This article was downloaded by:[Australian National University Library]
On: 7 May 2008
Access Details: [subscription number 773444842]
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954
Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

Australian Journal of Earth Sciences
An International Geoscience Journal of the Geological Society of Australia
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100753

Towards an electrical conductivity model for Australia

R. W. Corkery [ab]; F. E. M. Lilley [c]
[a] Department of Geology, Australian National University, Canberra, ACT, Australia
[b] Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT, Australia
[c] Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia

Online Publication Date: 01 October 1994

To cite this Article: Corkery, R. W. and Lilley, F. E. M. (1994) 'Towards an electrical conductivity model for Australia', Australian Journal of Earth Sciences, 41:5, 475 — 482

To link to this article: DOI: 10.1080/08120099408728157
URL: http://dx.doi.org/10.1080/08120099408728157

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article maybe used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Australian Journal of Earth Sciences (1994) **41**, 475–482

Towards an electrical conductivity model for Australia

R. W. CORKERY[1]* AND F. E. M. LILLEY[2]

[1] *Department of Geology, Australian National University, Canberra, ACT 0200, Australia.*
[2] *Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia.*

A compilation of the gross surface geology of the Australian continent is presented. On a grid-scale of 180 km, electrical conductances are estimated down to a depth of 10 km for both the Australian continent and the surrounding oceans, and used to form a numerical 'thin-sheet' model. Within the continent, the greatest contributions to conductance come from the sedimentary basins. Otherwise, the oceans have the strongest effect. The response of the model to time-varying magnetic fields is computed for a period of 1 h, as a guide to the electromagnetic induction pattern to be expected regionally from known Australian geology. The coast effect, as observed, is well-modelled given the accuracy of the exercise. Within the continent, strong observed conductivity anomalies are not reproduced unless conductances along their paths are increased substantially. The model will benefit from refinement, and appears to be a practical way of establishing the general electromagnetic induction pattern of Australia, set in its surrounding seas.

Key words: Australia, electrical properties, geomagnetism.

INTRODUCTION

The electrical conductivity structure of a continent may be studied using the natural fluctuations with time of the geomagnetic field. Data that show the electromagnetic response of a continent to such fluctuations are the records of magnetic observatories, both 'permanent' and 'temporary'. A set of temporary observatories is especially effective when deployed as a magnetometer array. In addition, the fluctuating electric field at the Earth's surface may be measured, as in the magnetotelluric method.

A variety of such studies have been made of the Australian continent. These studies range from the pioneering work of Parkinson (1959), through the initiation of portable magnetometer arrays by Gough *et al.* (1974), Lilley and Bennett (1972), Lilley (1976) and Woods and Lilley (1979), to the array study of Chamalaun and Cuneen (1990), and the recent Australia-wide array of geomagnetic stations (AWAGS) experiment of Chamalaun and Barton (1990). Such magnetometer arrays have the capacity to probe deeply, to upper mantle depths, and image structures that are fundamental to the tectonic history of the continent. It is therefore important in the interpretation of such studies to have a measure of the effect, in the observations, of the known Australian geology, especially the sedimentary basins; it is also important to know the effects of any conducting linkages of the continent with the surrounding seas (one possible such linkage is that described by White & Milligan 1984).

To address this question, a numerical model of the Australian continent was made on the basis of known geology, and a calculation was made of the response of the model to natural fluctuations with time in the geomagnetic field.

It was important that the response of the Australian continent be computed into its surrounding oceans, and for this purpose a 'thin-sheet' method was used (the term refers to a surface sheet that is thin in an electromagnetic sense: in the present case the surface sheet is taken as the outer 10 km of Earth). The computation itself is complex and specialist, and mathematical aspects of it will not be described in detail. The algorithm used is not original to the authors. The information on Australian geology on which the computation is based is extensive, and the exercise is one which can be expected to be improved and refined in the future.

In application, the large-scale electrical conductivity structure of Australia directly influences use of the applied electric and electromagnetic methods on the continent, and indirectly influences magnetic surveys through the variations with time which must be removed from magnetic survey data.

AUSTRALIA IN ITS SURROUNDING SEAS

The area modelled in the present paper incorporates the Australian mainland, Tasmania, Papua New Guinea/Irian Jaya, Sulawesi, Kalimantan/Sarawak and Java, and the surrounding oceans and intervening seas. This area is greater than 29 million km^2, and contains a complicated pattern of geological and oceanographic features. A summary of the aspects of the geology of this area, important for electrical conductivity, is now presented.

An initial view is taken of Australia as composed of three major regions, the western, central and eastern cratons. These regions are of Archaean, Proterozoic and

---

*Present address: Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia.

Palaeozoic ages, respectively, showing the eastward development of the continent with time. The cratons are tectonically stable, and are interlain and overlain in many places by sedimentary sequences.

Remembering this age progression, the subdivision of Australia into further tectonic elements is then taken as given by Palfreyman (1984). Many of the tectonic elements of Palfreyman share similarities regarding their electrical conductivity, and to construct the model of Australia and its environs a three-fold subdivision of lithologies is made, using the following categories: (i) crystalline rocks; (ii) sedimentary rocks; and (iii) seas and oceans.

