A SEAFLOOR MAGNETOTELLURIC SOUNDING IN THE TASMAN SEA

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Abstract. This paper reports an analysis of electromagnetic data from a site occupied on the floor of the Tasman Sea during an Australia-U.S. research program, the Tasman Project of Seafloor Magnetotelluric Exploration. This site (37°33'S, 155°58'E, depth 4450 m) is in the central portion of the Tasman Sea, and near both a fossil spreading ridge and the Tasmanid Seamount Chain. The extensive electric and magnetic data sets, covering 60 days, exhibit the signals of a most energetic oceanic environment. Conspicuous features of the electric field include an unusually large component induced by mesoscale fluid motions, as well as sporadically occurring high-frequency signal probably induced by ocean turbulence.

These motional fields contribute a significant background noise to the ionospheric storm and substorm magnetic activity from which the seafloor magnetotelluric impedance tensor is estimated, but permit a usable frequency band of 0.06 to 5.5 cph. Over this band the seafloor impedance is found to exhibit frequency-independent skew and anisotropy. The skew suggests the presence of some nearby lateral conductivity heterogeneity. The anisotropy is characterised by a principal axes ratio of 3.5, the major axis being oriented 24° clockwise from true north. Tentative inversion of the data implies the presence of an unusually high conductance in the uppermost seafloor. Altogether, information on upper mantle conductivity may reach a 500 km depth. The principal magnetotelluric axes are approximately aligned with both the trend of the seamount chain and with the Australian coastline. The ensemble of data from eight other sites occupied in the project should permit an assessment of the relative contribution of these two features.

Introduction

The magnetotelluric sounding described in this paper comprises the first results on earth electrical conductivity from an extensive experiment in the Tasman Sea, east of Australia (Figure 1). This study, called the Tasman Project of Seafloor Magnetotelluric Exploration (TPSME), involves a series of geophysical recordings made along a line of seafloor sites which continues inland to the Australian continent (Graham, 1984). Magnetotelluric recordings were made at seven seafloor sites.

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Additional simultaneous magnetic recordings were made at another two deep seafloor sites, and along the extension of the seafloor line on to the Australian continental shelf and continent. The TPSME experiment occupied some four months, from early December 1983 to the end of March 1984. The seafloor instruments have been described previously by Filloux (1980a). These instruments were deployed and retrieved during two cruises of the naval oceanographic vessel, HMAS COOK.

Previous seafloor magnetotelluric (SFMT) soundings have been made in the Pacific Ocean (e.g. Filloux, 1980b, 1982a, 1982b) and the Atlantic Ocean (Cox et al., 1980). The Tasman Sea formed 80-60 Myr ago during an episode of seafloor spreading (Weissel and Hayes, 1977) and now constitutes part of the Indian-Australian tectonic plate. The SFMT soundings in the Tasman therefore represent a valuable addition to previous results from the Pacific, Cocos and Atlantic plates (Oldenburg, Whittal and Parker, 1984).

The present paper is based on data recorded at site TP4 (37°33'S, 155°58'E, depth 4450 m) in the Central Tasman Sea. Site TP4 is distant from both the Australian coastline, and the Lord Howe Rise, and lies within 100 km of the fossil spreading ridge in the Tasman Sea. It also lies close to the Tasmanid Chain of seamounts which trends meridionally through the Tasman Sea (Figure 1).

Recorded Data

The recorded data from TP4 exhibit characteristics of an active oceanic environment. For a wide range of frequencies the telluric data contain significant activity that is uncorrelated with the (almost entirely ionospherically induced) magnetic data. The activity is similar to oceanically induced signal observed in previous seafloor studies (Chave and Filloux, 1984). Figure 2 shows a long-period deflection of the electric field occurring around 20 January 1984. This event represents the electric field induced by the ocean water movements associated with a mesoscale eddy. The long period signal thus induced limits the low-frequency end of an MT sounding.

Signals induced by tidal motion are also present in the electric field data, as are sporadically occurring high-frequency magnetic oscillations by the electrically conducting seawater together limiting the high-frequency end of an MT sounding.
Data Analysis

The magnetic and telluric components from TP4 were Fourier transformed, and band averaged. Bands containing tidal frequencies and harmonics were omitted from further analysis. Bands at periods longer than 2 hr were estimated using Fourier analyses of the complete 60 day record available at this site. Bands at shorter periods were estimated using Fourier analyses of 70 hr of recordings (which from inspection were relatively free of motionally induced short-period oscillations).

