Physics of the Earth and Planetary Interiors, 60 (1990) 147–154
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

The Continental Slope Experiment along the Tasman Project profile, southeast Australia

Antony White

School of Earth Sciences, The Flinders University of South Australia, Bedford Park, S.A. 5042 (Australia)

R.L. Kellett and F.E.M. Lilley

Research School of Earth Sciences, Australian National University, GPO Box 4, Canberra, ACT 2601 (Australia)

(Received November 27, 1987; revision accepted September 21, 1988)

White, A., Kellett, R.L. and Lilley, F.E.M., 1990. The Continental Slope Experiment along the Tasman Project profile, southeast Australia. Phys. Earth Planet. Inter., 60: 147–154.

Three seafloor magnetometers made recordings for up to 95 days between July and October 1986 at sites across the continental slope of southeast Australia along the profile of the 1984 Tasman Project of Seafloor Magnetotelluric Exploration (TPSME). Land magnetometers at TPSME sites at the coast and Canberra were reactivated to give simultaneous recordings. The seafloor magnetometers were at depths of 140 m, 2240 m and 3380 m and spanned the continental shelf between the coastline and the closest inshore TPSME ocean floor site (depth 4850 m). This experiment complements the TPSME by giving a much sharper definition of the geomagnetic coast effect in this critical region.

Data are presented in the form of Parkinson arrows for comparison with previously derived TPSME results along the profile. They show a strong coast effect with the maximum mid-way down the continental slope. The situation is closely two dimensional, and using this approximation some simple models have been computed. One which gives a relatively good fit at a period of 1 h comprises simply a conductive ocean overlying a uniform conductor at depth. Further work will be needed to determine whether lateral conductivity structure at depth is required to fit the data more closely.

1. Introduction

The Continental Slope Experiment (CSE) was conceived as a complement to the Tasman Project of Seafloor Magnetotelluric Exploration (TPSME) which was conducted in late 1983/early 1984 (Filloux et al., 1985; Lilley et al., 1989). Figure 1 shows the TPSME sites, half of which were land based and half in the Tasman Sea at depths of nearly 5 km. For technical reasons the closest inshore of the oceanic sites was in 4850 m of water, at the foot of the continental slope. Thus no sites spanned the region between the coast and the base of the continental slope; the CSE was planned to fill this gap by the deployment of three seafloor magnetometers. The experiment was made possible by the support of the new Australian oceanographic vessel R.V. FRANKLIN.

There have been a few previous experiments in which seafloor magnetometers have been deployed across the continental slope. Greenhouse (1972) made a number of observations across the southern Californian borderland region. His 'La Jolla' profile includes data from seven seafloor sites extending out into the deep ocean (3800 m depth). Two coast effects are seen, one coinciding with the actual coastline and a second with the continental shelf edge 250 km offshore. After extensive modelling it was concluded that a lateral subterranean conductivity contrast contributed only a second-order effect, with only a gentle rise in the sub-oceanic conductivity being necessary.