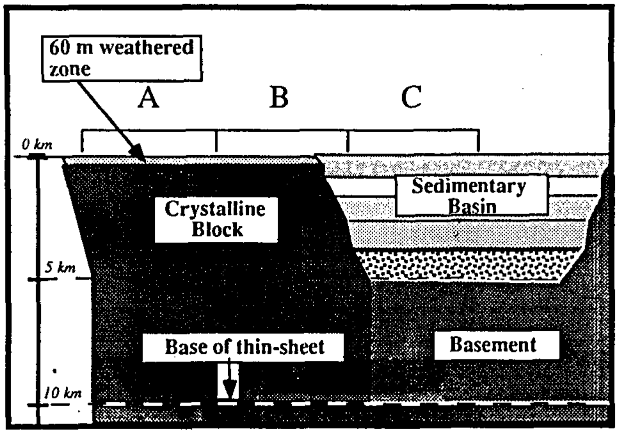

Figure 1 Examples of crustal sections for conductance calculations.

The first category comprises Precambrian shields, metamorphic terranes, volcanic provinces, and mobile thrust and foldbelts. These are the most resistive constituents of the model. The second category comprises the onshore and offshore sedimentary basins, which are conductive constituents. The third category, of the seas and oceans, comprises the most highly conductive constituents of all.

Very old sedimentary basins are placed into the first category, rather than the second, as such age is commonly associated with loss of porosity, and also loss of conductivity. In particular the Hamersley, Bangemall, Nabberu and Kimberley Basins of Western Australia, and the Victoria River, Daly River, Birrindudu and McArthur Basins of the Northern Territory are grouped in the first category. These sequences range in age from Early to Late Proterozoic, and are expected to be poor conductors.

The model requires values of electrical conductance. These values are obtained, for each grid element, by integrating the electrical conductivity from the surface down to depths of 10 km. Above this depth the most important variable will be thickness of sedimentary cover, and below this depth the model takes the conductivity structure to be horizontally layered.

Thus thickness of sedimentary cover is important in the model. The abyssal plains of the deep ocean are

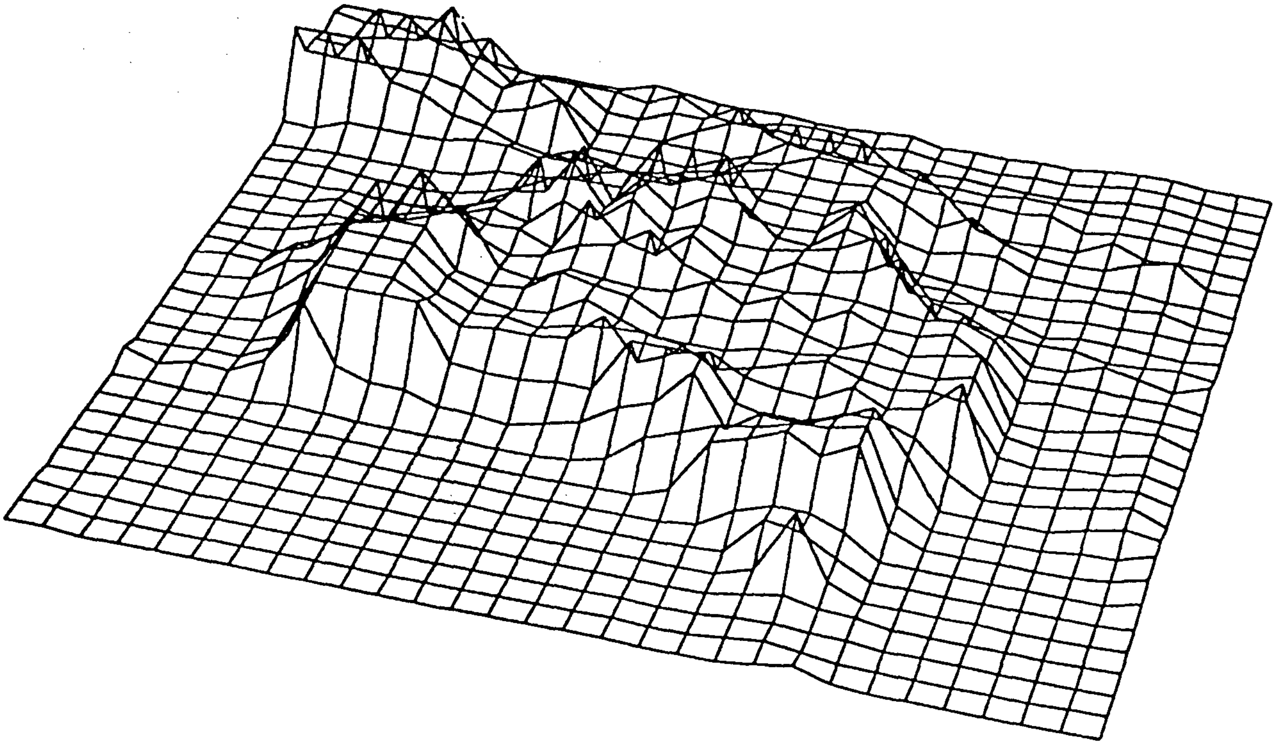

Figure 2 A 'wire diagram' of the grid conductances. A log vertical scale is used (increasing downwards) so that small variations of the conductance values in the continent can be seen, juxtaposed with the large variation at the coast.

