Exploration Geophysics (1993) **24**, 187–190

Thin-sheet electromagnetic modelling of the Australian continental crust

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Abstract

An electrical conductance model for the Australian region has been compiled, based on the gross surface geology and typical conductance values for crystalline terranes, sedimentary basins, seawater and ocean crust. The electromagnetic response of this "thin-sheet" model is consistent with the observed coast effect around the edge of the continent. Within the continent, strong conductivity anomalies previously identified by magnetometer array studies are not reproduced unless conductances along their paths are increased substantially. However, such enhancement may not be geologically unrealistic.

Key words: electromagnetic induction, thin-sheet modelling, crustal conductivity anomalies

The conductance model

The "thin-sheet" electromagnetic modelling algorithm of McKirdy *et al.* (1985) was used to compute the electromagnetic induction pattern to be expected from the known geology of the Australian region. This was done on a grid scale of 180 km and for an inducing period of 1 hour. The algorithm is coded to solve numerically for nodal electric field values via an iterative integration method, and, thence, to calculate analytically magnetic field values from the electric field values. In this study, magnetic field values were output as real Parkinson arrows (vectors). Parkinson arrows allow visualisation of correlations between the horizontal and vertical parts of the transient magnetic field that occur in proximity of conductive anomalies. Parkinson arrows are taken by convention to point towards the more-conductive side of a two-dimensional geoelectric structure.

The modelling algorithm required the thickness of the thin-sheet to be negligible compared with the electromagnetic skin-depth in the underlying layer. The upper 10 km of the Australian continental crust, surrounding waters and oceanic crust were modelled as a thin-sheet of laterally variable conductance (that satisfied the negligible thickness criteria). The deeper material was modelled as a series of uniformly conducting layers representing the lithosphere and mantle.

A coded thin-sheet conductance grid of the Australian continent is shown in Fig. 1. Conductance values corresponding to the 99 code numbers used in Fig. 1 are given in Table 1. The conductance (integrated conductivity) values were compiled using the broad division of lithologies shown in Table 2. For example, the conductance of a grid-node placed over 6000 m of ocean would be the product of ocean depth and ocean conductivity (approximately 19 800 S) and a negligible contribution from a remaining 4000 m of abyssal plain sediment and crystalline basement material. Within the continent, the least conribution to conductance comes from the crystalline terranes (e.g. 10 S for the Yilgarn Block), and the greatest from sedimentary basins (e.g. 1000 S for the onshore Carnarvon Basin). Offshore, conductance estimates range from 200 S for shallow (50 m) shelf areas, to 20 000 S for the deep (greater than 6000 m) ocean. Conductivities of 10^{-4} S.m^{-1} to 10^{-3} S.m^{-1} for crystalline materials are supported by studies of the Tennant Creek Block (Constable *et al.*, 1984) and the Yilgarn Block (Everett and Hyndman,

