Geoelectrical structure of Jeju Island deduced from 2D inversion of AMT and MT data

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Abstract: Two-dimensional (2D) interpretation of MT and AMT data observed in 2004 in Jeju Island is made using two inversion schemes developed by Uchida (1993) and Lee et al. (2002). These interpretations show that the subsurface of Jeju consists of roughly three layers. Reconstructed images along lines E and W reveal that the conductive layer beneath the topmost resistive layer of lava plateau can be a sediment layer. The geoelectrical structure along line E is more complex than that along line W, especially near Mt. Halla. The Uchida's (1993) scheme gives reasonable images, but much more time-consuming than that of Lee et al. (2002).

Keywords: MT, Jeju, geoelectrical structure, 2D inversion

1. INTRODUCTION

AMT and MT surveys at the mid-mountain area of Jeju Island have been performed by the Korea Institute of Geoscience and Mineral Resources (KIGAM) from 2004 to 2006 to figure out any possible remnant regime for geothermal resources related to the past volcanic activities, and to investigate deeply extended fractures or aquifer systems (Lee et al., 2006). The volcanic island of Jeju is oval in shape, and covers an area of 1,792 km^2 with 31 km along its minor axis and 73 km along its major axis of the N70E direction. Mt. Halla, which is 1,950 m high above sea level, rises in the center of Jeju and still looks like an active volcano. The mountain is known to be entirely composed of basalts and pyroclastic sediments, which are mostly formed by volcanic activity for a long time. Data from a large number of boreholes, deep electrical soundings (Lee et al., 1993), and stratigraphic profiling (Oh et al., 2000) reveal that the geological stratum of Jeju is composed of voluminous basaltic lava flow, crystalline volcaniclastics and sediments (Seogwipo Formation, SF), uncemented sediments (Unconsolidated Formation, UF), and basement rock of Cretaceous ~ Paleogene granite. Nam et al. (2006) performed a model study comparing observed MT data from Jeju to modeling results using a three-dimensional (3D) edge finite-element method (FEM) modeling algorithm (Nam et al., 2007), and suggested a resistivity model of Jeju Island, consists of four host layers with surface topography and surrounding sea of Jeju Island. Lee et al. (2006) performed 2D inversion of the AMT and MT data, which suggests a conductive anomaly at the central part of Mt. Halla.

To MT data obtained along eastern and western parts of Mt. Halla, we apply two different 2D inversion schemes developed by Uchida (1993) and Lee et al. (2002) and compare between two inversion results from the two methods, respectively, to investigate geoelectrical structures along lines E and W.

2. AMT & MT DATA IN JEJU ISLAND

In 2004, MT surveys were made along lines E and W in the south-north directions, which lie in the eastern and western parts of Mt. Halla, respectively (Fig. 1). Both AMT and MT data were obtained covering a frequency range of 0.00034 ~ 10,400 Hz. Remote reference data were measured at Kyushu, Japan, which is 480 km apart from Jeju Island, and used in processing the obtained data (Lee et al., 2006). Fig. 2 shows the data obtained at JJW360 and JJE395 which are in the middles of lines W and E, respectively. Sounding curves at the two sites show typical geoelectrical characteristics of Jeju, which are resistive in high frequencies, conductive in middle range, resistive again around 0.1~1 Hz, and finally less resistive in low frequencies.