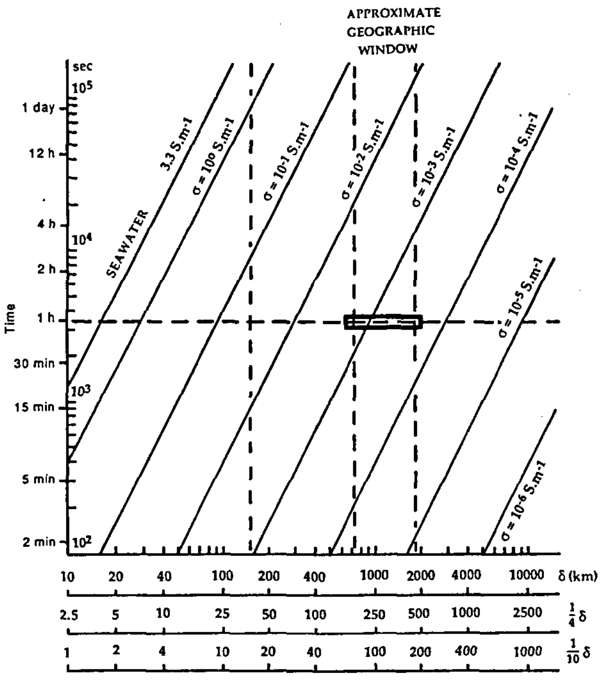

Figure 3 Graphical representation of thin-sheet conditions, assisting choice of period and conductivity of layer below the thin sheet. The slant lines are period (T) plotted against skin depth (δ) for different values of conductivity (σ); for more description see text.

generally covered in a thin, but laterally extensive layer of sediment about 0.5–1.0 km deep (Lilley *et al.* 1993). Onshore, Australian basins typically contain 2–3 km of sedimentary rocks; however, onshore pile thickness is also variable, and dependent on basin type: an extensional basin will generally contain a thicker sequence than an intercratonic 'sag' basin. The continental margin basins to the north, west and south of Australia are generally deep, with an average pile thickness greater than 5 km.

The conductances of regions containing seas and oceans, in category 3, are determined by the local seawater depth. In the area considered in this paper, the deepest ocean is of depth 7 km.

Regions of crystalline material (category 1), are given uniform (low) conductivity in this paper, because variations in a conductivity which is already low will have negligible effect. Thus the basic information for the construction of the thin-sheet model is the subdivision of oceans and basins, according to their bathymetric depths and pile thicknesses, respectively.

CONDUCTIVITY VALUES

Table 1 lists the conductivity values taken for the geological elements just discussed. A conductivity of 10^{-4} to 10^{-3} S.m^{-1} for crystalline materials is supported by studies of the Tennant Creek Block (Constable *et al.* 1984), the Yilgarn Block (Everett & Hyndman 1967a,b), the Willyama Block (Cull & Spence 1983) and, on other continents, the Lewisian foreland of Scotland (Hutton *et al.* 1980), the Fennoscandian Shield (Jones 1981) and others.

Table 1 Conductivity values taken for the elements of the thin-sheet model.

Description	Conductivity (S.m^{-1})
Precambrian blocks, fold belts, mobile zones	0.0002
Underlying crust	0.001
Oceanic crust	0.01
Sediments	0.1
Seawater	3.2

For sediments, both onshore and offshore, a value of 10^{-1} S.m^{-1} is taken (Vozoff *et al.* 1975; Constable 1991; Lilley *et al.* 1993). Continental crust below sediments is taken to have conductivity 10^{-3} S.m^{-1} (Spence & Finlayson 1983), and oceanic crust below sediments 10^{-2} S.m^{-1}; although in fact this latter value has little effect, as ocean conductance values are dominated by the seawater component.

Also required for the model is a layered structure to underlie the top 10 km surface sheet. Here there is inevitably, with the present thin-sheet algorithm, the approximation of having the same structure under both continent and oceans. However, it has been shown by Kellett *et al.* (1991) following the work of Bennett and Lilley (1974) that at a period of 1 h the coast effect for east Australia is mainly due to the high conductance of the ocean water (see also White *et al.* 1990); contrasts in oceanic and continental conductivity profiles have a lesser effect. Hence the approximation is considered reasonable in the present exercise. The actual values taken for the layered structure under the surface sheet are given in Table 2, and are representative of the profiles of Lilley *et al.* (1981); Ferguson *et al.* (1990); Kellett *et al.* (1991); and Heinson (1991). The first layer represents the lithosphere, the second layer the asthenosphere and upper mantle, and the third layer material below depth 650 km.