0031-9201/90/$03.50

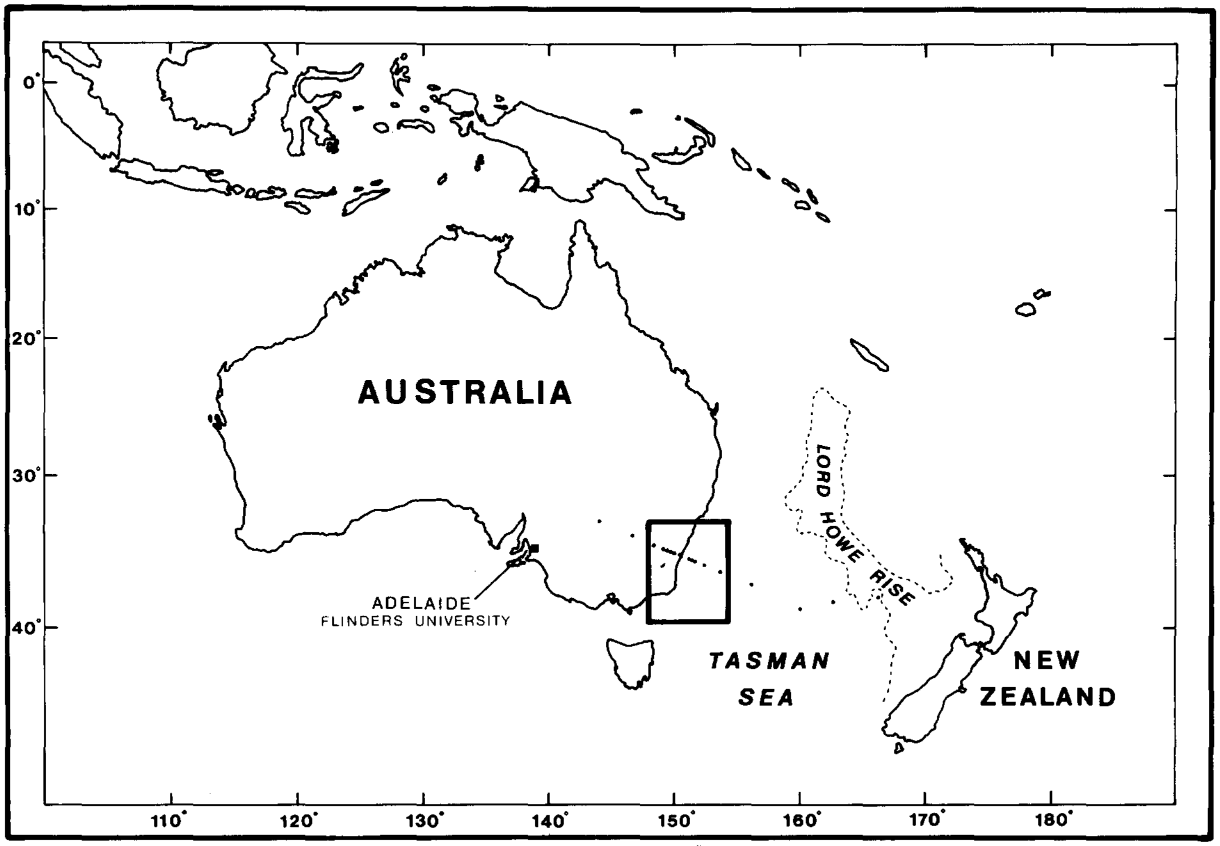

Fig. 1. Location map showing the setting of the Continental Slope Experiment and the Tasman Project sites (dots). The boxed area is shown in Fig. 4.

A profile across northern Honshu and the Japan trench (Yukutake et al., 1983; Ogawa et al., 1986) shows a strong coast effect which peaks at the western edge of the trench. Detailed 2D modelling of a wide range of conductivity structures was performed and the conclusion is that a conductive ocean over a resistive Earth is sufficient to produce the coast effect over the slope and eastern Honshu.

A profile from Vancouver Island onto the Juan de Fuca plate (DeLaurier et al., 1983) found a much subdued coast effect which required a good conductor at depth to cancel in part the induced current in the seawater. A more recent experiment in this region (EMSLAB group, 1988) resulted in a detailed pseudo-section of the real part of the vertical field transfer function across a southern section of the same continental margin. The section shows a single peak in the vertical field at the foot of the slope for long periods, which moves towards the shelf at shorter periods. The presence of a thick sedimentary wedge on the shelf dominates the coast effect at short periods.

These latter three studies are on continental margins with active subduction zones. In contrast, the Australian CSE and TPSME profile crosses a passive margin, and represents a detailed ocean–continent transect greater than 2000 km in length.

2. Instrumentation, deployment and recovery

The seafloor magnetometers are three-component fluxgate variometers with digital data acquisition. Data sampling every minute is microprocessor controlled, with an intermediate solid-

