GEOPHYSICAL RESEARCH LETTERS, VOL. 12, NO. 9, PAGES 545-548, SEPTEMBER 1985

A SEAFLOOR MAGNETOTELLURIC SOUNDING IN THE TASMAN SEA

I.J. Ferguson[1], J.H. Filloux[2], F.E.M. Lilley[1], N.L. Bindoff[1] and P.J. Mulhearn[3]

[1] Research School of Earth Sciences, Australian National University, Canberra

[2] Scripps Institution of Oceanography, University of California at San Diego

[3] Royal Australian Navy Research Laboratory, Sydney

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 Tasmantid 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. 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 Australian 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 Tasmantid 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 sporadic high-frequency signals thought to be induced by ocean turbulence. This high-frequency signal and the attentuation of any high-frequency magnetic oscillations by the electrically conducting seawater together limit the high-frequency end of an MT sounding.

Paper number 5L6568.
0094-8276/85/005L-6568$03.00

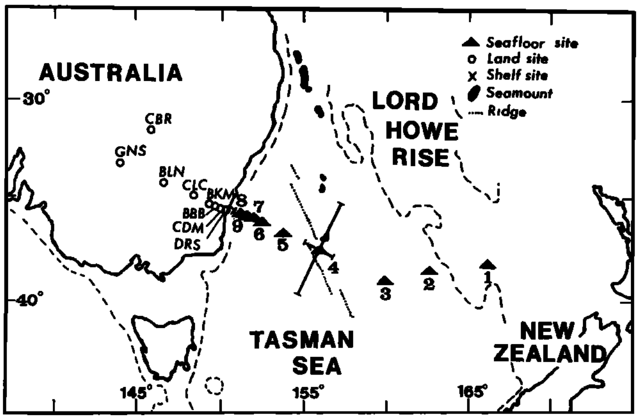

Fig. 1. Location of TPSME recording sites. Also shown are the fossil spreading ridge and the Tasmantid Seamount Chain. The large cross gives the orientation of the impedance tensor determined for site 4. In the text seafloor sites are referred to by the number shown preceded by the letters 'TP'.

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

$$\underset{\sim}{E} = Z\underset{\sim}{B} + \underset{\sim}{N}_E \qquad (1)$$

where $\underset{\sim}{E}$ denotes the horizontal electric field, $\underset{\sim}{B}$ the horizontal magnetic induction, $\underset{\sim}{N}_E$ the uncorrelated noise in $\underset{\sim}{E}$, 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 major axis aligned 24° clockwise from true north.

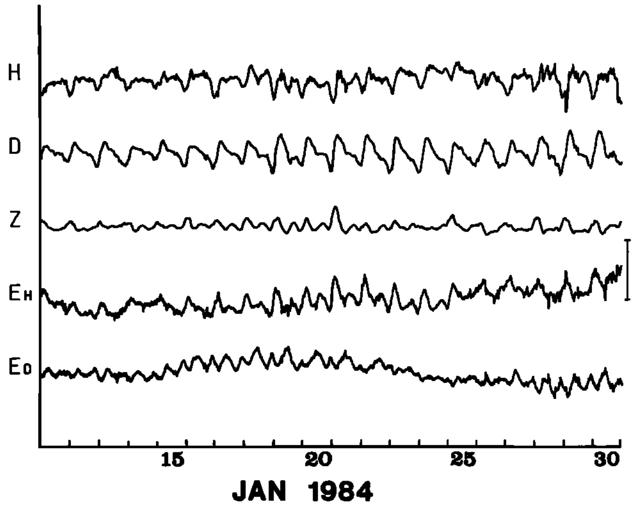

Fig. 2. A 20 day segment of data from site TP4. H, D, Z, EH, and ED refer to the magnetic variations to the magnetic north, to the magnetic east, vertically downwards and to the horizontal electric field to the magnetic north and to the magnetic east respectively. The scale bar corresponds to 100 nT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

A final impedance tensor estimate is obtained by combining impedance tensor components with corresponding admittance tensor components (see Filloux, 1977).This procedure assumes that any noise is equally distributed between $\underset{\sim}{E}$ and $\underset{\sim}{B}$. The magnitude and phase (lead) values for the final impedance tensor are shown in Figure 3, and the average orientations of its axes (over