Conductance values are thus calculated for each of the 900 grid units of the model. Depth-to-basement values, for onshore and offshore basins, are taken from publications containing drilling data (including the Deep Sea Drilling Project), seismic reflection data, and aeromagnetic data. A compilation of these depth-to-basement values, in some cases approximate, is given in Corkery (1992). The source used for information on ocean depth is the GEBCO (1982) 1:10 000 000 chart of the oceans in the Australian region.

Table 2. The layered structure taken to underlie the 10 km thick surface 'thin sheet'.

Description	Conductivity (S.m^{-1})
Lithosphere; 10–150 km	0.001
Upper mantle; 150–650 km	0.01
Lower mantle; >650 km	1.0

Some examples of conductance calculation are now given, with reference to Figure 1 which shows a simple configuration of 60 m of weathered zone ($\sigma = 10^{-1}$ S.m^{-1}) overlying a crystalline craton ($\sigma = 2 \times 10^{-4}$ S.m^{-1}) adjacent to a sediment-filled graben 5000 m thick ($\sigma = 10^{-1}$ S.m^{-1}); the graben is underlain by a resistive basement ($\sigma = 10^{-3}$ S.m^{-1}). The base of the sheet is at depth 10 km.

At site A in Figure 1, the conductance is:

$$(60 \times 10^{-1}) + (9940 \times 2 \times 10^{-4}) = 8 \text{ S}$$

(note the dominating effect of the weathered zone relative to that of the basement) and at site C,

$$(5000 \times 10^{-1}) + (5000 \times 10^{-3}) = 505 \text{ S}$$

At site B, where the cell crosses a tectonic boundary, a weighted sum is estimated (in this case 80% of the conductance at A plus 20% of the conductance at C to give 107 S).

DETAILS AND COMPUTATION OF THE MODEL

The area of the model is divided into a 30 × 30 grid, with a grid node spacing of 180 km. Limitation on the number of grid divisions comes primarily from the magnitude of the computing task involved. Also, at each grid point a local conductance (down to depth 10 km) is determined. The continental conductances range from 8 S (as determined for site A in the example above) to 1000 S (for deep onshore sedimentary basins). The ocean conductances range from 200 S (for a shallow continental shelf, of depth less than 50 m) to 19 000 S (for deep ocean, depth greater than 6000 m).

For computation purposes the 900 conductance values are divided up into 99 different ranges, (50 onshore, and 49 offshore), and each range assigned a representative value. The model thus constructed, of 99 different conductances, is shown as a perspective plot in Figure 2. In the plot the conductive oceans and sedimentary basins form topographic lows, and the resistive crustal blocks (such as the Precambrian of Western Australia) form topographic highs. Note that the Canning, Officer and Great Artesian Basins can easily be seen. Figure 2 uses a log scale to show the variable conductance of the crustal elements. If a linear scale were used, the whole Australian continent would appear as a plateau of relatively uniform resistive material, with respect to the highly conductive oceans below. More information on the actual values of conductance that form the model is given in Corkery (1992).

The code of McKirdy *et al.* (1985) was used to calculate the response of the model to time-varying magnetic fields.