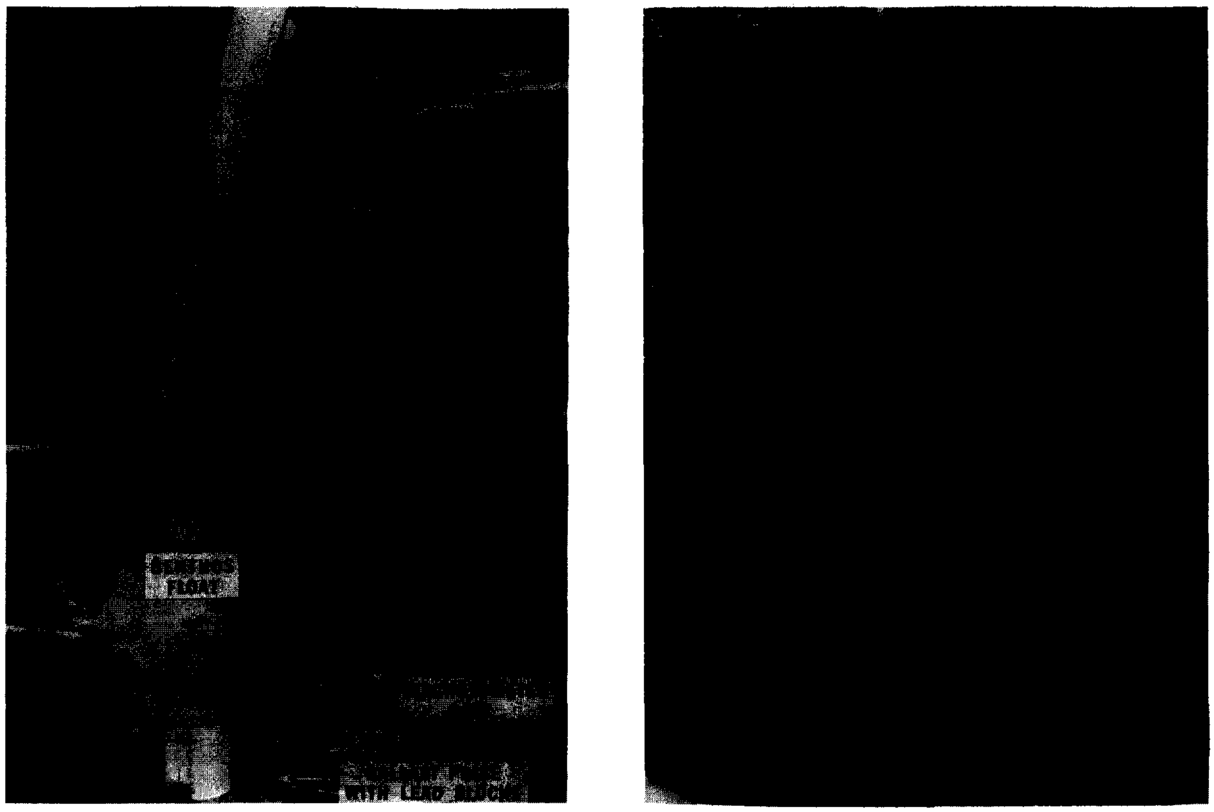

Fig. 2. A seafloor magnetometer about to be deployed, 17 July 1986 (left). Recovery of the magnetometer at CS3 (140 m water depth), 13 December 1986 (right).

state memory holding the incremental data recorded during an interval of up to 1 h. Every hour the data are transferred to a cassette tape, together with the end-of-hour full-field count along each fluxgate sensor. The magnetometer electronics were developed at Flinders University (Chamalaun and Walker, 1982). Modifications for use as seafloor magnetometers included gimballing the sensor unit or, in some cases, incorporating tilt gauges for recording the attitude of the fluxgate sensors.

Each seafloor magnetometer is contained in a cylindrical aluminium pressure casing to which are attached two Benthos glass floatation spheres (in protective 'hard hats' as shown in Fig. 2). A self-contained release housing is rigidly attached to the magnetometer pressure casing. It uses a vacuum release system similar to that designed by Dr. J.H. Filloux of Scripps Institution of Oceanography (Filloux, 1987). The base plate, held to the release housing by a vacuum, is attached to an extended ballast plate to ensure stability of the instrument package on the ocean floor. A preset timer fires a small explosive release which, by breaking a small aluminium capillary tube, allows water to enter the evacuated housing. The instrument package, freed from its ballast plate, floats up to the ocean surface where its flashing light and radio beacon allow it to be located and recovered.

Three such magnetometers were deployed at seafloor sites CS3, CS4 and CS5 on 17 July 1986 on R.V. FRANKLIN Cruise 5, and retrieved subsequently on 13 December 1986 on R.V. FRANKLIN Cruise 10. Figure 2a illustrates a magnetometer about to be deployed, and Fig. 2b one being recovered. The three seafloor sites chosen were approximately equispaced between the first land station CS2 (Durras, DRS) and the closest inshore of the TPSME stations (TP8, in 4850 m of water). Site CS3 was at the top of the continental slope in 140 m of water, and sites CS4 and CS5 were down-slope in 2240 m and 3380 m of water respectively.