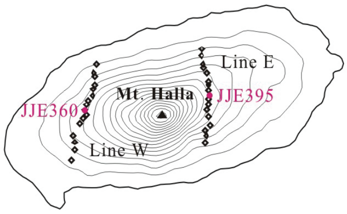
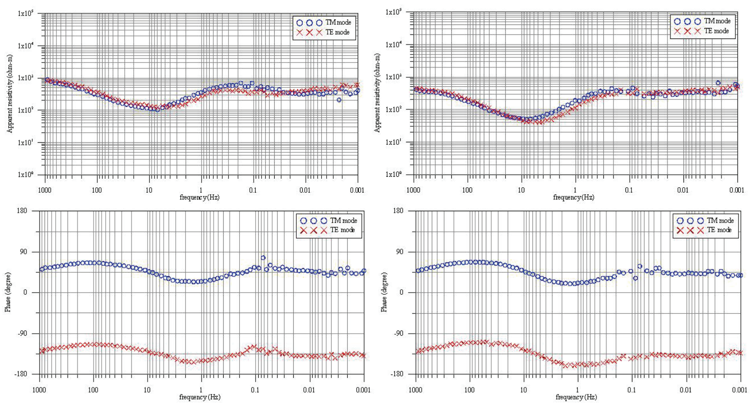


Fig. 1. Survey sites where AMT and MT measurements were made in 2004.



(a) (b)

Fig. 2. Observed apparent resistivities and phases at JJE395 (a) and JJW360 (b).

3. 2D INVERSION ALONG LINES E & W

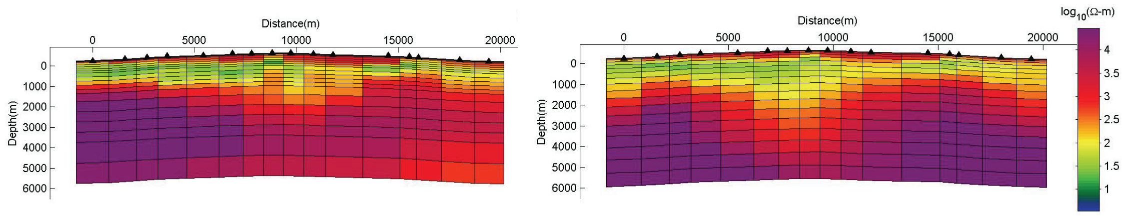
To data obtained in Jeju Island in 2004, this study applies two different 2D inversion schemes which have been developed by Uchida (1993) and Lee et al. (2002), and we denote as UCHIDA, and LEE, respectively. These inversion schemes are based on the Gauss-Newton method to minimize functional $U = \|\mathbf{W}(\mathbf{d}-\boldsymbol{F}(\mathbf{m}))\|^2 + \lambda^2\|\mathbf{Cm}\|^2$, where $\mathbf{W}$ is a weighting matrix, $\mathbf{d}$ the observed data, $\mathbf{m}$ the model parameters, $\boldsymbol{F}$ a nonlinear forward function which gives MT responses to $\mathbf{m}$, $\mathbf{C}$ a roughening matrix of $\mathbf{m}$, and λ a smoothing parameter called as Lagrange multiplier. The first and second terms of U are a data misfit term and a smoothness constraint term, respectively. The inversion iterations of both methods continue until they meet specific tolerance levels of data misfit measures which are defined as $[(\mathbf{W}(\mathbf{d}-\boldsymbol{F}(\mathbf{m})))^2/N]^{1/2}$, where N is the number of data, and $\mathbf{W}$ is given according to the measurement error in UCHIDA while is set to $\mathbf{I}$ in LEE.

UCHIDA uses a statistically optimized smoothness constraint term, which is called Akaike's Bayesian Information Criterion (ABIC) representing goodness of a model in a sense of balancing between the terms of data misfit and smoothness constraint (Uchida, 1993). Since ABIC is a function of λ^2, but not an analytic form, therefore, many forward calculations must be tested at each iteration. LEE, on the other hand, set λ to be a spatial variable at each parameterized block, which is calculated to enhance the stability of the inversion.

We use 78-frequency (from 0.037 Hz to 780 Hz) TM-mode data observed at 16 stations in inversion along line E, which is the same in inversion along line W. Line E spreads 20 km long in the south-north direction and has 646 m high above the sea level at its highest station. Apparent resistivities range from 2.79 to 7832.41 ohm-m with its logarithmic mean of 240.58 ohm-m, while phases from 0.32 to 89.80 degrees. This wide range of data may cause a difficulty in inversion.