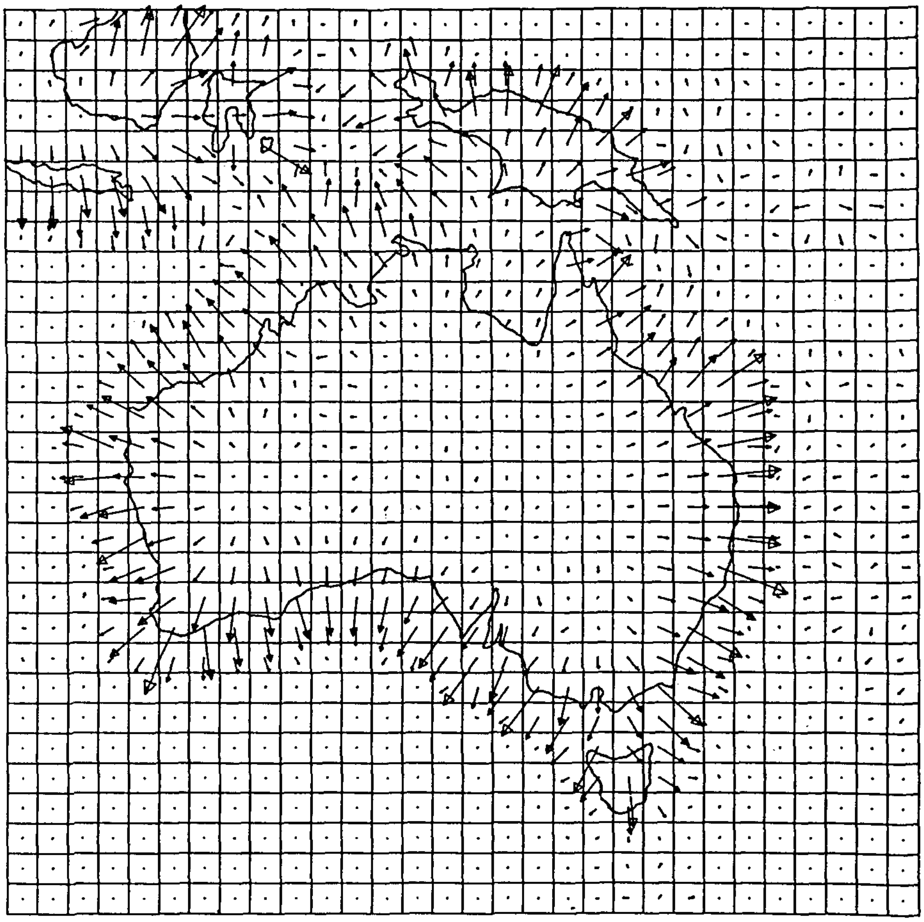

Figure 4 Electromagnetic response of the thin-sheet model of Australia and environs at period 1 h, presented as Parkinson arrows. Real (in-phase) component. The grid on the figure is 30 × 30 as described in the text. The arrow length-scale is given by an arrow which exactly spans a grid unit having a magnitude of 0.3.

Details are not given in this paper but may be found particularly in Corkery (1992), and more generally in Heinson (1991) and Weaver (1982).

The code requires satisfaction of a range of conditions, the most important of which are: (i) the thickness of the thin-sheet must be less than 1/3 of its own skin depth; (ii) the thin-sheet must be thin relative to the skin depth (δ) of the layer beneath it; (iii) the spacing (p) into which the thin-sheet model is divided should not be greater than $(1/4)\delta$; (iv) the total side length of the modelled area should not be less than several δ; (v) sharp conductivity boundaries in the model, unless perpendicular to the grid edges, should be a skin depth or so away from the grid edges; and (vi) the conductance values at the edges of the grid continue out to infinity.

Figure 3 shows conditions (i) to (iv) drawn on a graph of log T versus log δ, for various values of σ.

To examine condition (i), a horizontal line is drawn on Figure 3 for T = 1 h, the common period for the presentation of observed geomagnetic induction information (as by Parkinson arrows), and so a suitable period for the thin-sheet calculation. For the present model, the limitation of condition (i) comes from deep ocean, which is of typical depth 5 km. The skin depth for seawater should thus be three times 5 km (i.e. 15 km) or more. Figure 3 shows that this condition is satisfied for T = 1 h.

Condition (ii) becomes, on Figure 3, the vertical line $\delta = 150$ km, where thin-sheet thickness is 10 km, and 1/15 is taken to be 'small'. The space to the left of this line is prohibited.

Condition (iii) becomes, on Figure 3, the vertical line $\delta = 720$ km, so that 180 km is not greater than $\delta/4$. The space to the left of this line is prohibited. This condition is more restrictive than condition (ii).

Condition (iv) becomes, on Figure 3, the vertical line $\delta = 1800$ m, for a 30 × 30 grid with p = 180 km. Then the total side length, 5400 km, is 3δ. This condition means that the area to the right of this line is prohibited.

Condition (v) ensures that boundary conditions are satisfied. The north–south oriented square grid is overlain on the Australian region so that all parts of the Australian coastline are at least a distance δ away from the grid boundaries. There are some geographic features in the grid that are too close to the boundaries, such as the islands to the north of Australia, and the Lord Howe Rise; however, the effects of the continental geology and the oceans are expected to mainly determine the electromagnetic response of the Australian continent.

Condition (vi) also ensures that the boundary conditions are satisfied. Careful placement of the grid edges over oceans ensures satisfaction of this condition, and emphasizes the suitability of an island continent like Australia for this type of computation.