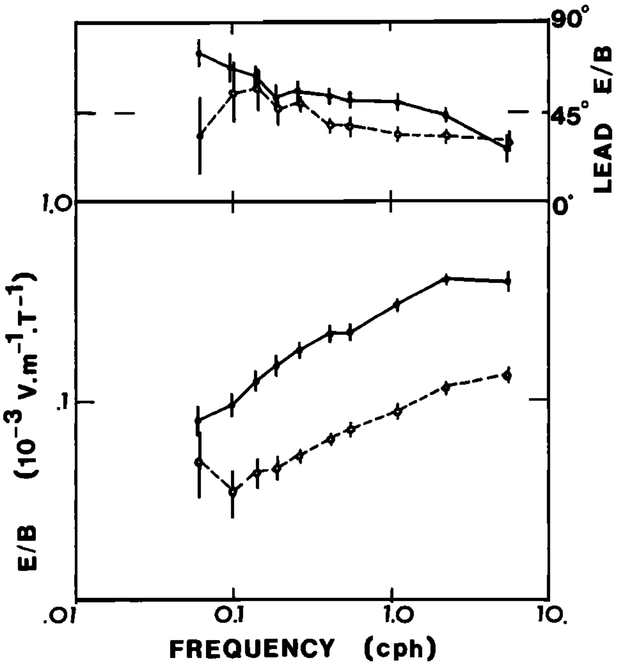

Fig. 3. Magnitude and phase lead values for the impedance tensor at TP4. Solid circles: for the major principal axis. Open circles: for the minor principal axis.

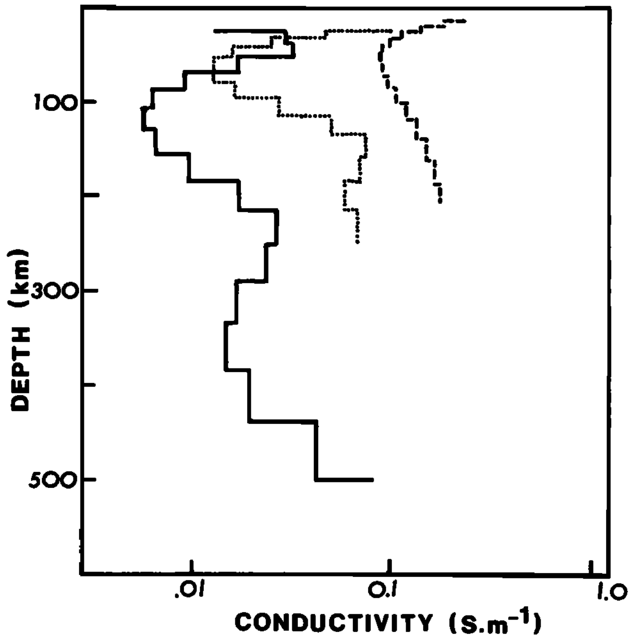

Fig. 4. One-dimensional inversions of the MT response functions at TP4. Solid line corresponds to the major principal axis data, dashed line corresponds to the minor principal axis data, and dotted line to an inversion of the geometric mean of the major and minor axis data.

the resolved frequency range) are shown on Figure 1.

The impedance tensor is strongly anisotropic and is characterized by an almost frequency-independent ratio of major to minor axis magnitudes of 3.5. There are, however, more complicated phase differences between the two axes. The phase lead for the minor axis is significantly less than that for the major axis for frequencies between 0.3 and 3 cph.

One-dimensional inversions were made of the impedance values determined for each of the principal axes. In addition using an extension of the approach by Berdichevsky and Dmitriev (1976) an inversion was also made using the geometric mean of these data. Figure 4 shows the resulting electrical conductivity models for all three data sets. These inversions used an iterative algorithm which minimized variations in conductivity; that is, the algorithm minimized the integral of the differential of the logarithm of conductivity with depth. The data sets were first inverted using the D^+ algorithm of Parker and Whaler (1981) in order to determine the best possible χ^2 fit to the data. The iterative algorithm was then applied, until a value of misfit close to either the best possible χ^2 or the expected value of χ^2 (if larger) was obtained.

Interpretation

The prominent characteristic of the TP4 impedance tensor is its strong anisotropy. This characteristic is reflected in the inverted models (Figure 4) where the inverted electrical conductivities for the minor principal axis are approximately an order of magnitude greater than those for the major axis. The major axis is aligned parallel to the Australian coastline and subparallel to the adjacent Tasmantid Seamount Chain.

