Re-visit seafloor magnetotelluric data and image local high-resolution electrical conductivity structure in the western Pacific

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SUMMARY

Characterizing the physical properties of the lithosphere-asthenosphere system beneath oceans, such as seismic velocity and electrical conductivity, is critical for revealing its enigmatic nature. In this study, electromagnetic observations from 46 Ocean Bottom Electro-Magnetometers (OBEMs) across 27 sites in the Philippine Sea and the western Pacific Ocean were reanalyzed, some of which offer up to 3 years of recovery data. This expanded on previous one-year data analyses by utilizing all available data and combining both standard and generalized remote reference techniques with land geomagnetic stations as reference sites. Our improvements to seafloor magnetotelluric (MT) responses yielded significantly reduced error bars across the entire period band and increased coherence between observed and predicted electric fields. Conductivity inversions were performed for each site, considering the 3D topographical heterogeneity overlaying 1D mantle model. Our results reveal similar lithosphere thicknesses (~60 km) beneath the sites located in West Philippine and Shikou-Parece Vela Basins, while the Pacific exhibits a thicker lithosphere, reaching about 210 km. We noticed lithosphere thickness is slightly larger in the eastern side of the spreading ridge than in the western side in the Shikoku-Parece Vela Basin. Additionally, the asthenosphere underlying a part of the West Philippine Basin appears to be more conductive than beneath the Shikoku-Parece Vela Basin. We also introduced the use of induction vectors, an independent tool distinct from MT and not used in previous studies. After accounting for topographic effects in MT responses, we noticed an alignment between observed and modeled induction vectors, despite not explicitly fitting the vectors during the processes. Our combined approach, including 3D topography correction and MT response analysis, effectively reveals robust 1D conductivity models down to 300 km, while the induction vectors further provide insights into lateral electrical variations.

Keywords: Electrical conductivity; Ocean Bottom Electro Magnetometer; Philippine Sea Plate; Lithosphere–Asthenosphere system

INTRODUCTION

Understanding the Earth's lithosphere-asthenosphere system, especially beneath the oceans, is critical for studying plate tectonics and Earth's dynamic processes. The oceanic regions, due to their less complex geological history compared to continents, offer a more fundamental view of the lithosphere-asthenosphere system (LAS). The typical oceanic LAS often exhibits a resistive lithospheric layer overlying a high conductivity layer which can be defined as electrical asthenosphere.

The Philippine Sea is one of the largest marginal basins of the Pacific Ocean. It is subdivided into three domains based on geomorphology, including the West Philippine Basin (WPB) in the west, the Shikoku-Parece Vela Basin (SPVB), and the Izu–Bonin Trench and Mariana Trench in the east (Figure 1). Magnetic anomaly estimations support that SPVB is a back-arc basin formed behind the Izu–Bonin–Mariana arc during episodes of east-west spreading in the Miocene (Kobayashi and Nakada 1978; Okino et al. 1998), and the WPB opened between about 60 and 30 Ma by spreading along an extinct spreading center (Hilde and Lee 1984). These two young basins could provide us an opportunity to explore the electrical nature of the upper mantle and mantle wedge without being affected by a long-complicated history.

Despite extensive geophysical explorations, the electrical properties of the mantle within the Philippine Sea Plate remain not very clear. This is partly due to the challenges of acquiring electromagnetic (EM) data in marine environments, and the EM signals attenuate as they travel through the conductive water column. Accordingly, we revisit the EM study reported by Baba et al. (2010) and Tada et al. (2014), incorporating up to three years of additional recovery data for selected sites, combining two remote reference methods to estimate magnetotelluric (MT) responses and correct the topographic effect at each site based on their 1D structure to update the 1D conductivity models.