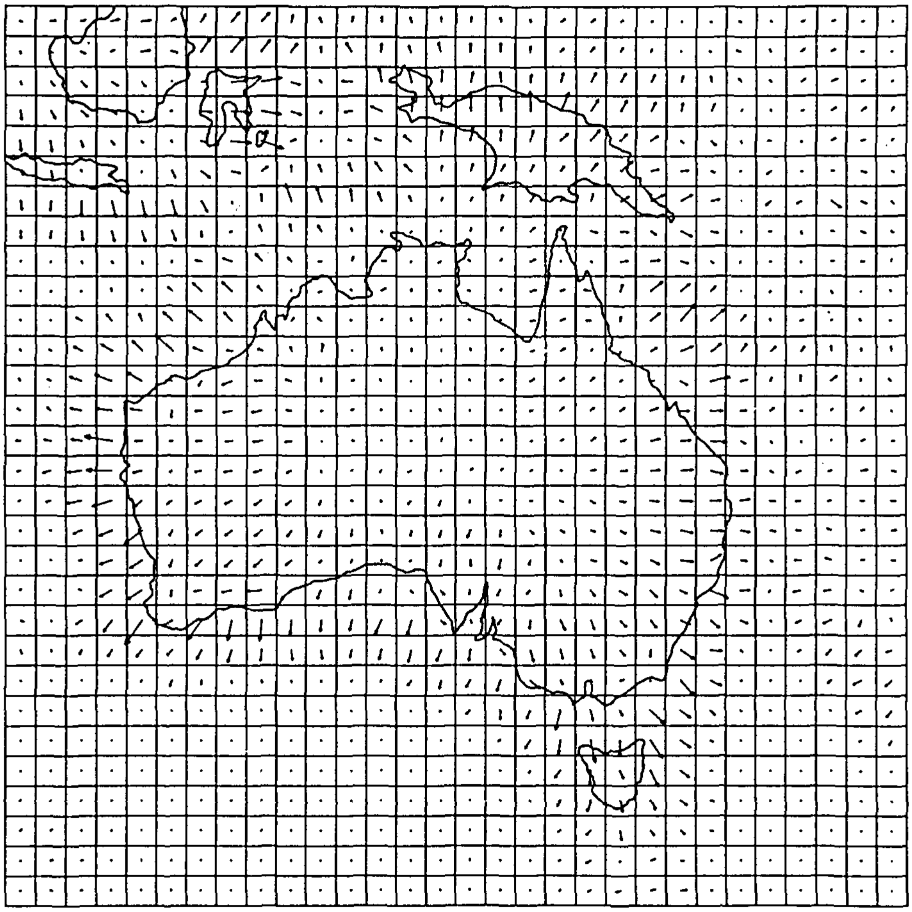

Figure 5 Electromagnetic response of the thin-sheet model at period 1 h, presented as Parkinson arrows. Quadrature (out-of-phase) component. Arrow scale as for Figure 4.

Conditions (ii) to (iv) define, for period 1 h on Figure 3, the narrow heavy rectangle, right of centre, as the allowable δ–σ space for the model calculation. Thus a conductivity in the layer immediately below the thin sheet is taken of $\sigma = 10^{-3}$ S.m^{-1}. This value is appropriate, as 10^{-3} S.m^{-1} is a reasonable value for lithospheric conductivity (Lilley *et al.* 1981).

RESULTS

The computed response of the thin-sheet model is presented here as a pattern of Parkinson arrows, to enable direct comparison with published observed results. To obtain such arrows, a fit is made of the vertical magnetic field fluctuations Z with the simultaneous horizontal field fluctuations at the same site, H (north) and D (east). Then, having transformed to the frequency domain,

$$Z = AH + BD$$

where all quantities are frequency dependent, and complex; A and B are functions of geology, only. The Parkinson arrow is then plotted with component A to the south, and B to the west; and, in the vicinity of an electrical conductivity contrast, the real arrow will generally point towards the higher conductivity side.

Computed Parkinson arrows for the model, thus plotted, are presented in Figure 4 (real) and Figure 5 (quadrature). The outstanding result is the coast effect, especially in the real arrows; this pattern reflects the fact that the strongest conductivity contrasts in the model are at continent–ocean boundaries. The coarse spacing of the model means that the coast effect is not computed for as sharp a conductivity contrast as actually occurs along (for example) the coast of southeast Australia; however, given this circumstance the typical maximum length of the coast effect arrows (0.7) is comparable to observed arrows for the Australian coastline (see Parkinson & Jones 1979).

Away from the coastlines, the model results show some 'inland' pattern, but without features as strong as now known to occur for Australia. Again, there is doubtless a smoothing effect caused by the 180 km grid spacing; a finer scale grid may be needed to fully emphasize such phenomena.

However, accepting the coarse nature of the 30×30 grid, a numerical experiment was carried out in which the conductances of a line of grid cells, approximately along the path of the curved intracratonic conductor of Barton and Chamalaun (1991), were artificially enhanced, to simulate a strong continental conductivity anomaly.

The results of enhancement of the conductances to 1500 S are shown in Figure 6, for the real (or in phase)