In order to be able to relate the continental slope experiment directly to the TPSME, two of the TPSME land sites were reactivated. These sites were site CS1 (Black Mountain, BKM), and site CS2 (Durras, DRS) at the coastline.

3. Magnetograms and analysis

All seafloor data were processed from the cassette tapes, calibrated and rotated into magnetic field components *H*, *D* and *Z*. Land station data were similarly prepared and, to maintain consistency with data sets from TPSME, the sampling rate was interpolated to 32 h. Sample magnetograms are shown in Fig. 3.

Of the three seafloor magnetometers, site CS4 recorded for 53 days, while sites CS3 and CS5 each recorded for over 90 days. After final reduction there were 52 days of simultaneous variation data for all three sites, and 89 days simultaneous for sites CS3 and CS5. Data quality was generally very good with the exception of that from one sensor of the magnetometer at site CS4 which was noisy for much of the recording period. The attitude of this sensor was close to the horizontal east component, *D*. The magnetograms shown in Fig. 3 therefore do not include component *D* for site CS4.

Visual inspection of the magnetograms shows that *H* is largely unaffected across the profile while *D* shows marked attenuation and phase shift at site CS5. There is a similar effect observable in *D* at site CS4 (not shown in Fig. 3 as mentioned above). The vertical component *Z*, on the other hand, shows enhancement at the seafloor sites, particularly at site CS4.

Some analysis of the data has been undertaken and preliminary transfer function estimates have been obtained. The accepted method following Everett and Hyndman (1967) and Schmucker (1970) has been used with in-phase vectors reversed to conform with the Parkinson convention. The transfer function vectors are thus comparable with those from the TPSME and are termed 'Parkinson arrows'. It is important to note that the transfer functions for all three seafloor sites were derived with respect to the horizontal components (*H*, *D*) from site CS3, representing a 'quasi-surface' horizontal field. They are thus comparable with the TPSME Parkinson arrows from fig. 5d of Lilley et al. (1989) which were derived using the horizontal field at Canberra Magnetic Observatory.

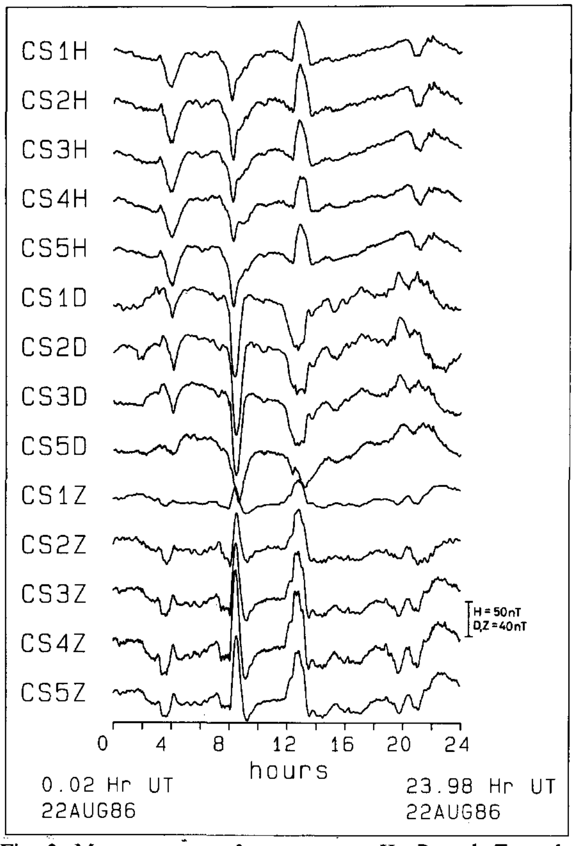

Fig. 3. Magnetograms of components *H*, *D* and *Z* at the Continental Slope Experiment sites on 22 August 1986. The *D* component for site CS4 is not shown because of the poor quality of the data.

4. Interpretation and preliminary modelling of the data

Figure 4 illustrates the Parkinson arrows for 1.14 h period, together with TPSME arrows at 1 h period (Ferguson, 1988; Lilley et al., 1989). The CSE arrows clearly show a pronounced coast effect with maximum amplitude at site CS4 mid-way down the continental slope. The in-phase arrows look consistent with a two-dimensional structure for the ocean–continent transition. The quadrature arrows, however, appear to show a more complex picture and may be influenced by electric current channelling effects in the Tasman Sea (Ferguson, 1988). At this stage the analysis is preliminary and more detailed analysis is needed before these effects can be more certainly quantified.