38	38	32	59	69	80	91	89	91	89	66	72	83	83	83	89	89	80	74	95	87	93	85	87	76	72	72	80	83	85
19	29	26	38	38	16	57	61	61	61	70	55	76	83	83	87	83	80	72	83	87	93	85	85	74	67	70	76	83	85
32	31	19	13	01	16	55	51	51	72	74	57	57	36	61	76	70	80	78	80	74	78	85	83	74	65	65	74	85	87
16	17	01	01	01	16	51	16	53	87	80	78	55	36	23	16	16	21	55	64	64	67	61	61	65	64	65	70	76	85
12	14	14	14	14	28	55	51	16	87	87	87	98	61	54	18	28	36	31	28	59	59	61	57	74	64	64	65	70	70
01	01	01	11	18	52	54	65	78	80	87	87	89	62	48	34	11	11	21	33	36	70	87	83	83	57	74	67	74	78
72	74	58	58	58	58	54	54	58	51	54	60	62	52	28	13	16	16	11	34	56	36	59	72	74	72	57	52	76	78
99	91	89	89	89	89	80	62	60	58	51	34	24	24	24	19	19	19	11	58	67	58	56	74	76	76	74	83	83	96
92	83	83	91	93	96	91	70	56	38	34	34	01	01	01	12	16	16	03	72	75	83	87	85	78	67	74	67	87	87
98	91	96	87	98	98	85	64	51	32	01	31	03	01	01	13	21	16	02	08	64	64	87	89	87	76	78	76	83	74
98	98	93	70	91	91	64	52	31	01	01	13	01	06	01	01	12	13	02	03	55	57	55	66	94	74	78	85	89	78
98	93	87	67	67	54	51	42	16	31	03	09	01	09	03	08	08	05	03	01	11	57	57	63	67	65	78	76	70	78
93	93	78	61	54	51	01	06	16	13	41	01	08	14	02	11	14	03	05	03	01	11	17	51	74	72	57	65	78	59
85	85	93	67	51	01	01	01	10	31	18	05	03	01	04	11	09	10	07	07	09	11	07	21	67	63	63	65	65	74
80	72	76	51	23	01	01	01	01	21	33	09	11	13	11	03	11	04	16	04	10	11	05	26	76	65	67	65	65	70
91	89	76	51	38	01	01	01	12	21	16	03	05	07	26	11	11	06	12	20	07	13	07	05	85	87	72	61	59	72
91	96	85	59	19	01	01	01	04	16	26	18	04	11	27	29	28	14	13	08	08	11	11	05	72	85	74	70	61	74
93	96	96	80	51	01	01	01	04	13	10	15	07	05	05	07	31	16	07	03	07	11	07	10	74	87	74	70	61	74
91	91	93	91	63	01	01	01	02	09	07	07	05	01	11	04	02	07	12	14	03	11	06	01	89	85	74	63	59	70
91	89	83	85	57	01	01	01	01	42	51	51	42	42	01	01	01	13	26	26	06	06	15	57	89	86	74	63	57	74
67	89	70	74	54	01	51	56	56	67	72	78	63	56	25	09	01	26	04	04	02	01	14	87	89	89	87	67	59	63
91	89	93	93	93	83	87	93	93	93	96	96	93	87	67	34	13	04	03	02	01	01	57	89	89	89	89	74	74	59
89	89	91	91	91	93	93	93	96	96	98	98	98	98	96	92	64	04	02	01	02	01	61	89	87	87	91	89	78	63
87	87	87	89	89	89	91	91	93	93	96	96	98	98	98	96	92	80	54	38	38	54	85	89	87	89	89	89	89	70
85	87	87	87	89	89	89	89	91	91	93	93	96	96	93	93	91	91	80	25	38	58	87	89	89	87	89	89	89	83
85	85	85	85	87	87	89	89	89	89	91	91	91	91	91	91	89	91	89	63	02	61	87	89	89	87	91	91	89	85
85	85	83	85	87	87	87	87	89	89	89	89	89	89	89	89	89	89	89	72	61	72	74	89	89	89	89	91	89	85
74	83	83	85	85	85	85	85	87	87	87	89	89	89	87	87	85	89	89	76	74	78	78	89	89	89	91	91	91	89
74	74	83	85	85	85	85	85	85	85	87	85	87	85	85	87	83	87	87	76	67	76	87	87	89	89	89	91	87	85
74	74	80	80	80	80	80	83	83	83	83	83	85	83	83	80	80	85	85	85	72	63	83	89	89	89	89	89	89	87

FIGURE 1
The grid structure for the Australian continent. Each grid square measures approximately 180 × 180 km.

1967a,b). Sediments, both onshore and offshore, have conductivity values of 10^{-1} S.m^{-1} (e.g. Lilley and Tammemagi, 1972; Vozoff *et al.,* 1975; Constable, 1991).

The placement of the (necessarily square) grid ensured that strong conductivity gradients near the boundaries were essentially absent — a necessary boundary condition of the algorithm of McKirdy *et al.* (1985). Conductances along the edges of the grid are assumed to continue to infinity in a direction normal to the grid edges. Conductivity values of the layered half-space, below the thin-sheet are given in Table 3 and are based on the results of Lilley *et al.,* (1981). A detailed explanation of model construction is given by Corkery (1992).

Inductive response of the model

The model was solved for two mutually perpendicular polarisations of the inducing field. Parkinson arrows for the model run are given in Fig. 2. The arrows point away from the continental land masses towards the deep oceans, and show a smooth decrease in magnitude inland away from the major conductive contrast marked by the coastline. Thus, the geomagnetic coast effect, as observed, is well-modelled given the relatively coarse grid spacing of 180 km. The inductive response of this thin-sheet model does not show the presence of any major conductivity anomalies on the continent.

