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Magnetotelluric and Geomagnetic Depth Sounding Methods Compared

THE electrical conductivity structure of the Earth may be explored by measuring the electric and magnetic field variations induced by magnetic storms. At any point on the surface of the Earth five parameters that vary with time may be observed: the northward (X), eastward (Y) and vertically down (Z) magnetic field components, and the northward (A) and eastward (B) surface electric field components. In the magnetotelluric (MT) method only the horizontal components X, Y, A and B are observed, whereas in the geomagnetic depth sounding (GDS) method only the magnetic components X, Y and Z are observed. As these methods are equivalent only under certain special circumstances, there is usually an advantage in observing all five parameters.

Here we report some observations made of all five parameters in southern Australia, when, for the first time, telluric recording equipment was operated in conjunction with a magnetic variometer array. The array experiment was that reported by Gough *et al.*[1], and twenty-five magnetic variometers were in operation simultaneously at the sites shown in Fig. 1. Three sets of telluric recording equipment were moved across the array[2] during the experiment to occupy nine of the magnetometer sites as marked on Fig. 1. An example of the simultaneous magnetic and telluric recordings is given by Tammemagi and Lilley[2], and an example

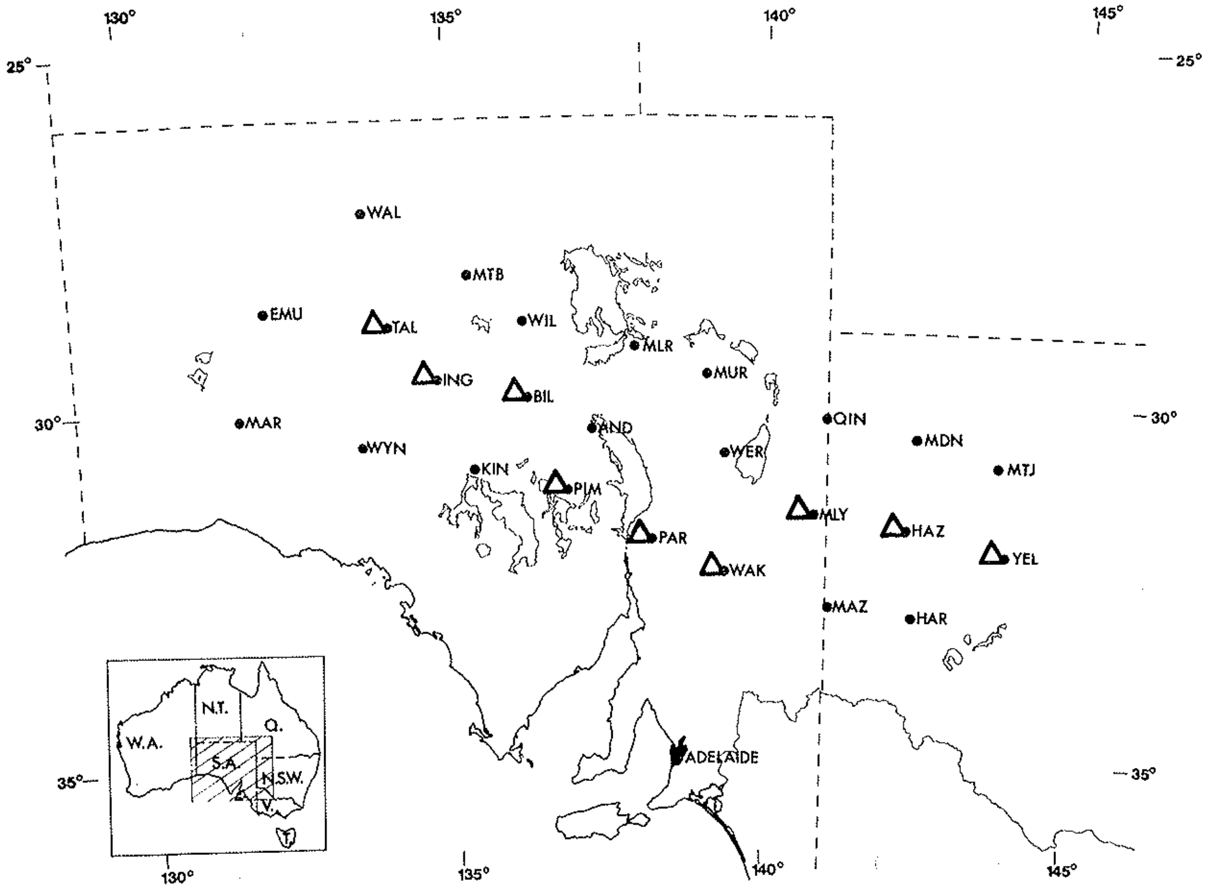

Fig. 1 Map of observing sites in southern Australia. ●, Magnetic only; △•, magnetic and telluric.

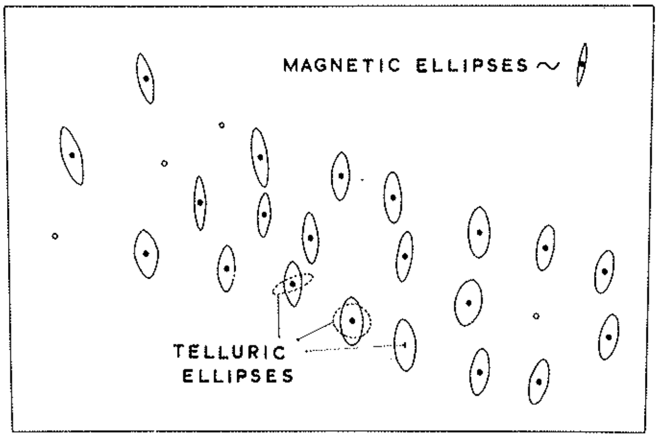

Fig. 2 Ellipses of horizontal polarization. (– – –) Telluric ellipses for PIM, PAR and WAK superimposed on the magnetic ellipses (——) for twenty-one stations. Period $T=44$ min.

of the magnetic variations observed at all array stations will be presented by D. I. Gough, M. W. McElhinny and F. E. M. L. in due course. It is possible to display combinations of the data in novel ways, for example superimposed horizontal polarization ellipses for twenty-one magnetic stations and three telluric stations are shown in Fig. 2.