The effect of frequency on the in-phase Parkinson arrows is illustrated in Fig. 5. With decreasing period, there is a consistent rotation of the arrows southwards from the direction of the normal to the mean strike of the continental slope. It is also noticeable that the maximum amplitude occurs at about 0.5 h period. It is conceivable that the general deflection of the arrows southward, and the increase of this deflection with frequency, reflects the proximity of the profile to the south coast of mainland Australia.

Analogue modelling of the region around Tasmania to the south of the CSE profile has been performed by Dosso et al. (1985). A concentration of electric current in Bass Strait is a major feature at all frequencies for a source electric field polarized in the east–west direction. However, a source electric field polarized in a north–south direction produces only small amounts of electric current in Bass Strait. The mechanism is by local induction, and is notable only at high frequencies. The rotation of the arrows in Fig. 5 may indicate a response to these two effects.

Nevertheless, interpretation of the conductivity

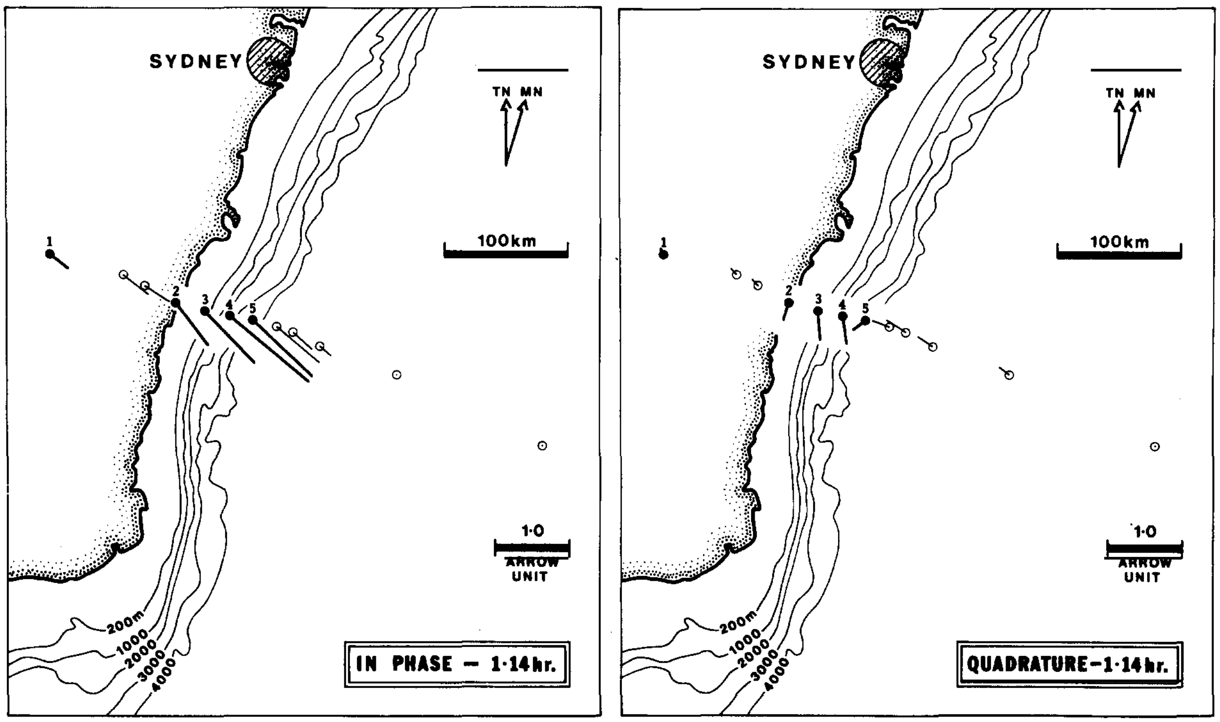

Fig. 4. Parkinson arrows for 1.14 h period. Continental Slope Experiment sites are shown by solid circles. The arrows from the Tasman Project (open circles and sites CS1 and CS2) are taken from Ferguson (1988) and Lilley et al. (1988) and are for 1 h period. Site TP8 is the open circle just east of the 4000 m depth contour.

