Geomagnetic Fluctuation Anomalies Across the Southeast Australian Coast

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Summary

Magnetic surveys are used in both mineral and hydrocarbon exploration to map the characteristic patterns of magnetisation of crustal rocks. However there is a part of the magnetic field of the earth which fluctuates with time and changes over seconds, minutes and hours. This fluctuating part of the magnetic field is due to the flow of electric currents both internal and external to the earth.

The fluctuating part is anomalously strong at coastlines, a phenomenon known as the 'Geomagnetic Coast Effect' which extends for distances of order 100 km either side of the coastline. A significant portion of the coast effect can be explained by large scale induction of electric current in the seawater. The electric conductivity structure of the continental margin will also influence the flow of electric current.

The south-east Australian coast is an ideal location for investigating this phenomenon due to its simple two-dimensional character and narrow continental shelf. Measurements of the fluctuating magnetic field were made using stationary magnetometers on land and seafloor during the Tasman project of Seafloor Magnetotelluric Exploration and the more recent Continental Slope Experiment. Within the accuracy of the station spacing, the coast effect has a maximum amplitude halfway across the continental slope.

Introduction

Magnetic surveys are used in both mineral and hydrocarbon exploration to map the characteristic patterns of magnetisation of crustal rocks. However there is a part of the magnetic field of the Earth which fluctuates with time and changes over seconds, minutes and hours. This fluctuating part of the magnetic field is due to the flow of electric currents both internal and external to the earth, and is a consequence of large-scale natural electromagnetic induction taking place at the Earth's surface.

Understanding the process of electromagnetic induction gives information on the electric conductivity structure of the Earth, and also allows correction for magnetic disturbances which occur during regular magnetic surveys. The present paper reports measurements to study the natural electromagnetic induction occurring in the coastal region (both onshore and offshore) of southeast Australia, where the 'geomagnetic coast effect' is particularly well defined.

Fluctuations of the magnetic field

Spatial variations in the Earth's steady magnetic field reflect the magnetic properties (magnetic susceptibility and magnetic remanence) of the upper crust. Below the depth of the Curie point isotherm for the main magnetic minerals, typically 20 to 30 km, the rocks do not contribute to the crustal component of the magnetic field.

Superimposed on the steady magnetic field are magnetic field fluctuations, induced by external ionospheric and magnetospheric electric currents. The form of the fluctuations at the surface of the Earth is influenced by the Earth's electric conductivity structure over a range of depths. Telluric currents induced by the magnetic field fluctuations flow at depths ranging from the surface to the lower mantle (Fig. 1), much deeper than the surface layer of crustal magnetisation.

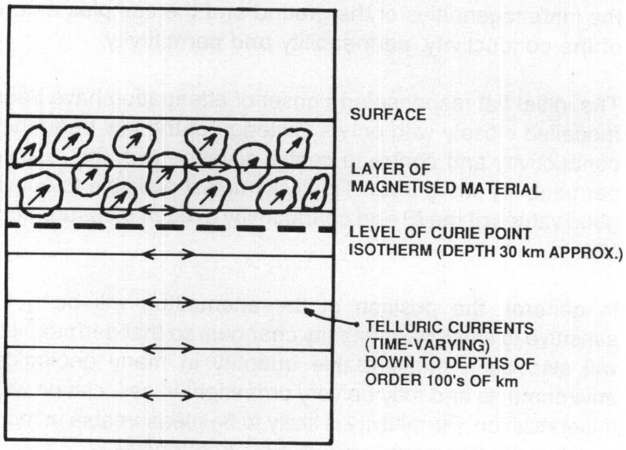

FIGURE 1

Sketch illustrating a crustal magnetized layer and the flow of time-dependent telluric currents in the Earth.

Anomalous magnetic field fluctuations occur at major lateral changes in the Earth's electric conductivity structure, such as at coastlines. The main effect of such anomalies is to cause a strong vertical component of the fluctuating magnetic field. At coastlines this phenomenon is known as the 'geomagnetic coast effect'.

In crustal magnetic surveys it is common practice to correct for magnetic fluctuations by subtracting from the data geomagnetic recordings made at a fixed base station. This correction involves the approximation that magnetic fluctuations are uniform over the survey area; an approximation which may be poor in regions of anomalous magnetic fluctuations. In these regions however it is possible to map the magnetic fluctuation pattern and to more accurately subtract the effect of fluctuations from spatial magnetic survey data.

