF), Plio-Pleistocene unconsolidated sediments (UF), and basement rocks of welded tuffs and granite (Yoon, 1997).

MT DATASET OBSERVED IN JEJU

MT surveys were performed along five lines surrounding the mid-mountain area of Mt. Halla. A total of 108 measurements were made using Phoenix MTU-5A systems. Frequency ranges covering roughly 8 decades from 3×10^{-4} Hz to 10^{3} Hz was gathered in the survey. A far remote reference site is located at Ogiri in Japan, approximately 480 km apart from the center of the island. The sounding curves of apparent resistivity and phase generally show typical three-layered responses. Resistive top layer (basaltic lava), conductive middle layer (SF and UF) and resistive bottom layer (basement) were well-matched with the general stratigraphy.

In several studies on Jeju Mt dataset, the existence of conductive anomaly at the center of the island has been mentioned. Excluding the factors that can distort the MT data is one way to confide the results of interpretation. The sea-effect of MT dataset was validated the induction arrows, all of which for frequencies below 0.1 Hz pointed to the sea. Besides the sea-effect, MT dataset contains severe static shifts (Lee et al., 2009).

ITERATIVE SEA-EFFECT CORRECTION

In this study, an iterative method proposed by Yang et al. (2010) was applied to correct the sea-effect in MT data observed in Jeju. The impedance tensor of sea-effect-corrected data (Z_c) can be applied the multiplication of inverse impedance tensor of sea-effect (Z_s) and impedance tensor of the observed data (Z_0). At the first iteration, Z_s can be computed using an initial subsurface structure with (Z_m') and without (Z') the sea-effects.

$$Z_c = [Z_s]^{-1} Z_0 = Z_m' (Z')^{-1} Z_0. \quad (1)$$

In next iteration, Z_0 is replaced with Z_c in Equation (1) in previous iteration. As the iteration proceeds, an inverted model is getting closer to the true model.

INVERSION INCORPORATING STATIC SHIFTS

For the correction of static effect, an inversion incorporating static shifts was applied. Sasaki (2004) proposed 3D MT inversion technique incorporating static shifts as variable. The linearized problem can be shown as,

$$\Delta\mathbf{d} = \mathbf{J}\Delta\mathbf{m} + \mathbf{G}\mathbf{s}, \quad (2)$$

where $\Delta\mathbf{d}$ is a vector of differences between observed and predicted data, $\Delta\mathbf{m}$ is a model correction vector, $\mathbf{J}$ is a sensitivity matrix, $\mathbf{s}$ is a vector of static-shift parameters and $\mathbf{G}$ is a matrix which relates $\mathbf{s}$ to observed data.
Minimizing the objective function is equivalent to solving an observation equation. The iteration is continued until root-mean-square (RMS) misfits are reduced to acceptable level.

RECONSTRUCTED IMAGES

A linearized least-squares inversion incorporating static shifts was conducted using the sea-effect-corrected MT 3D data. MT dataset observed at 85 sites of the central part of Jeju Island, within the rectangle in Fig. 1. Fifteen frequencies from sounding data are selected in range of 3×10^{-3} Hz to 300 Hz. The sea and surface topography were not considered. The inversion blocks had a dimension of 2 km × 2 km in horizontal direction, while the vertical dimension varied with depth (20 × 14 × 19 blocks in x, y, and z directions, respectively). Data weighting was adopted based on the errors of measured data. Reconstructed images show three-layered electrical system of Jeju with a pattern of resistive-conductive-resistive aspects. SF and UF are marine-based and conductive, so that electrically indistinguishable to each other. At the final (15^{th}) iteration, the RMS misfits of inversion of MT data without and with sea-effect correction were 3.75 and 3.32, respectively. Both the inversions extract similar but severe static shifts at each site. Very conductive body in the center of the island was still found and it seems to be extended down to about 3 km in depth in both of the reconstructed results. In vertical sections along the central survey line, the existence of the real conductive anomaly in the structures under the Mt. Halla is getting more credible. It seems to be extended deeper than 5 km, though the feature smeared out as it goes deeper.

CONCLUSIONS

MT dataset observed in Jeju was wide-band of 8 decades with good quality but distorted by the sea- and static effects. To figure out any possible remnant geothermal regime under the island, MT data has been examined with respect to the sea-effect correction and inverted incorporating static shifts parameterization. Iterative sea-effect corrections have applied to the data and the inversion results before and after the sea-effects correction have compared. The sea-effect correction generally recovers the distortions at low frequencies and RMS misfits of inversion using MT data with sea-effect correction converged to a lower value than that without the sea-effect correction. The inversion results still show the conductive anomaly in a similar depth. It is another evidence of possibility that the conductive anomaly is not an artifact but a real structure. Additional investigation including exploration drilling is needed to identify the conductive anomaly.

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