However, several continental conductivity anomalies have been identified by previous magnetometer array studies (see, for example, Lilley 1982). Woods and Lilley (1980) suggested a conductive path running across Australia and most recently Chamalaun and Barton (1990) have suggested the possible existence of a U-shaped 'Intercratonic Conductive Zone' confined largely to the main sedimentary basins between cratonic blocks. In order to model the inductive response of such a conductive zone (Fig. 3) we find that the conductance values along its path must be increased to about 1500 S. This implies that an enhancement in the contrast between the resistive blocks and the conductive basins of 3-5 times is necessary to approximate the salient features of the AWAGS magnetometer array observations of Chamalaun and Barton (1990). Such an enhancement, being less than an order of magnitude, is geologically realistic.

TABLE 1
Grid-node conductance codes and their respective values.

Code	Conductance (S)	Code	Conductance (S)	Code	Conductance (S)
01	10	34	670	67	7270
02	30	35	690	68	7650
03	50	36	710	69	8030
04	70	37	730	70	8410
05	90	38	750	71	8790
06	110	39	770	72	9170
07	130	40	790	73	9550
08	150	41	810	74	9930
09	170	42	830	75	10310
10	190	43	850	76	10690
11	210	44	870	77	11070
12	230	45	890	78	11450
13	250	46	910	79	11830
14	270	47	930	80	12210
15	290	48	950	81	12590
16	310	49	970	82	12970
17	330	50	990	83	13350
18	350	51	1190	84	13730
19	370	52	1570	85	14110
20	390	53	1950	86	14490
21	410	54	2330	87	14870
22	430	55	2710	88	15250
23	450	56	3090	89	15630
24	470	57	3470	90	16010
25	490	58	3850	91	16390
26	510	59	4230	92	16770
27	530	60	4610	93	17150
28	550	61	4990	94	17530
29	570	62	5370	95	17910
30	590	63	5750	96	18290
31	610	64	6130	97	18670
32	630	65	6510	98	19050
33	650	66	6890	99	19430

TABLE 2
Conductivity values of the lithological types considered in the model.

Description	Depth (km)	Conductivity (S.m^{-1})
Crystalline Terranes	10	2×10^{-4}
Sedimentary Basins	variable	10^{-1}
Seas and Oceans	variable	3.2

TABLE 3
The one-dimensional, geoelectric structure underlying the thin-sheet model shown in Fig. 1.

Description	Depth (km)	Thickness (km)	Conductivity (S.m^{-1})
Lithosphere	10 - 150	140	10^{-3}
Upper Mantle	150 - 650	500	10^{-2}
Lower Mantle	650 +	-	1.0

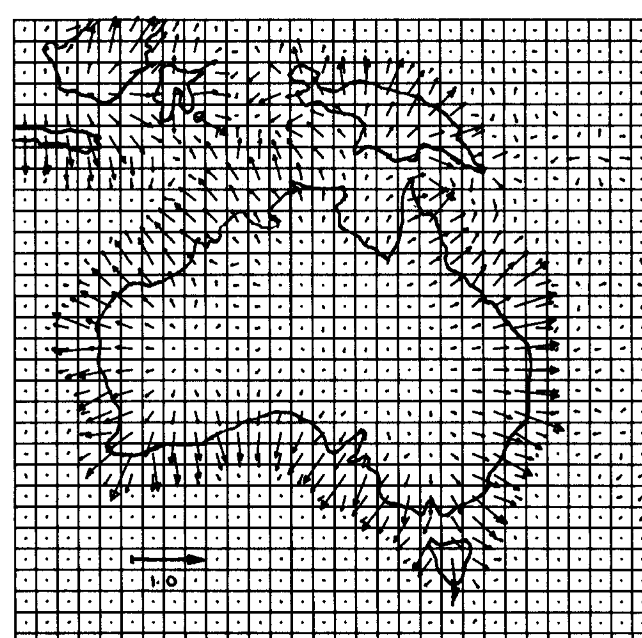

FIGURE 2
Modelled Parkinson arrows for an inducing period of one hour. Note the smooth decrease in arrow magnitude away from the major conductive contrast marked by the coastline. Within the continent, the arrow pattern is relatively subdued.

The model will benefit from a smaller grid spacing, requiring both more geological data and faster computing. The method appears to be a practical way of establishing the gross electromagnetic induction pattern of Australia, set in its surrounding seas. A more detailed account of the thin-sheet model, its construction, computation and comparison with field induction observations is given by Corkery and Lilley (in press).