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 integratred 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 Tasmantid 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 anistropic data suggest a rapid conductivity rise may ocur beneath site TP4 at a depth of 100-200 km.

Acknowledgements. We firstly acknowledge the major part played in the TPSME experiment by the HMAS COOK. H. Moeller, G. Pezzoli and T. Koch were essential members of the experimental team. Many people have offered valuable advice and discussion concerning data analysis and interpretation, particularly A.D. Chave, P. Tarits, and R.L. Parker. Dr. Parker kindly made available his inversion programs for the results presented in Figure 4.

The TPSME experiment was run under the U.S.-Australia Science and Technology Agreement. U.S. participation was funded in part by NSF grants OCE 83-01216 and OCE 83-12339.

References

Berdichevsky, M.N. and V.I. Dmitriev, Distortion of magnetic and electric fields by near-surface lateral inhomogeneities, Acta Geodaet. Geophys. et Montanist Acad. Sci. Hung., 11 (3-4), 447-483, 1976.

Chave, A.D. and J.H. Filloux, Electromagnetic induction fields in the deep ocean off California: oceanic and ionospheric sources, Geophys. J.R. astr. Soc., 77, 143-171, 1984.

Cox, C.S., J.H. Filloux, D.I. Gough, J.C. Larsen, K.A. Poehls, R.P. Von Herzen and R. Winter, Atlantic lithosphere sounding, J. Geomag. Geoelectr., 32, Suppl. I, SI 13-32, 1980.

Denham, D., The Tasman Sea earthquake of 25 November 1983 and stress in the Australian plate, Tectonophysics, 111, 329-338, 1985.

Filloux, J.H., Ocean-floor magnetotelluric sounding over North Central Pacific, Nature, 269, 297-301, 1977.

Filloux, J.H., Observation of very low electromagnetic signals in the ocean, J. Geomag. Geoelectr., 32, Supple. I, SI 1-12, 1980a.

Filloux, J.H., Magnetotelluric soundings over the northeast Pacific may reveal spatial dependence of depth and conductance of the asthenosphere, Earth Planet Sci. Lett., 46, 244-252, 1980b.

Filloux, J.H., Seafloor magnetotelluric soundings in the Mariana Island Arc Area, A.G.U. Geophysical Monograph Series Vol. 27. The Tectonic and Geological Evolution of Southeast Asian Seas and Islands, part 2, 255-265, 1982a.

Filloux, J.H., Magnetotelluric experiment over the ROSE area, J. Geophys. Res., 87, 8364-8378, 1982b.

Graham, H. (Ed.), New evidence sought on continental drift, Australian Physicist, 21, 79-80, 1984.

Larsen, J.C., Low frequency (0.1 - 6.0 cpd) electromagnetic study of deep mantle electrical conductivity beneath the Hawaiian Islands, Geophys. J.R. astr. Soc., 43, 17-46, 1975.

Oldenburg, D.W., Conductivity structure of oceanic upper mantle beneath the Pacific plate, Geophys. J.R. astr. Soc., 65, 359-394, 1981.

Oldenburg, D.W., K.P. Whittall and R.L. Parker, Inversion of ocean bottom magnetotelluric data revisited, J. Geophys. Res., 89, 1829-1833, 1984.

Parker, R.L. and K.A. Whaler, Numerical methods for establishing solutions to the inverse problem of electromagnetic induction, J. Geophys. Res., 86, 9574-9584, 1981.

Vogt, P.R. and J.R. Connolly, Tasmantid guyots, the age of the Tasman Basin and motion between the Australian plate and the mantle, Geol. Soc. America Bull., 82, 2577-2584, 1971.

Weissel, J.K. and D.E. Hayes, Evolution of the Tasman Sea reappraised, Earth Planet Sci. Lett., 36, 77-84, 1977.

Wellman, P., Hotspot volcanism in Australia and New Zealand; Cainozoic and Mid-Mesozoic, Tectonophysics, 96, 225-243, 1983.

N.L. Bindoff, I.J. Ferguson and F.E.M. Lilley, R.S.E.S., Australian National University, Canberra, 2601, Australia.

J.H. Filloux, Ocean Research Division A030, Scripps Institution of Oceanography, UCSD, La Jolla, Ca. 92093, U.S.A.

P.J. Mulhearn, Royal Australian Navy Research Laboratory, Darlinghurst, N.S.W. 2010, Australia.

(Received May 9, 1985;
accepted June 19, 1985)