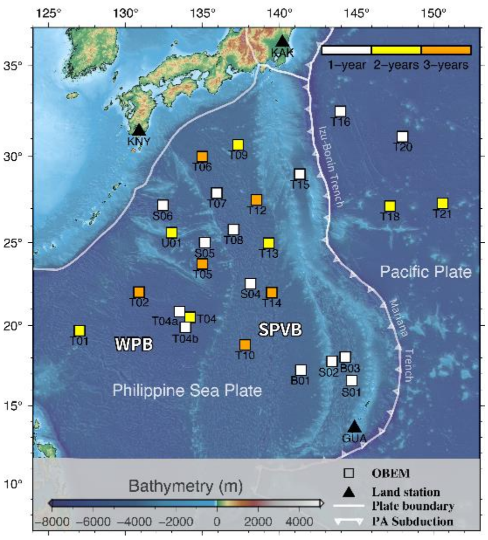

Figure 1. Map of station locations superimposed on the bathymetric. Squares indicate the OBEM stations, with varying colors representing the duration of data collected at each location. Black triangles mark the location of geomagnetic observatories whose data served as remote references for estimating responses. WPB, West Philippine Basin; SPVB, Shikoku-Parece Vela Basin.

DATA AND DATA PROCESSING

Building upon existing work by Baba et al. (2010) and Tada et al. (2014), this study utilizes magnetotelluric data from across the Philippine Sea and Pacific. We analyzed the data from 46 ocean bottom electromagnetometers (OBEMs) deployed at 27 sites, with some locations boasting up to three years of continuous recordings (Figure 1). Base on previous one-year data studies, our approach incorporates all available data for a more comprehensive analysis. Additionally, we employed both standard and generalized remote reference techniques (Chave & Thomson, 2004) to enhance the quality of MT responses using on-land geomagnetic stations as references, and process the magnetic field data to obtain tippers and observed induction vectors. Finally, we constructed updated MT responses based on maximizing the coherence between predicted and observed electrical fields.

TOPOGRAPHIC EFFECT CORRECTION AND INVERSION

Accurate electrical conductivity models of the Earth's mantle require correcting for distortions of EM fields caused by variations in bathymetry and coastlines (Schwalenberg & Edwards, 2004; Key & Constable, 2011). These distortions can lead to misinterpretations of subsurface structures. To address this challenge, we follow established methodologies (Baba & Seama, 2002; Baba & Chave, 2005; Baba et al., 2010, 2013, 2017) and implement a 3D topographic effect correction. We consider the effects from both regional large-scale and local small-scale topography effects. For each site, the model consisted of 1D structure inverted by site's MT response with a superimposed 3D seawater representing the topography. We then perform iterative 1D inversions on the data corrected for the topographic effect to minimize the root-mean-square misfit between observed and predicted MT responses.

RESULTS AND CONCLUSIONS

Our analysis yielded several key findings. First, by combining standard and generalized remote reference methods, we achieved MT responses with smaller errors and improved coherence between observed and predicted electric fields. Notably, the generalized remote method proved particularly effective for shorter periods. Additionally, extending MT data collection periods to three years significantly reduced response errors by about 40%.

Furthermore, applying 3D topographic corrections to the refined MT responses facilitated more accurate 1D inversions, enabling a deeper understanding of sub-seafloor electrical conductivity structures. The conductivity structures reveal the conductive anomaly at ~50-100 km depth under sites T01 and T02 in the West Philippines Bason. We further determined the lithosphere thickness from conductivity structures, which show that the thickness is similar, about 60 km, beneath the sites in the West Philippine and Shikoku-Parece Vela Basins, while it's thicker in the Pacific, reaching approximately 210 km. Interestingly, our analysis of the Shikoku-Parece Vela Basin revealed the slightly larger lithosphere thickness on the eastern side of the spreading ridge where closer to the island arc than on the western side. The underlying causes of these variations require further investigation.

Finally, the estimation of topographic effects on MT responses led to an alignment between observed and modeled induction vectors, even though we did not explicitly incorporate them into the fitting process. This suggests that non-1D features of MT and induction vectors are roughly explained by considering topography effect and that induction vector residuals can provide valuable insights into lateral electrical variations within the studied region.

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