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Three-dimensional interpretation considering the static and the sea-effects of magnetotelluric data obtained in Jeju, Korea

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A B S T R A C T

Three-dimensional (3D) magnetotelluric (MT) surveys have been performed in Jeju, the largest volcanic island in Korea to figure out any possible structures or potential anomaly for remnant deep geothermal resources. Various approaches have been applied to interpret MT data observed in Jeju. MT dataset shows generally simple stratigraphy of four layers, though contains the severe static and the sea-effects. In our previous works, the induction vectors and 3D inversion results have commonly indicated the existence of a conductive anomaly in central parts of the island, beneath Mt. Halla. The 3D inversion dealt the static shifts as inversion parameters. The Jeju MT dataset, however, still contains the effect of conductive sea water surrounding the island.

The sea-effect on MT impedance can be represented as a distortion tensor and excluded from the Jeju MT dataset by an iterative sea-effect correction. In this study, 3D inversion incorporating static shift parameterization was conducted using MT dataset corrected using 1D resistivity model obtained from the iterative scheme. Reasonably reconstructed images are obtained through the 3D inversion and using the MT dataset with sea-effect correction. The inversion result still shows the conductive anomaly in a similar depth. RMS misfits converged to a lower value than that of inversion using MT data before the sea-effect correction. From the fact, it is highly possible that the conductive anomaly is not an artifact but a real underground structure. Further investigation about the anomaly including exploration drilling is needed to see if it is from a fracture containing conductive sea water or related to the old volcanic activities.

1. Introduction

Magnetotelluric (MT) method is a powerful tool for investigating various kinds of geological structure under the earth's surface. It has been widely used in exploration of not only the conventional energy (e.g. oil and gas) but also the renewable energy such as geothermal resources (Goldstein, 1988; Key et al., 2006; Orange, 1989). MT technique usually focused on the deeper geologic target than the other EM methods, though, supplementary high-frequency data from audio-frequency MT (AMT) can take a part to figure out the shallow structures and eventually improve the resolution of reconstructed images (Lee et al., 2006). A remote reference processing enhances the quality of MT data by removing coherent noise (Song et al., 2006a). Combining these techniques, several MT (incorporating AMT) surveys have been conducted in Korea (Lee et al., 2005, 2009b; Song et al., 2006b) for geothermal application since 2002.

From 2004 to 2006, research team at Korea Institute of Geoscience and Mineral Resources (KIGAM) of Korea and National Institute of Advanced Industrial Science and Technology (AIST) of Japan performed joint MT surveys at mid-mountain area of Jeju, the largest volcanic island in Korea. The purposes of the MT surveys were to see if there still remains a geothermal regime and if there exist deeply extended fractures or an aquifer system beneath the mid-mountain region of Mt. Halla. AMT data were also acquired at each MT site, so that wide band, good quality data were acquired from the (A)MT surveys. MT dataset of Jeju, however, suffered from severe static shifts and sea-effect (Lee et al., 2009a).

The effect of static shift is due to the presence of small-scale near-surface inhomogeneities, and manifests itself as a vertical shifting of the apparent resistivity curve by a frequency-independent factor without any corresponding change in the phase curve (Sasaki, 2004). Control of the static shifts in the inversion can be done by employing the static effect as variables. A vector of static-shift parameters in the objective function is assumed to have a Gaussian distribution (Ogawa and Uchida, 1996). The sea-effect is due to the sharp electrical contrast between the sea and the land, and cause spurious anomalies in resultant images of the electrical structure, especially for deeper parts of the earth. Jeju is surrounded by conductive sea, so that the sea-effect yields serious effects on the low-frequency MT data. Many attempts have been

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suggested to effectively remove the sea-effect from observed MT data. A method which employed electrical and magnetic distortion tensor to correct the sea-effect for MT data (Nolasco et al., 1998) had dimensional limitation and the other method which used 3D forward algorithm in the removal of the sea-effect (Santos et al., 2001) needed the precise prior information before the correction. In this study, we adopted a newly suggested method of an iterative sea-effect correction (Yang et al., 2010), which neither suffers from dimensional limitations nor requires exact a priori information. Through the comparison of reconstructed images by MT inversion of observed data and by those of corrected data, we could find the feasibility of sea-effect correction technique for the real MT data and derived more reliable subsurface structures beneath the Jeju Island.

2. Geological characteristics of Jeju Island

The geology of inland Korea is characterized by old formation covered by thin sedimentary layers. Jurassic or Cretaceous granite can be found at very shallow depths in large part of the country. For more than thousand years, there were neither any volcanic activities, nor strong tectonic activities in Korea. Thus high temperature geothermal resources such as hydrothermal system can hardly be expected. So far, geothermal utilization in Korea has been confined in direct use, mainly on public baths in low-temperature geothermal water down to several hundred meters. After KIGAM started a research on measuring and analyzing the thermal properties in 2003, utilization of geothermal resources of shallow subsurface became expanded to district heating and greenhouse uses in some regions (Song, 2004).