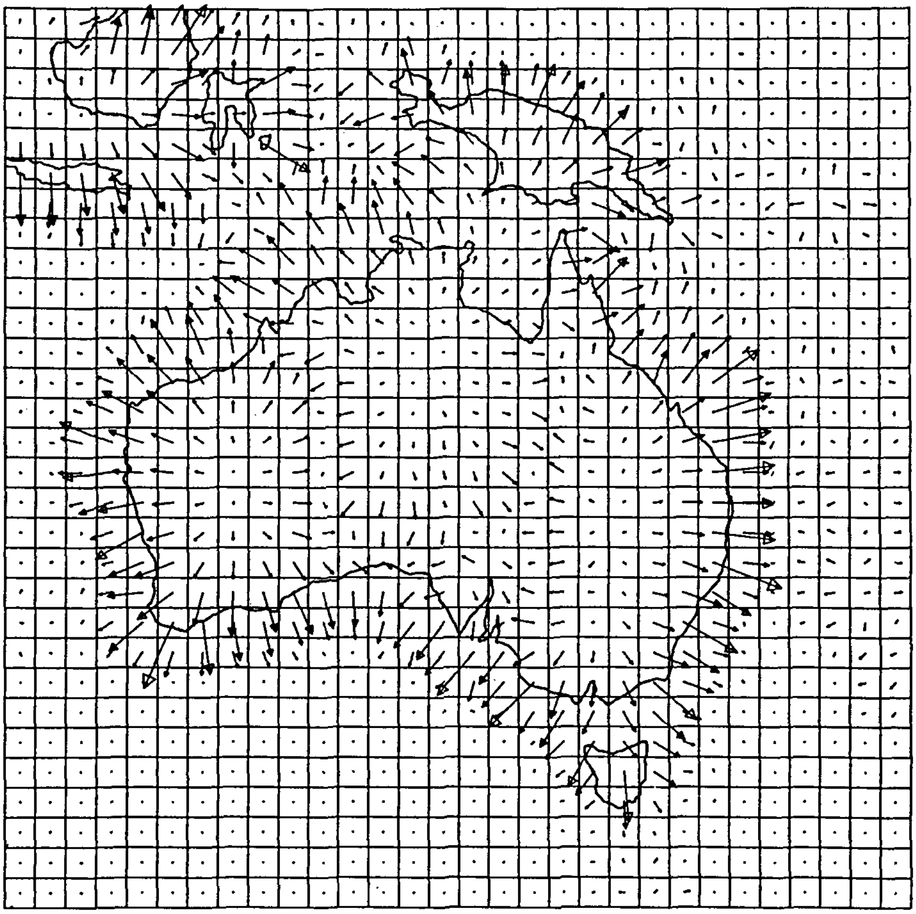

Figure 6 As for Figure 4, but with the thin-sheet model enhanced using conductances of 1500 S along the path of a possible AWAGS conductor. The arrow pattern for inland Australia indicates that significant (simulated) electric currents flow along the path of the enhanced grid nodes.

case. It can be seen that the major continental conductivity path is now shown clearly in the Parkinson arrows. The arrows are not, in fact, as strong as Australian arrows near continental conductivity anomalies, but again the limiting effects of the 30 × 30 grid must be remembered.

CONCLUSIONS

With the existing knowledge of Australian geology, and of the likely electrical conductivity of the various rock types, it now appears practical to assemble a numerical model of the Australian continent, set into its surrounding seas. Such a model can be used in a thin-sheet electromagnetic computation to predict or simulate the electromagnetic response of the Australian continent. Such computations have a variety of applications: two examples are the calculation of regional telluric effects, and their distortion; and the prediction of the fluctuating field patterns to be expected during magnetic surveys.

The present paper has described a reasonably complete, albeit initial, such exercise. There is scope in the future for grids of finer spacing, which will allow the modelling of spatially sharper conductivity structures. Also, there is clearly scope for refinement in the geological information on which the model is based.

On the observational side, in the future more field results should increasingly restrict the possible structure of the model, and indicate the extent to which the observations are accounted for by induction in the Australian crust and oceans, before recourse is made to deeper conductive structures. While magnetometer array studies map the horizontal boundaries of anomalous conductors quite well, the depths to such conductors have proved difficult to determine, not least because of the 'three-dimensional' nature of the electromagnetic induction phenomena taking place. In many cases such induction may be taking place in a surface layer where (as shown in this paper) the conductance may be high.

Thin-sheet modelling, as demonstrated above, thus contributes to the understanding of continental induction phenomena. In the present case the exercise carried out to create an 'AWAGS' type conducting path produced the quite moderate result that enhancing a line of conductances to some 1500 S is sufficient for the purpose. The results do not of themselves solve the cause of the Australian conductivity anomalies, but leave open the possibility of a sedimentary basin origin if the sedimentary basins contain a path of high conductivity. One practical cause of such high conductivity may be salt concentrations, the full extent of which is still being determined in Australian basins.

The development of such a conductivity model as described here, to become a basic part of continental geophysics, will thus be aided by additional field results.

ACKNOWLEDGEMENTS

This paper is based on the honours thesis of RWC, and thanks are expressed to Dr M. J. Rickard and Professor K. L. Lambeck in whose respective precincts the work was carried out. The thin-sheet program was kindly provided by Professor J. T. Weaver of the University of Victoria, British Columbia, and set up for the ANU computer by Dr G. S. Heinson, who also contributed much useful advice. Dr C. E. Barton and Dr F. H. Chamalaun have given much encouragement, especially concerning the AWAGS data set.

REFERENCES

Barton C. & Chamalaun F. H. 1991. AWAGS: Towards an 'aeromagnetic risk' map of Australia, and a basis for regional magnetic field surveys. *BMR Research Newsletter* **14**, 12–13.

Bennett D. J. & Lilley F. E. M. 1974. Electrical conductivity structure in the south-east Australia region. *Geophysical Journal of the Royal Astronomical Society* **37**, 191–206.

Chamalaun F. H. & Barton C. 1990. Comprehensive mapping of Australia's geomagnetic variations, *EOS* **71**, 1867, 1873.

Chamalaun F. H. & Cuneen P. 1990. The Canning Basin geomagnetic induction anomaly. *Australian Journal of Earth Sciences* **37**, 401–408.

Constable S. C. 1991. Electrical studies of the Australian lithosphere. *In* Drummond B. J. ed. *The Australian Lithosphere*, Geological Society of Australia, Special Publication **17**, 121–140.