The geomagnetic coast effect

The geomagnetic coast effect has been recognised for some time in land magnetic field fluctuation recordings by stationary magnetometers, for example at magnetic observatories (Parkinson, 1959). The vertical magnetic field fluctuations have the following characteristics:

(1) The magnitudes are large near the coast and decrease with increasing distance inland.
(2) The maximum magnitude occurs in the period range 20 min. - 4 h.

The strong electric conductivity contrast between the oceans (4 $S.m^{-1}$) and the continents (usually 10^{-2}–10^{-5} $S.m^{-1}$) is considered to be the major source of the coast effect. Various studies (eg. Schmucker, 1964; Everett and Hyndman, 1967; Bennett and Lilley, 1974) have however shown that the form of the coast effect changes between different tectonic settings. These results indicate that further electric conductivity contrasts between the crust/upper mantle of the continents and oceans must also contribute to the coast effect. The development of seafloor magnetometers (Filloux, 1973) will allow a more accurate definition of such conductivity contrasts. An extensive review of the coast effect may be found in Parkinson and Jones (1979).

It is convenient to parameterise the vertical magnetic field fluctuations associated with the coast effect in terms of Parkinson arrows. The vertical magnetic field fluctuations occurring at an electric conductivity boundary are correlated with the fluctuations in the horizontal components of the magnetic field and this relationship may be expressed by the transfer functions A, B in

$$Z = AH + BD.$$

In this expression H, D and Z denote the north, east and downwards components of the observed magnetic fluctuations and all quantities are complex and functions of frequencies. The transfer functions A, B may be graphically represented as Parkinson arrows (Parkinson, 1959).

Observations of the coast effect for southeast Australia

The southeast coast of Australia forms an ideal location for studying the geomagnetic coast effect. The coastline has a two-dimensional form and a narrow continental shelf and slope. Earlier studies of the region by Bennett and Lilley (1974) indicated that in addition to the electric conductivity contrast between the Tasman Sea and the Australian continent, it was necessary that there be a conductive zone beneath the oceanic crust or lithosphere in order to explain the observed coast effect.

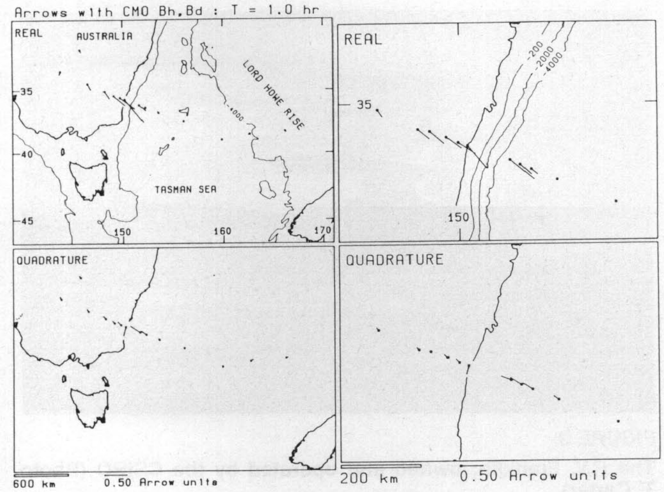

FIGURE 2

Parkinson arrows for a fluctuation frequency of 1 cycle h.$^{-1}$ computed for the Tasman Sea region by Ferguson (1988) and Lilley *et al.*, (1988). All arrows computed using local vertical fluctuation data and Canberra Magnetic Observatory horizontal fluctuation data. Note that especially for seafloor sites, arrows thus obtained are different from those obtained using entirely local data. The right-hand diagrams show the coast region at an expanded scale, and contain some additional arrows not included in the left hand diagrams.

The Tasman Project of Seafloor Magnetotelluric Exploration (TPSME) has provided electric and magnetic field recordings on the Tasman seafloor and magnetic field measurements across southeast Australia (Ferguson, 1985; Filloux *et al.*, 1985). Figure 2 shows a set of Parkinson arrows for the TPSME recording sites. The arrows show that the coast effect extends at least several hundred kilometres on either side of the coast and the maximum observed coast effect occurs near the Australian coastline, between the coast and the most western seafloor site.

Measurements on the continental slope

The Continental Slope Experiment (CSE) was designed to increase the data coverage across the continental shelf and slope of southeast Australia where the TPSME project indicated the strongest coast effect. The experiment involved the deployment of three seafloor recording magnetometers and the operation of four land magnetometers, along a line which also included the Canberra Magnetic Observatory of the Bureau of Mineral Resources. The seafloor magnetometers were deployed from the CSIRO oceanographic vessel R.V. Franklin (Fig. 3) in July 1986 and retrieved in December 1986 (Fig. 4). The instruments are three component, digital fluxgate magnetometers developed at the Flinders University of South Australia (the magnetometer electronics are described by Chamalaun and Walker, 1982).