Though we can hardly find high temperature geothermal resources for power generation in land, Quaternary volcanic rocks are exposed in some islands in the South and East Sea. Jeju is one of them and the last volcanic activity of Mt. Halla recorded by historic literature occurred in 1007 A.D. It is why we focus on Jeju as a candidate of high temperature geothermal development and MT survey is applied in Jeju. The origin of volcanic structure in Jeju is known to be having no relation either with the ridge of the North Pacific Ocean or the volcanic front of Japan. Although a recent publication on geothermal resources in Korea showed that there is no high temperature anomaly in Jeju Island (Kim and Lee, 2007), it is from the lack of well data deep enough and there is no research results yet. The purpose of the surveys, thus, is to delineate the deep geological structures including possible deeply extended fractures or volcanic vein beneath the mid-mountain area, which may be related with remnant geothermal regime associated with volcanic eruptions.

Jeju is the largest island located at South Sea of Korea, 31 km long along the minor axis and 73 km long along the major axis of direction N70°E (Fig. 1). Mt. Halla (a height of 1950 m) at the center of the island is formed with a great mass of volcanic rock and more than 360 parasitic volcanic cones cover the surface of the island. Based on the topography of the bathymetry from ETOP2 data given by National Geophysical Data Center (Fig. 1, NGDC, http://www.ngdc.noaa.gov), the sea water boundary is getting deeper stepwise and finally reaches a flat 100 m deep.

Geological structure of Jeju has mainly formed since the late Pliocene (Yoon, 1997). Most parts of the island are covered with Quaternary basaltic lava on the Quaternary sedimentary formations which are composed of Pleistocene consolidated sedimentary rocks (Seogwipo Formation, SF) and Plio-Pleistocene unconsolidated sediments (U-Formation, UF). SF and UF are electrically indistinguishable from each other since both are marine-based and electrically conductive (<10 Ω-m). SF has extremely low permeability and lies about 50–60 m below the sea level with an average thickness of 100 m (Koh, 1997). Thickness of UF which has formed of well-sorted find quartzose sand and silts before the onset of volcanism varies from 70 to 250 m with an average 150 m. Basement rocks, formed of welded tuffs and granite, lie at a depth of about 250–300 m below the sea level (Yoon, 1997). General geological stratigraphy of Jeju has been deduced as a simply four-layered structure (Koh, 2007).

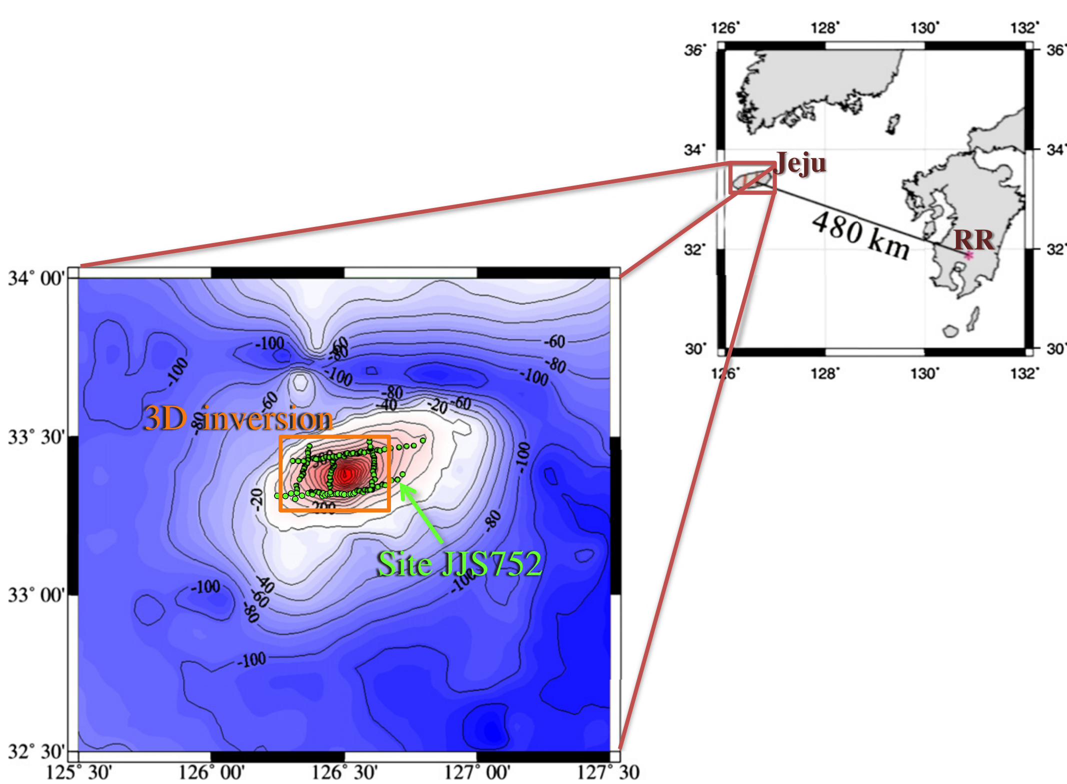

Fig. 1. A bathymetry map around Jeju and MT measurement sites on the island. MT surveys were performed at 108 sites along the 5 lines.