Constable S. C., McElhinny M. W. & McFadden P. L. 1984. Deep schlumberger sounding and the crustal resistivity structure of central Australia. *Geophysical Journal of the Royal Astronomical Society* **79**, 893–910.

Corkery R. W. 1992. Thin-sheet modelling of the Australian Continental Crust. BSc(Hons) thesis, Department of Geology, Australian National University, Canberra (unpubl.).

Cull J. P. & Spence A. G. 1983. Magnetotelluric soundings over a Precambrian boundary in Australia. *BMR Report* **250**.

Everett J. E. & Hyndman R. D. 1967a. Geomagnetic variations and the electrical conductivity structure of south-western Australia. *Physics of the Earth and Planetary Interiors* **1**, 24–34.

Everett J. E. & Hyndman R. D. 1967b. Magnetotelluric investigations in south-western Australia. *Physics of the Earth and Planetary Interiors* **1**, 49–54.

Ferguson I. J., Lilley F. E. M. & Filloux J. H. 1990. Geomagnetic induction in the Tasman sea and electrical conductivity structure beneath the Tasman seafloor. *Geophysical Journal International* **102**, 299–312.

Gebco. 1982. 1:10 000 000 Map, **5–10**, *General Bathymetric Chart of the Oceans*, Canadian Hydrographic Service, Ottawa, Canada.

Gough D. I., McElhinny M. W. & Lilley F. E. M. 1974. A magnetometer array study in southern Australia. *Geophysical Journal of the Royal Astronomical Society* **36**, 345–362.

Heinson G. S. 1991. Interpretation of seafloor magnetotelluric data using thin-sheet modelling. PhD thesis, Australian National University, Canberra (unpubl.).

Hutton V. R. S., Ingham M. R. & Mbipom E. W. 1980. An electrical model of the crust and upper mantle in Scotland. *Nature* **287**, 30–33.

Jones A. G. 1981. Geomagnetic induction studies in Scandinavia. II. Geomagnetic depth sounding, induction vectors and coast-effect. *Journal of Geophysics* **50**, 23–36.

Kellett R. L., Lilley F. E. M. & White A. 1991. A two-dimensional interpretation of the geomagnetic coast effect of southeast Australia, observed on land and seafloor. *Tectonophysics* **192**, 367–382.

Lilley F. E. M. 1976. A magnetometer array study across southern Victoria and the Bass Strait area, Australia. *Geophysical Journal of the Royal Astronomical Society* **46**, 165–184.

Lilley F. E. M. & Bennett D. J. 1972. An array experiment with magnetic variometers near the coasts of South-east Australia. *Geophysical Journal of the Royal Astronomical Society* **29**, 49–64.

Lilley F. E. M., Filloux J. H., Mulhearn P. J. & Ferguson I. J. 1993. Magnetic signals from an ocean eddy. *Journal of Geomagnetism and Geoelectricity* **45**, 403–422.

Lilley F. E. M., Woods D. V. & Sloan M. N. 1981. Electrical conductivity from Australian magnetometer arrays using spatial gradient data. *Physics of the Earth and Planetary Interiors* **25**, 202–209.

McKirdy D. McA., Weaver J. T. & Dawson T. W. 1985. Induction in a thin sheet of variable conductance at the surface of a stratified earth. II. Three-dimensional theory. *Geophysical Journal of the Royal Astronomical Society* **80**, 177–194.

Palfreyman W. D. 1984. Guide to the geology of Australia. *BMR Bulletin* **181**.

Parkinson W. D. 1959. Direction of rapid geomagnetic fluctuations. *Geophysical Journal of the Royal Astronomical Society* **2**, 1–14.

Parkinson W. D. & Jones F. W. 1979. The geomagnetic coast effect. *Reviews of Geophysics and Space Physics* **17**, 1999–2015.

Spence A. G. & Finlayson D. M. 1983. The resistivity structure of the crust and upper mantle in the central Eromanga Basin, Queensland, using magnetotelluric techniques. *Journal of the Geological Society of Australia* **30**, 1–16.

Vozoff K., Kerr D., Moore R. F., Jupp D. L. B. & Lewis R. J. G. 1975. Murray Basin magnetotelluric study. *Journal of the Geological Society of Australia* **22**, 361–375.

Weaver J. T. 1982. Regional induction in Scotland: An example of three-dimensional numerical modelling using the thin sheet approximation. *Physics of the Earth and Planetary Interiors* **28**, 161–180.

White A., Kellett R. L. & Lilley F. E. M. 1990. The Continental Slope Experiment along the Tasman Project profile, southeast Australia. *Physics of the Earth and Planetary Interiors* **60**, 147–154.

White A. & Milligan P. R. 1984. A crustal conductor on Eyre Peninsula, South Australia. *Nature* **310**, 219–222.

Woods D. V. & Lilley F. E. M. 1979. Geomagnetic induction in central Australia. array experiment with magnetic variometers near the coasts of south-east Australia. *Journal of Geomagnetism and Geoelectricity* **29**, 449–458.

(Received 20 December 1992; accepted 5 January 1994)