Interpretation of the data has been carried out for the Pimba-Yelta line (PIM-YEL) using both MT and GDS methods, and the results of each are compared here. The MT curves of apparent resistivity, calculated from impedance tensors rotated into principal axes, are shown in Fig. 3; in each case, the direction of maximum apparent resistivity is close to north-south, and that of minimum resistivity close to east-west. The most notable feature is the very low apparent resistivity recorded at Waukaringa (WAK) and Mulyungarie (MLY). On the assumption that the line Pimba-Yelta lies across a two-dimensional conductivity inhomogeneity, these data have been interpreted[2] in terms of the model shown under the curves in Fig. 3.

To introduce the GDS interpretation, some magnetic variation maps are shown in Fig. 4 for circular polarization of the horizontal field. The strongest feature is the phase change of approximately a half cycle in the Z phase map, which has been emphasized by the heavy dashed line. This feature is explained by the presence of a good conductor directly below the region of the phase change. Simple models would predict a zero of amplitude along this line, although the station spacing may have been too coarse to detect such a null. Therefore it should be noted that the non-zero contours of Z amplitude crossing the heavy dashed Z phase line may be quite erroneous.

The electrical conductivity below the PIM-YEL traverse has been modelled by numerical techniques[3,4] for two-dimensional structures. Several models like that of Fig. 3 show responses which fit the magnetic phase data well, but the magnetic amplitude data are less conclusive. The answer to this difficulty may lie in developing methods which give a better statistical estimate of the response of an area to geomagnetic variations, like the transfer of Schmucker[5] or the induction tensor of Lilley and Bennett[6]; a study of this problem is in preparation. In the meantime, a preliminary examination of the data at both longer and shorter periods indicates that the conductor is quite shallow, and may be tapering off to either side.