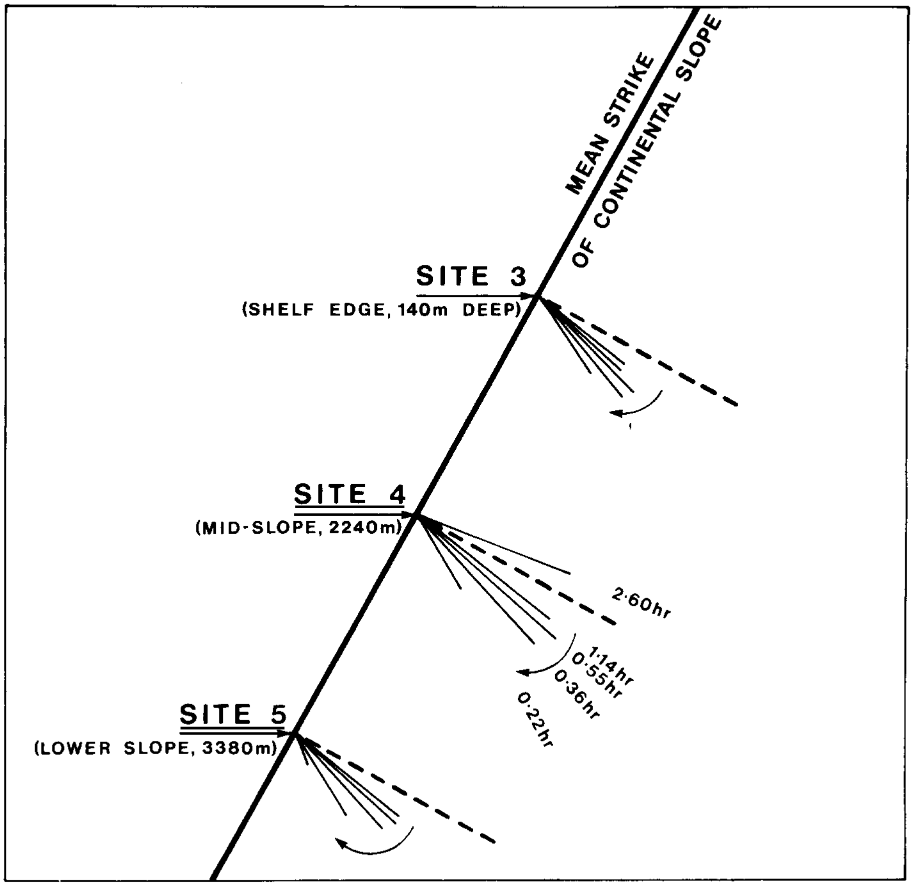

Fig. 5. Rotation of the in-phase Parkinson arrows with decreasing period. Note that the sites are not disposed geographically in this diagram and that the dashed lines show the direction normal to the mean strike of the continental slope.

structure beneath the ocean–continent transition zone can probably justifiably proceed on the basis of two-dimensional modelling. The responses of a variety of preliminary models have thus been computed, using the algorithm of Brewitt-Taylor and Weaver (1986); (see also Brewitt-Taylor and Weaver (1976) and Weaver and Brewitt-Taylor (1978)). Pending a full modelling study, just one of these models is presented here in Fig. 6.

The data points in Fig. 6 are from transfer functions for the land and seafloor sites for a period band centred on 1.14 h, taking the component perpendicular to the coastline. The model presented consists simply of an ocean of conductivity 3.3 S m^{-1} and appropriate bathymetry, including continental slope and continental shelf, set in a medium of uniform conductivity 5×10^{-3} S m^{-1}. At depth 400 km there is an (arbitrary) increase in conductivity to 1 S m^{-1}. The model is designed particularly to check the extent to which seawater by itself can account for the observed coast effect. A comparison of the model response and the data points indicates that the fit is relatively good at this period. The fit at shorter periods is not as close, especially in the quadrature part, but at longer periods both parts fit the observed data well. More information on geological structure now awaits the refinement of such a model. These matters are being actively pursued, together with the application of two-dimensional inversion techniques to the data.