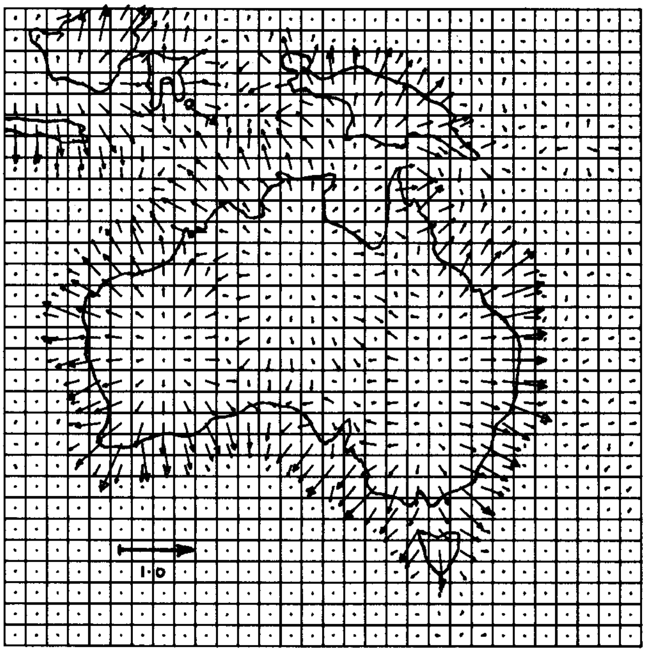

FIGURE 3
Modelled Parkinson arrows for the model shown in Fig. 1, but with increased conductance values (1500 S) along the path of the Intercratonic Conductive Zone discussed by Chamalaun and Barton (1990). The arrows indicate that significant electric currents, in this model, flow along the path of the enhanced grid nodes.

References

Chamalaun, F.H. and Barton C. (1990). 'Comprehensive mapping of Australia's geomagnetic variations'. EOS Trans. *Am. Geophys. Un.* **71**, 1867, 1873.

Constable, S.C. (1991). 'Electrical studies of the Australian lithosphere'. In 'The Australian Lithosphere' (ed. Drummond, B.J.). *Geol. Soc. Australia, Special Publication* **17**, 121-140.

Constable, S.C., McElhinny, M.W. and McFadden, P.L. (1984). 'Deep Schlumberger sounding and the crustal resistivity structure of central Australia'. *Geophys. J. R. astr. Soc.* **79**, 893-910.

Corkery, R.W. (1992). 'Thin-sheet modelling of the Australian Continental Crust'. Honours thesis, Department of Geology, Australian National University, Canberra (unpublished).

Corkery, R.W. and Lilley F.E.M. (in press). 'Towards an electrical conductivity model of Australia'. *Australian J. Earth Sci.*

Everett, J.E. and Hyndman, R.D. (1967a). 'Geomagnetic variations and the electrical conductivity structure of south-western Australia'. *Phys. Earth Plan. Int.* **1**, 24-34.

Everett, J.E. and Hyndman, R.D. (1967b). 'Magnetotelluric investigations in south-western Australia'. *Phys. Earth Planet. Int.* **1**, 49-54.

Lilley, F.E.M. (1982). 'Geomagnetic field fluctuations over Australia in relation to magnetic surveys'. *Bull. Aust. Soc. Explor. Geophys.* **13**, 68-76.

Lilley, F.E.M. and Tammemagi, H.Y. (1972). 'Magnetotelluric and geomagnetic depth sounding methods compared in Southern Australia'. *Nature Phys. Sci.* **240**, 184-187.

Lilley, F.E.M., Woods, D.V. and Sloane, M.N. (1981). 'Electrical conductivity from Australian magnetometer arrays using spatial gradient data'. *Phys. Earth Planet. Int.* **25**, 202-209.

McKirdy, D.McA., Weaver, J.T. and Dawson, T.W. (1985). 'Induction in a thin sheet of variable conductance at the surface of the Earth. II. Three-dimensional theory'. *Geophys. J. R. astr. Soc.* **80**, 177-194.

Vozoff, K., Kerr, D., Moore, R.F., Jupp, D.L.B. and Lewis, R.J.G. (1975). 'Murray Basin magnetotelluric study'. *J. Geol. Soc. Australia* **30**, 361-375.

Woods, D.V. and Lilley, F.E.M. (1980). 'Anomalous geomagnetic variations and the concentration of telluric currents in southwest Queensland, Australia'. *Geophys. J. R. astr. Soc.* **62**, 675-689.