Both the MT and GDS interpretations for the PIM-YEL traverse indicate that a good conductor exists beneath the WAK-MLY section. Because of the separation (or anisotropy) of the measured curves of apparent resistivity, the MT model of Fig. 3 was determined within relatively wide limits. No model could, however, be found whose theoretical response exactly satisfied both the MT curves and the GDS data. One of the best compromise models is similar in dimensions to that of Fig. 3, but with resistivities as marked in brackets. As this model fits neither set of data exactly, it must indicate some departure of the actual condi-

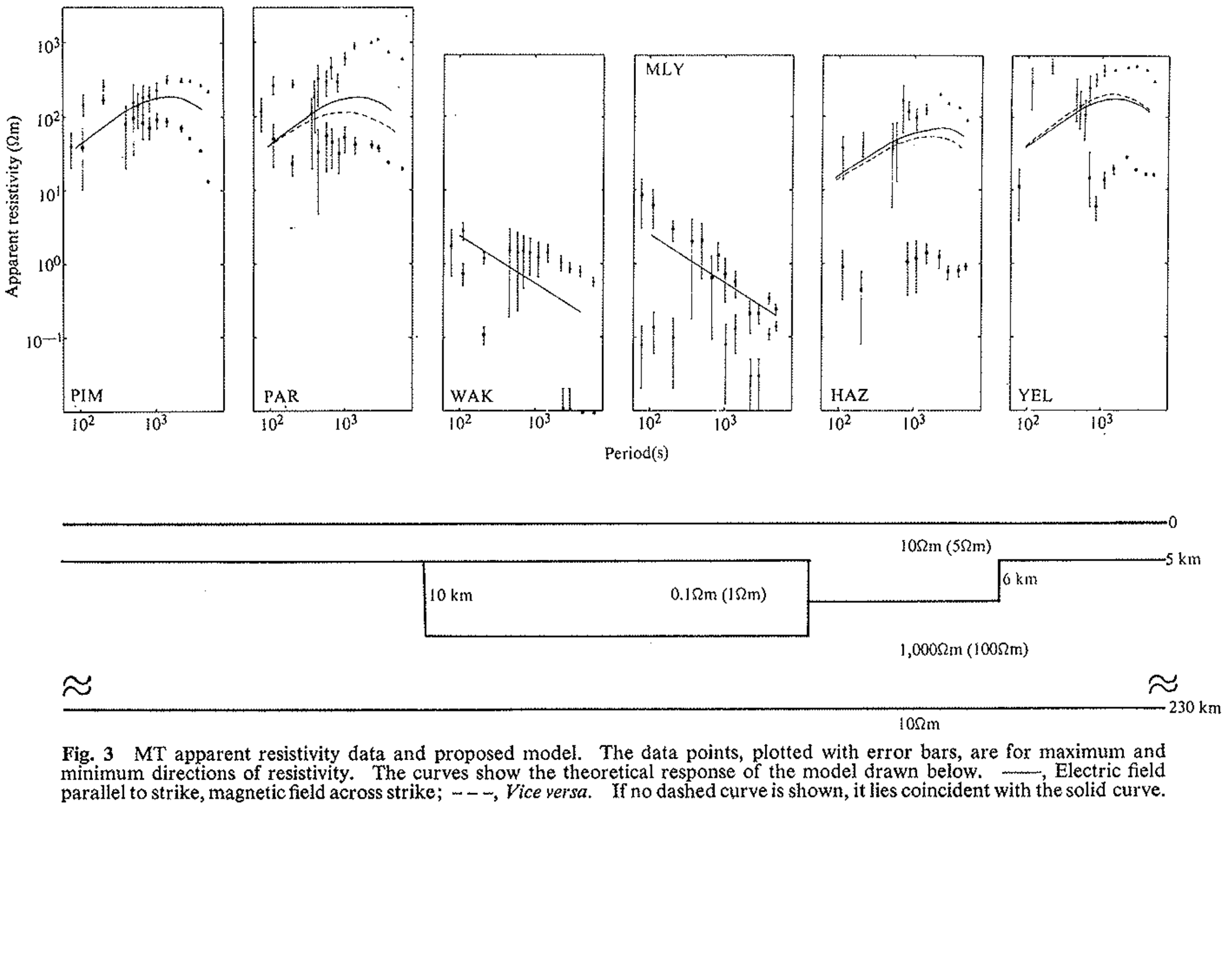

Fig. 3 MT apparent resistivity data and proposed model. The data points, plotted with error bars, are for maximum and minimum directions of resistivity. The curves show the theoretical response of the model drawn below. ——, Electric field parallel to strike, magnetic field across strike; – – –, *Vice versa*. If no dashed curve is shown, it lies coincident with the solid curve.