Figure 6 also demonstrates a number of other points, notably: (1) the full character of a coast-effect profile which is known from far inland to far

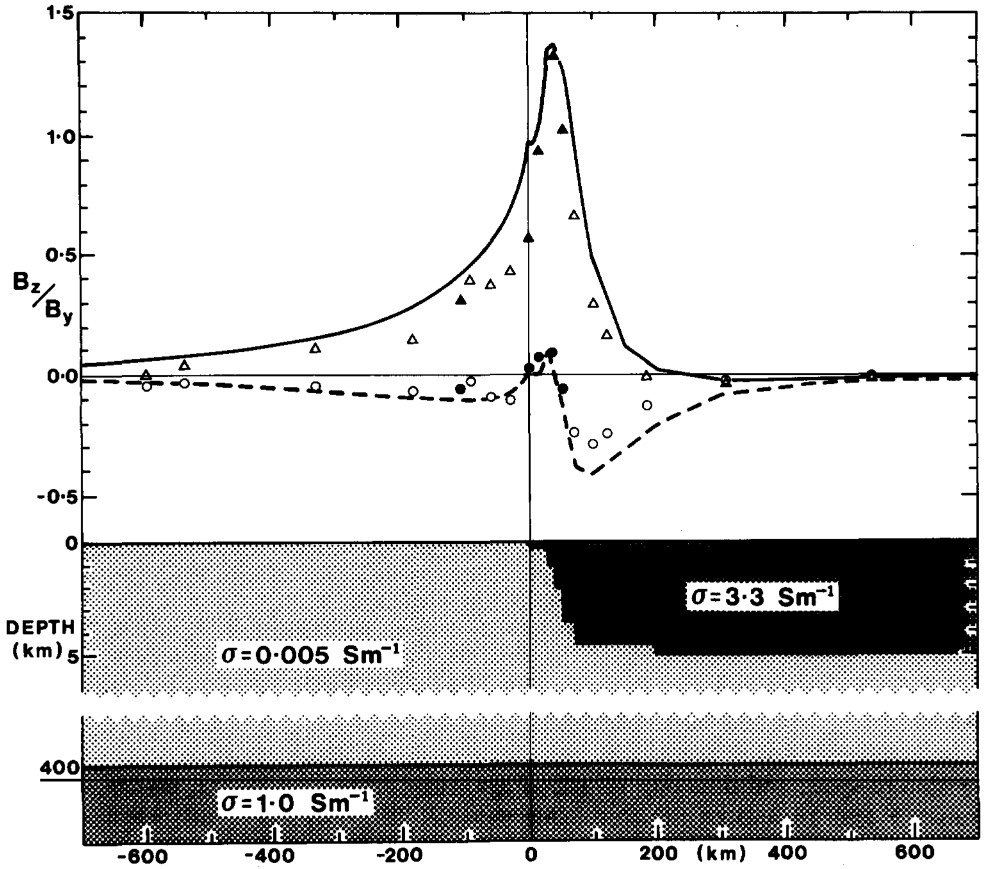

Fig. 6. Comparison of observations with response of a simple two-dimensional model of the ocean for electromagnetic induction at a period of 1 h. The real parts of the observations are denoted by triangles, the quadrature parts by circles. Solid symbols represent sites occupied during the Continental Slope Experiment and the open symbols represent sites occupied during TPSME (Ferguson, 1988; Lilley et al., 1989).

out to sea, and the restricted nature of observations which are confined to the land side only; (2) that the position of the maximum effect in the vertical field fluctuations may be expected about half-way down the continental slope.

5. Conclusion

In this experiment three new seafloor magnetometers operated successfully in water depths from 140 m to 3400 m and were recovered 5 months after deployment. They were sited on the continental shelf and slope along the TPSME profile in order to complement the TPSME experiment in the ocean–continent transition region. The data obtained demonstrate the importance of observations across the continental slope in fully characterizing the geomagnetic coast effect. It is clear from preliminary modelling that accurate data are critical in such an area, in order to provide adequate control over the range of allowable models. If the data from the present experiment were omitted from Fig. 6, the range of acceptable models would be quite different. The modelling indicates that the ocean waters account for much of the observed geomagnetic coast-effect at a period of 1 h. The full frequency range of the observations will need to be exploited to seek more information on geological structure.

Comparison with other measurements made across the continental slope is not straightforward.

A coast-effect (or perhaps more accurately an ocean edge effect) is found not only at the physical coastline but also at the continental shelf edge where there is usually an abrupt increase in the water depth. This is most clearly seen in southern California where there is a very wide continental shelf (Greenhouse, 1972). The results of the present experiment confirm that a steep continental slope produces a typically large ocean edge response. Of the previous experiments referred to earlier, only the Vancouver Island–Juan de Fuca plate profile (DeLaurier et al., 1983) shows a significant dampening of this primary effect, requiring the presence of a good conductor at 'sub-lithospheric depths'. The case for such a conductor under the passive rifted margin of southeast Australia is not obvious, but at this stage the existence of some conductivity structure at depth cannot be ruled out.