An impedance tensor $Z$ was calculated according to

$$ E = ZB + N_E \quad (1) $$

where $E$ denotes the horizontal electric field, $B$ the horizontal magnetic induction, $N_E$ the uncorrelated noise in $E$, and all quantities are complex and discrete functions of frequency. Coherences between different components indicate that the tensor is adequately resolved only over a frequency range covering periods between 11 min and 16 hr. This result confirms the effects of the strong oceanically induced signal noted earlier in the electric field data.

The impedance tensor determined for site TP4 is substantially skewed over the resolved frequency range. The skew is characterized by diagonal terms in $Z$ that are largely frequency-independent and lie close to the real axis. The skew is therefore plausibly explained by a local distortion of telluric currents by a near-surface conductivity heterogeneity, and does not necessitate a complex three-dimensional conductivity distribution (Cox et al., 1980). The geographic orientation of the TP4 telluric instrument during the recording period is known only approximately and hence the value of skew is not known precisely. However after rotation of the telluric data by 26° clockwise, the impedance tensor becomes consistent with a two-dimensional conductivity structure, with

![Fig. 1. Location of TPSME recording sites. Also shown are the fossil spreading ridge and the Tasmanid Seamount Chain. The large cross gives the orientation of the impedance tensor determined for site 4. In the text seafloor sites are referred to by the number shown preceded by the letters 'TP'.](image)

![Fig. 2. A 20 day segment of data from site TP4. H, D, Z, EH, and ED refer to the magnetic variations to the magnetic north, to the magnetic east, vertically downwards and to the horizontal electric field to the magnetic north and to the magnetic east respectively. The scale bar corresponds to 100 nT (magnetic) or 10 $\mu$V.m$^{-1}$ (electric).](image)

![Fig. 3. Magnitude and phase lead values for the impedance tensor at TP4. Solid circles: for the major principal axis. Open circles: for the minor principal axis.](image)
A relatively definite aspect of the TP4 conductivity structure is a high conductance in the uppermost 50-80 km. This characteristic is indicated by the low magnitude and low phase of the MT impedance (for both principal axis orientations) at high frequencies. It is reflected in the inverted models which, despite differences, all show a high integrated conductance for depths of less than 80 km.

The results of one-dimensional inversions of anisotropic impedance data must be interpreted with care. However, Berdichevsky and Dmitriev (1976), and Larsen (1975), have shown that inversion of certain modified response functions can minimize the effects of electric field distortion due to shallow conductivity structures. Accordingly, if the deeper conductivity structure at TP4 is one-dimensional then a feature of the profile suggested by the inverted models is a relatively sharp conductivity rise between 100 and 200 km. This rise is evident in the model derived for the meaned response function as well as in the models derived for each principal axis. There is also possibly a conductivity rise at 400-500 km depth, although this feature is resolved only in the major principal axis model.

The high seafloor conductivities observed for site TP4 are most plausibly explained by remnant effects associated with the seamount chain near the site. The conductances in the upper 50-80 km at TP4 are of comparable magnitude to those observed near the Pacific Rise at 12°N, an active spreading region (Filloux, 1982b). However since electrical conductivity decreases significantly with lithospheric age (Filloux, 1980b; Oldenburg, 1981) the high conductance of the ~60 Myr old crust at TP4 is unlikely to be due to thermal effects associated with the Tasman fossil spreading ridge. The Tasmanian seamount chain is a feature much younger than the spreading ridge, and its formation is attributed to the northward movement of the Australian plate over a mantle hotspot (Vogt and Conolly, 1971; Wellman, 1983). Current seismicity at 40°-45° S in the Tasman Sea (Denham, 1985) may be associated with the southward extension of the chain, and suggests that the region around TP4 may have overlain the hotspot only 10-15 Myr ago.

Conclusions

The first magnetotelluric data for the Tasman Sea are typical of data from an active ocean environment. Analysis reveals significant features of the electrical conductivity structure at the site. Firstly, the conductivity structure is strongly anisotropic, with impedance in a north-south direction approximately a factor of three greater than in the east-west direction. Secondly, the conductance in the upper 80 km beneath the site is very high. This high conductance is attributed to remnant effects associated with a seamount chain that passes close to the site.
Finally one-dimensional inversions of the anisotropic data suggest a rapid conductivity rise may occur beneath site TP4 at a depth of 100-200 km.

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