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Electrical resistivity structure under the western Cosmonauts Sea at the continental margin of East Antarctica inferred via a marine magnetotelluric experiment

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Abstract

The western Cosmonauts Sea, off the coast of East Antarctica, was a site of rifting of the Gondwana supercontinent and subsequent early seafloor spreading. To improve our understanding of the breakup of Gondwana, we conducted a marine magnetotelluric experiment to determine the electrical resistivity structure within the uppermost several hundred kilometers beneath the western Cosmonauts Sea. Magnetotelluric response functions at two sites, obtained after considering possible influences of non-plane magnetic field sources, suggest that these responses include distortions by topographic variations and conductive anomalies around the observation sites. Three-dimensional forward modeling confirmed that these distortions due to topographic variations and a thin (~2-km thick) conductive layer immediately under the sites (mostly sediments) are severe. Furthermore, three-dimensional forward modeling to investigate the resistivity structure at deeper depths revealed an upper resistive layer ($\geq$300 Ω-m), with a thickness of <100 km, and an underlying conductive half-space (~10 Ω-m). The upper resistive layer and the underlying conductive structure most likely represent dry and water/melt-rich oceanic upper mantle, respectively. The upper resistive layer may be thinner than anticipated under the old seafloor of the study area (likely >90 Ma), and may suggest a conductive anomaly in the upper mantle produced by mantle convection and/or upwelling.

Keywords: Electrical resistivity structure; Marine magnetotellurics; Offshore East Antarctica; Gondwana breakup; Continental margin

1. Introduction

Continental breakups create crust–mantle and/or lithosphere–asthenosphere structures with distinct features at continental margins. Continental crust and lithosphere are generally thicker (~40 km and ~200 km, respectively) than oceanic crust and lithosphere (~6 km and $\geq$60 km, respectively). Moreover, crust and lithosphere are typically stretched and thinned during continental rifting through normal and detachment faulting, resulting in the formation of a ramp-like continent–ocean transition zone between continents and oceans involving crust–mantle or

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lithosphere–asthenosphere structures (e.g., McKenzie, 1978; Le Pichon and Sibuet, 1981; Lister et al., 1986). Crust–mantle and lithosphere–asthenosphere structures at continental margins reflect these processes of continental breakup.

The breakup of the Gondwana supercontinent is the latest well-studied geological event of this type (e.g., Storley, 1995). The western Cosmonauts Sea, located on the continental margin of East Antarctica, is a key area for investigating this breakup because, according to plate reconstruction models, its ancient location was at a junction of continents including Antarctica, Sri Lanka/India, Africa, and Madagascar (e.g., Norton and Sclater, 1978; Lawver et al., 1992). A surface wave seismic study beneath the western Cosmonauts Sea showed a crustal thickness of 20–30 km, and perturbations that were faster and slower at depths of ~80 km and ~150 km, respectively, than results of a standard seismic wave velocity model (AK135) (Ritzwoller et al., 2001). The 20–30-km thick crust is intermediate in thickness between that of typical oceanic crust (~6 km) and the crust of East Antarctica (30–50 km) (Ritzwoller et al., 2001; Baranov and Morelli, 2013), suggesting that the crustal structure beneath the western Cosmonauts Sea reflects continent–ocean transitional features. The enhanced velocity perturbation at a depth of ~80 km and the reduced perturbation at a depth of ~150 km indicate the presence of lithospheric and asthenospheric structures, respectively, and the thickness of the lithosphere lid corresponds to its seafloor age (Ritzwoller et al., 2001).

Although studies such as that of Ritzwoller et al. (2001) provide good images of crust–mantle and lithosphere–asthenosphere structures beneath Antarctica, the resolution of the images is not sufficient to investigate the structures under the western Cosmonauts Sea, where a complex breakup process occurred at the junction of several continents making up Gondwana. Finer-scale geophysical studies are necessary to investigate crust–mantle and lithosphere–asthenosphere structures in such geologically complex regions. Aerogeophysical surveys in and around the western Cosmonauts Sea have provided detailed magnetic and gravity anomaly maps of offshore and onshore areas (Jokat et al., 2010; Nogi et al., 2013). The maps reveal a clear continent–ocean boundary zone within a distance of 100 km of the nearby East Antarctic coast (Jokat et al., 2010; Nogi et al., 2013). An integrated geophysical data analysis of the eastern portion of the western Cosmonauts Sea has also revealed that continent–ocean transitional crust (thickness of ~10–20 km) prevails within several hundred kilometers offshore of the East Antarctic coastline (Stagg et al., 2004).

On the western side of the western Cosmonauts Sea, the Gunnerus Ridge, which extends offshore from East Antarctica (Fig. 1), is underlain by continental crust with a thickness of ~30 km, which may have formed during the stretching of East Antarctica during the breakup of Gondwana (Roeser et al., 1996). In Lützow–Holm Bay, southeast of the Gunnerus Ridge (Fig. 1), the crust consists of continental and continent–ocean transitional features (thickness of 30–50 km) (Kanao, 1997). In the Riiser-Larsen Sea, west of the Gunnerus Ridge (Fig. 1), the lineations of magnetic and gravity anomalies differ from those on the eastern side of the ridge, which suggests different evolutionary processes involving seafloor and crust–mantle structures on either side of the ridge (Nogi et al., 2004). West of the Riiser-Larsen Sea, the presence

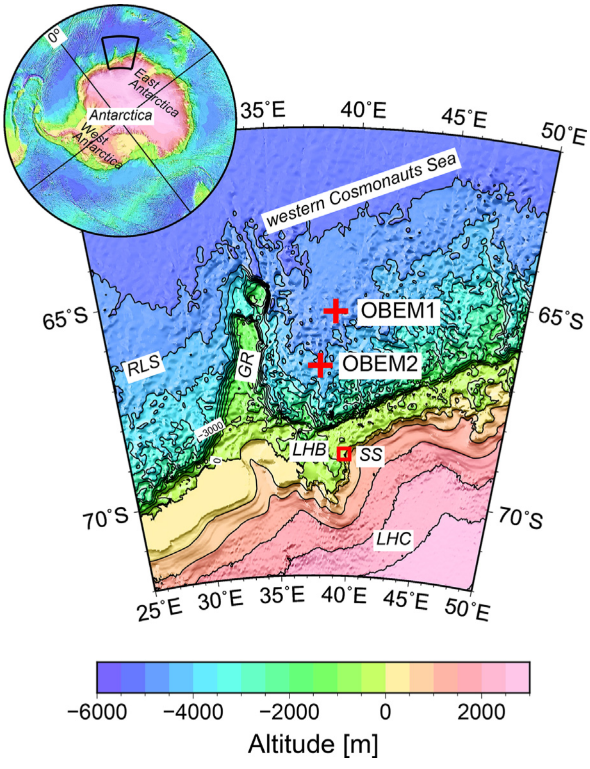

Fig. 1. Map of the marine electromagnetic experiment conducted in the western Cosmonauts Sea off the coast of East Antarctica, showing site locations and names. The red crosses indicate observation sites, and the red square indicates the location of the Japanese Syowa Station (SS). The contour interval for the topography is 500 m. Other abbreviations denote the following: GR: Gunnerus Ridge; LHB: Lützow–Holm Bay; LHC: Lützow–Holm Complex; RLS: Riiser-Larsen Sea.