Acknowledgements

We are grateful to the National Facility Steering Committee for provision of space and time on R.V. FRANKLIN Cruises 5 and 10 and to the captain and crew of the vessel for their willing assistance and interest in the project. Funding was provided by the Australian Research Grants Committee and the Flinders University Research Committee. The Observatory Section of the Bureau of Mineral Resources is thanked for data from the Canberra Magnetic Observatory, and J.H. Filloux, I.J. Ferguson, N.L. Bindoff and M.N. Sloane are thanked for much useful discussion and advice. J.T. Weaver is thanked for providing the modelling program used. Of the authors, R.L. Kellett is the recipient of an Australian National University Research Scholarship.

References

Brewitt-Taylor, C.R. and Weaver, J.T., 1976. On the finite difference solution of two-dimensional induction problems. Geophys. J.R. Astron. Soc., 47: 375–396.

Brewitt-Taylor, C.R. and Weaver, J.T., 1986. A computer program for the solution of electromagnetic induction problems. Department of Physics, University of Victoria, British Columbia , Canada, 91 pp.

Chamalaun, F.H. and Walker, R., 1982. A microprocessor based digital fluxgate magnetometer for geomagnetic deep sounding studies. J. Geomag. Geoelectr., 34: 491–507.

DeLaurier, J.M., Auld, D.R. and Law, L.K., 1983. The geomagnetic response across the continental margin off Vancouver Island: Comparison of results from numerical modelling and field data. J. Geomag. Geoelectr., 35: 517–528.

Dosso, H.W., Nienaber, W. and Parkinson, W.D., 1985. An analogue model study of electromagnetic induction in the Tasmania region. Phys. Earth Planet. Inter., 39: 118–133.

EMSLAB group, 1988. The EMSLAB electromagnetic sounding experiment. Eos, 69 (7): 89–99.

Everett, J.E. and Hyndman, R.D., 1967. Geomagnetic variations and electrical conductivity structure in south-western Australia. Phys. Earth Planet. Inter., 1: 24–34.

Ferguson, I.J., 1988. The Tasman Project of Seafloor Magnetotelluric Exploration. Ph.D. Thesis, Australian National University, Canberra.

Ferguson, I.J., Filloux, J.H., Lilley, F.E.M., Bindoff, N.L. and Mulhearn, P.J., 1985. A seafloor magnetotelluric sounding in the Tasman Sea. Geophys. Res. Lett., 12: 545–548.

Filloux, J.H., 1987. Instrumental and experimental methods for oceanic studies. In: J.A. Jacobs (Editor), Geomagnetism, Academic Press, New York, pp. 143–248.

Filloux, J.H., Lilley, F.E.M., Ferguson, I.J., Bindoff, N.L. and Mulhearn, P.J., 1985. The Tasman Project of Seafloor Magnetotelluric Exploration. Explorat. Geophys., 16: 221–224.

Greenhouse, J.P., 1972. Geomagnetic time variations on the sea floor off Southern California. Ph.D. Thesis, S.I.O. ref. 72-67, University of California San Diego.

Lilley, F.E.M., Filloux, J.H., Ferguson, I.J., Bindoff, N.L. and Mulhearn, P.J., 1988. The Tasman Project of Seafloor Magnetotelluric Exploration: experiment and observations. Phys. Earth Planet. Inter., 53: 405–421.

Ogawa, Y., Yukutake, T. and Utada, H., 1986. Two-dimensional modelling of resistivity structure beneath the Tohoku district, northern Honshu of Japan, by a finite element method. J. Geomag. Geoelectr., 38: 45–79.

Schmucker, U., 1970. Anomalies of geomagnetic variations in the south-western United States. Bull. Scripps Inst. Oceanog., 13. University of California Press, Los Angeles, 165 pp.

Weaver, J.T. and Brewitt-Taylor, C.R., 1978. Improved boundary conditions for the numerical solution of E-polarization problems in geomagnetic induction. Geophys. J.R. Astron. Soc., 54: 309–317.

Yukutake, T., Filloux, J.H., Segawa, J., Hamano, Y. and Utada, H., 1983. Preliminary report on a magnetotelluric array study in the northwest Pacific. J. Geomag. Geoelectr., 35: 575–578.