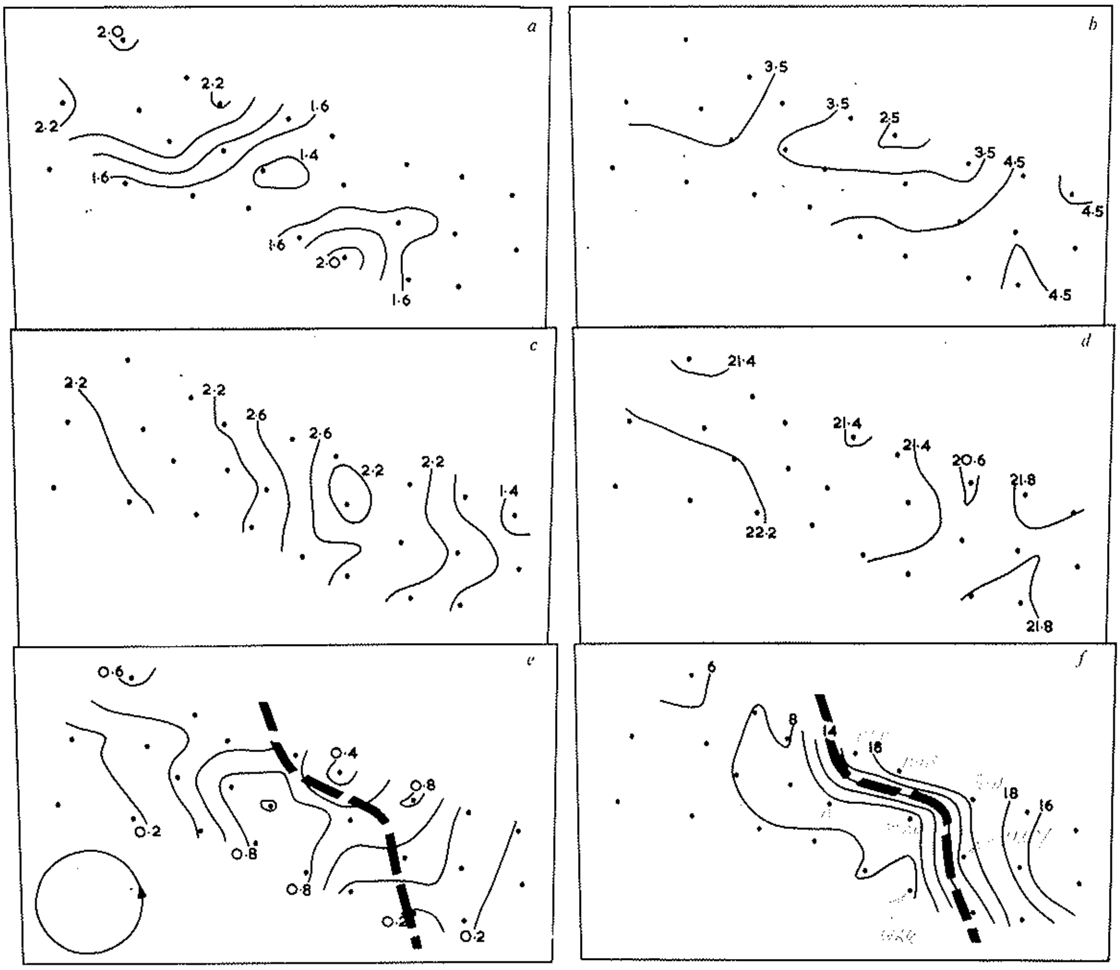

Fig. 4 Contoured maps of amplitude and phase values obtained by Fourier transforming magnetograms; for a circular polarization, period $T=25$ min. *a*, X amplitude; *b*, X phase; *c*, Y amplitude; *d*, Y phase; *e*, Z amplitude; *f*, Z phase.

tions from the original simplifying assumptions. The mechanisms which caused the anisotropy of the apparent resistivity curves have probably distorted them, particularly at Waukaringa and Mulyungarie. Also the magnetometer array may have been too sparsely located to detect the narrow Z amplitude peaks which occur above the edges of the good conductor in the MT model of Fig. 3.

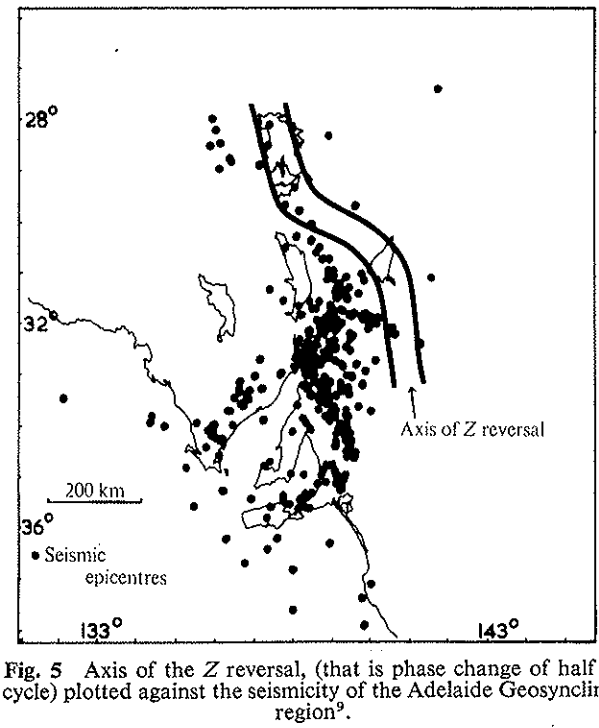

Fig. 5 Axis of the Z reversal, (that is phase change of half a cycle) plotted against the seismicity of the Adelaide Geosyncline region[9].

Our studies have demonstrated the complementary nature of the MT and the GDS methods. The magnetotelluric method has acted as a calibrator, yielding important information on the absolute resistivity values involved, as well as locating the anomaly between Partacoona (PAR) and Hazelvale (HAZ) and showing it to be located in the crust.

The magnetometer array has acted as a delineator, locating the anomaly and tracing its path. It has also yielded valuable information concerning the anisotropy of the observed apparent resistivities shown in Fig. 3. This anisotropy is not accounted for by any of the models like that in Fig. 3; to be explained by induction, it would require a very strong conductivity contrast striking east-west and lying either to the north or south of the magnetotelluric traverse. This possibility is precluded, however, by the absence from the magnetometer data of the anomalous Z pattern which should also then be observed. We thus suspect that the MT anisotropy is caused locally by conduction in small-scale inhomogeneities rather than by induction on a regional scale. Accurate interpretation of such anisotropy may well be impossible.

Geologically, the line of good conductor may be buried sediment, perhaps a strongly downwarped flank of the Adelaide Geosyncline. Alternatively it may indicate a shear-zone associated with the continental tectonics of Australia[7], although the fact that it lies along the eastern boundary of the seismic activity is very curious. Fig. 5 summarizes this evidence. It will be of interest to look for this conductor both to the north and to the south of the present array.

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