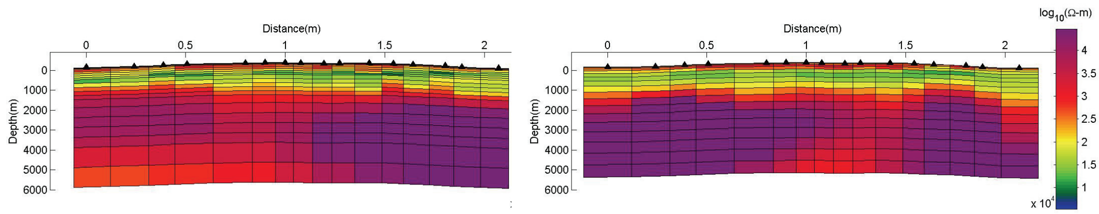
Fig. 3 shows a comparison between TM-mode inversion results derived from UCHIDA and LEE to the data along line E. In applying UCHIDA, we used 322 inversion blocks with 217 x 27 modeling meshes. During the inversion process, Lagrange multiplier was reduced from 160 to 14.142, while rms misfit from 28.157 to 4.678. For LEE, 20 × 35 inversion blocks with 40 × 70 modeling meshes are adopted. In Lee, because the numbers of inversion blocks and modeling meshes are defined automatically according to the numbers of stations and frequencies, the shortage of the number of meshes may affect the quality of inversion results. The data misfit decreased from 0.6639 to 0.3566. UCHIDA converged after nine iterations spending 3781 minutes on 3.0 GHz PC while LEE spent 17 minutes for six iterations.

Line W with 22 km long has its highest station at 395 m high above sea level. Apparent resistivities change in a range from 20.80 to 2358.84 ohm-m (logarithm mean of 148.26 ohm-m), while phases from 1.55 to 85.47 degrees. This narrower range of apparent resistivities may give better inversion profiles than those of line E. Fig. 4 shows MT 2D inversion results of line W. Lagrange multiplier and rms data misfit were reduced from 640 to 4.999, and from 29.612 to 2.933, respectively, during seven iterations in UCHIDA of 322 inversion blocks with 231 x 37 modeling meshes. We used 20 x 26 inversion blocks and 40 x 52 modeling meshes for LEE. The inversion process of LEE reduced the data misfit from 0.6748 to 0.1279. UCHIDA with eleven iterations spent 3453 minutes while LEE with ten iterations did 27 minutes.



(a) (b)

Fig. 3. Resistivity sections along line E derived from UCHIDA (a) and LEE (b). The right hand side of each profile corresponds to the north.



(a) (b)

Fig. 4. Resistivity sections along line W derived from UCHIDA (a) and LEE (b). The right hand side of each profile corresponds to the north.

4. DISCUSSION and CONCLUSIONS

Inversion results show the geoelectrical structures of Jeju can be divided into roughly three layers. The topmost resistive layer having a resistivity larger than 10^3 ohm-m is considered lava plateau whose depth varies from 300 m to 500 m beneath the surface. The lava plateau is composed of a basaltic lava flow covering most part of Jeju Island, which gets thicker as it gets closer to under the peak of elevation of survey lines.

The second layer is conductive having a thickness of several hundred meters being seen as horizontally flat below line W, but having indented lower boundaries below line E. The conductive second layer, extending to a depth about 1,000 m from the sea level beneath the highest station, can be SF and UF. Above all, more conductive and thin layer at a depth of about 500 m is shown in Fig. 4. Results from UCHIDA reveal the thin layer more clearly than those from LEE. The thin conductive layer also can be found in Fig. 3a. The third resistive layer can be a basement rock of granite.

Comparing the two schemes, UCHIDA gives more reasonable results but needs much more time than LEE. Both schemes work generally well, but may face up to a limitation when inverting static shifted data. A more accurate and efficient 2D inversion method considering additional skill of data processing, like static correction, is needed.

5. ACKNOWLEDGMENTS

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