Figure 5 shows examples of the magnetic field fluctuations recorded during the experiment. The time interval illustrated contains periods of magnetic storm and substorm activity. The amplitude of the Z component reaches a maximum at site CS4. This result indicates that to within the station spacing of the present experiment the maximum coast effect occurs half-way across the continental slope.

FIGURE 3
The R.V. Franklin, owned and operated by the CSIRO (Photo T. Carter).

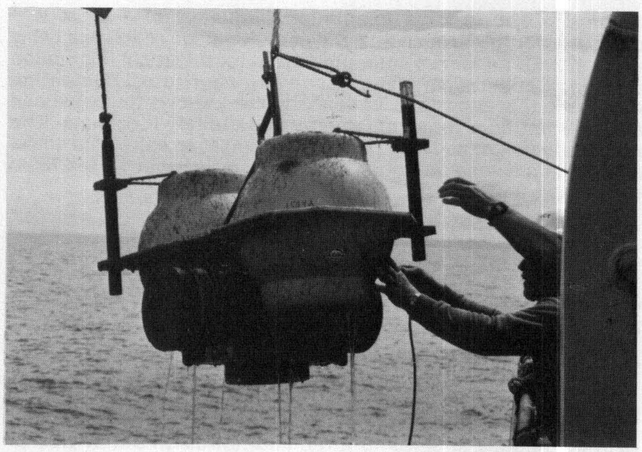

FIGURE 4.
One of the Flinders University seafloor recording magnetometers being retrieved after a deployment of five months.

Parkinson arrows determined for the three seafloor sites (from data such as in Fig. 5) are shown in Fig. 6. Comparison of the CSE Parkinson arrows with those in Fig. 2 shows that the arrows define a continuous pattern between the Australian continent and the Tasman deep seafloor. The arrows confirm that the maximum coast effect occurs half-way across the continental slope.

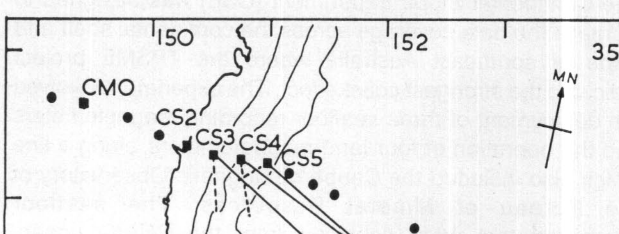

FIGURE 6
Parkinson arrows for a fluctuation frequency of 1 cycle h.$^{-1}$ determined for the Continental Slope Experiment. Solid lines indicate real arrows, dashed lines indicate quadrature arrows. The arrows have been determined using local vertical fluctuation data, and horizontal fluctuation data from the most shallow site (CS3). Note different arrows would be obtained using entirely local data from each site.

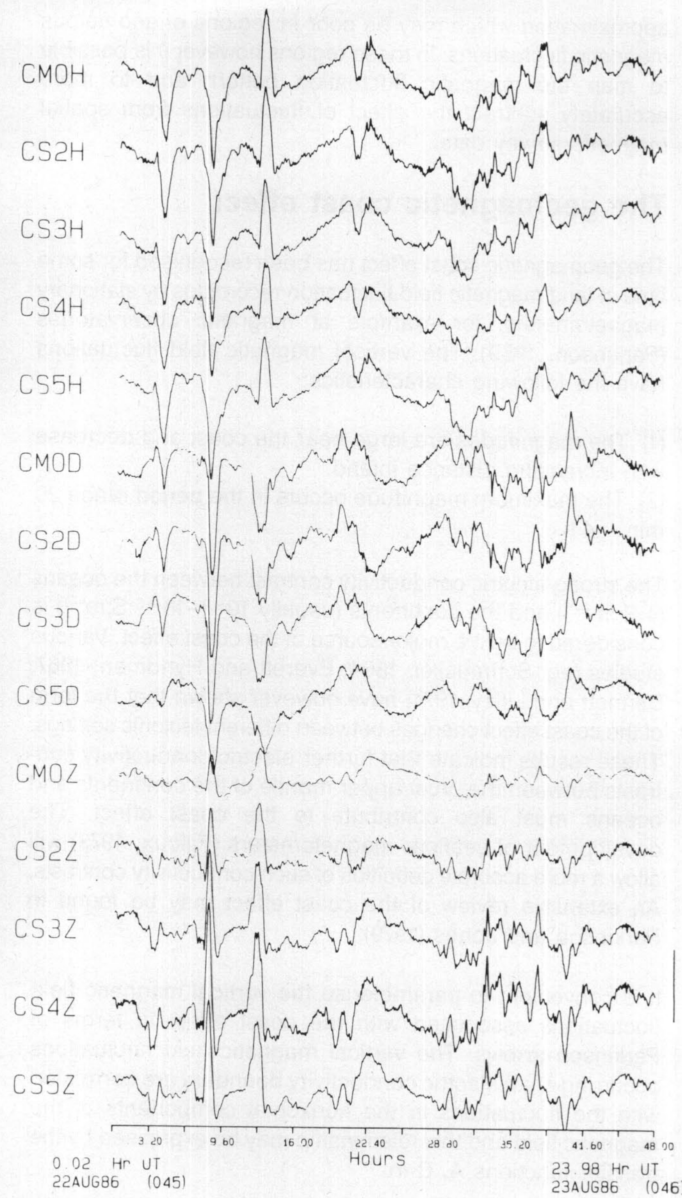

FIGURE 5
Examples of magnetic fluctuation data recorded during the continental slope experiment. Site positions are shown in Fig. 6. H, D and Z denote the components of magnetic fluctuation. The vertical bar is of scale 60 nT. The records are of two days duration. The Canberra Magnetic Observatory data have been provided by the Bureau of Mineral Resources.

The combined data set from the TPSME and CSE studies will be used to model the geomagnetic coast effect, and to investigate the electric conductivity structure of the continental margin of southeast Australia, using two-dimensional numerical modelling techniques.

Conclusions

The results of geomagnetic fluctuation studies show that the southeast Australian coastline causes anomalous vertical magnetic field fluctuations which extend at least several hundred kilometres from the coast. The studies have closely defined these anomalous fluctuations and in particular a new study has defined the coast effect where it is a maximum over the continental slope. The results could already be used to accurately correct for temporal magnetic fluctuations occurring during regular magnetic surveys.

The anomalous magnetic fluctuations are also being used to define the electric conductivity structure of the Australian continental margin. As well as providing tectonic information, the resulting conductivity models may allow prediction of the geomagnetic coast effect at other parts of the Australian continent.

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Seismic Velocity Field Estimation — Strategies for Large-scale Nonlinear Inverse Problems

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Summary

The estimation of the seismic velocity field in two or three dimensions, by modelling the travel times of particular seismic phases or by matching observed and computed seismograms, represents a large-scale nonlinear inverse problem. The solution can be obtained by determining the minimum of a misfit function between observations and theoretical predictions, subject to some regularisation conditions on the behaviour of the model parameters. The minimisation can be achieved without the inversion of large matrices by using a search scheme based on the local properties of the misfit function. At each step in the iterative process, a subspace of a small number of directions is constructed in model space and then the minimum sought in a quadratic approximation on this set. At least two directions are required for rapid convergence. This approach is very suitable when the model parameters are of different types, since partitioning by parameter class avoids dependence on scaling.

If the model is to remain close to a reference then the regularisation term is particularly important and different types of a priori information (e.g. geological) can be introduced via the character of this term. When fit-to-data is emphasised there is the chance of finding features suppressed in a more conservative approach, but at the risk of introducing spurious detail.

Introduction

The estimation of the seismic velocity field plays a central role in many aspects of seismology, yet none of the measurements we make give the seismic velocities directly. We have to resort to indirect methods to infer the velocity parameters based on particular physical models, e.g. the recovery of interval velocities from stacking velocities depends on the assumption of some form of stratification.

When an attempt is made to reconstruct the seismic velocity field in two or three dimensions using surface or down-hole observations, we are faced with a large scale inverse problem. If we use the full seismic waveforms from many receivers, the number of data points is of the order of 10^9, and 10^5–10^6 model parameters need to be estimated to produce a full two-dimensional picture. Even if attention is concentrated on travel time picks for particular seismic phases, there will often be many thousand data values and hundreds of model parameters. In this case, the likely resolution is lower so that a coarser parametrisation of the velocity field is appropriate.

Inversion for the velocity field

The aim of an inversion procedure is to generate a set of model parameters for which the calculated values of the data