Geophys. J. R. astr. Soc. (1985) **83**, 775–786

Resistivity studies over the Flinders conductivity anomaly, South Australia

S. C. Constable* *Australian National University, Canberra, ACT 2600, Australia*

Accepted 1985 May 1. Received 1985 April 10; in original form 1984 August 13

Summary. Seven Schlumberger resistivity soundings with maximum current electrode spacings of 20 km have been conducted south of Lake Frome in South Australia. These experiments were done partly to test new electrical sounding equipment and partly to investigate a large conductivity anomaly previously delineated by other workers using magnetometer array and MT methods (the 'Flinders' anomaly). These previous studies left some doubt as to the depth to the conductive region responsible for the anomaly.

The electrical soundings did not detect a buried conductive zone, which constrains it to lie deeper than 5–7 km. However, the study did show the surface sediments of the region to be very conductive; resistivities of 2–9 Ωm were measured over thicknesses of 50–400 m, with sediment thickness inferred to be up to 2 km to the north of the studied area. This raises the question of whether current channelling in the surface sediments could have been responsible for the earlier results. Simple modelling and application of the criteria given by Jones suggest this may be so.

The equipment used for this study is a low power (200 W), computer controlled system which employs synchronous stacking and other signal processing to achieve signal to noise improvement ratios of up to 1000.

Key words: conductivity anomalies, current channelling, resistivity sounding

1 Introduction

The structure of the Australian crust has been studied for some time using natural source field electromagnetic techniques such as magnetometer arrays ('geomagnetic depth sounding' or GDS) and magnetotellurics (MT) (for a recent review of Australian work see Constable 1985). In 1978 it was decided to supplement this work with a controlled source method, and a programme of deep (20 km maximum electrode spacing) and very deep (200 km maximum electrode spacing) Schlumberger resistivity soundings was started. These experiments were similar to the resistivity studies undertaken by the South African Council for Scientific and Industrial Research (Van Zijl 1977). The results of several very deep soundings on the central Australian shield are reported elsewhere (Constable 1983;

* Present address: Scripps Institution of Oceanography, Mail Code A030, La Jolla, California 92093, USA.

Constable, McElhinny & McFadden 1984). The purpose of the present paper is to describe the equipment used in these studies and to report the results of seven deep soundings conducted in the region of a large conductivity anomaly first reported by Gough, Lilley & McElhinny (1972) and Lilley & Tammemagi (1972).

A site to test the recently constructed electrical sounding equipment was required, and the area south of Lake Frome in South Australia was considered suitable. It is sparsely populated, with little topographical relief, and it was hoped that the resistivity soundings might detect the conductor responsible for the GDS anomaly, whose depth of burial was uncertain.

The resistivity soundings failed to detect a conductive body within the crust, but their depth of investigation was at best only 5–7 km. However, the surface sediments were shown to have very low resistivities, suggesting that they are at least partly responsible for the GDS anomaly.

2 Equipment and techniques

The Schlumberger resistivity method is an established and (in principle, at least) simple technique. A DC electric current, I, is passed through the ground by means of two widely spaced current electrodes, A and B, while a potential difference resulting from the current flow, ΔV, is measured across an electric dipole MN centred between A and B. The electrode array is colinear and MN is much smaller than AB. For each AB an apparent resistivity is computed:

$$\rho_a(AB) = \frac{\pi (AB - MN)^2}{4I} \frac{\Delta V}{MN}. \tag{1}$$

The apparent resistivity curve of ρ_a as a function of AB is then usually interpreted in terms of a 1–D layered structure.

Because the signal (ΔV) diminishes as $1/(AB)^2$, deep and very deep soundings have in the past required hundreds or even thousands of amps of current. An alternative approach, employed here, is to use moderate currents of 1 A or less and enhance the resulting signals by stacking and other techniques.

Direct current is never really used for resistivity sounding, but rather the emission current is commutated or of very low frequency. Since periods of up to 100 s are required to avoid induction effects, digital signal processing is clearly more desirable than analogue enhancement. A schematic block diagram of the resistivity sounding equipment constructed at the Australian National University (ANU) is shown in Fig. 1. A desktop computer controls both the collection of data and the generation of current.

Data collection is accomplished with the aid of a 14-bit analogue to digital converter (ADC) which incorporates an adjustable gain of 20–1760 and high cut analogue filtering. Optical isolation of this unit from the rest of the equipment is essential to prevent the formation of ground loops which directly couple the power supply with the receiver.

The power supply is configured in a controlled current mode (because I is a parameter in equation (1)) and has a capacity of 1.5 A at 144 V. It is a programmable supply, and the control signal is provided by the computer by means of a 12-bit digital to analogue converter (DAC), or programmer. In this way, the computer can directly control the amount of current supplied to the current electrodes at any time. This facilitates synchronous detection of ΔV and allows a very low frequency sinusoidal current to be used. The more traditional square wave is easily generated using switching circuitry, but produces skin effect or induction transients at the time of switching. The transients increase with electrode spacing

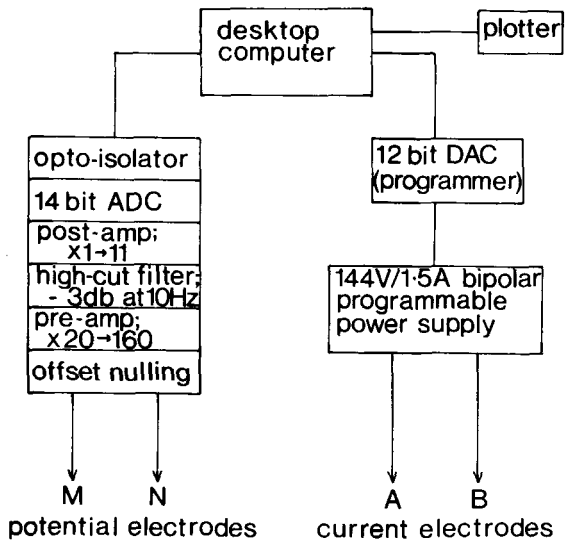

Figure 1. Block diagram of the ANU electrical sounding system. The desktop computer controls the current supplied to the A and B electrodes by way of the programmer. Measurements of potential difference across M and N are made using the 14 bit ADC, which incorporates high-cut filtering, amplification (a gain of 20–1760) and optical isolation from the computer and power supply.

and earth conductivity and may last for 30 s or more (e.g. Van Zijl & Joubert 1975). Current is supplied to the electrodes using 20 km of insulated copper wire having a resistance of 12 Ω km^{-1}. Two specially constructed motor-driven reeling machines allow the wire to be laid and recovered from the back of a motor vehicle at speeds of up to 15 km hr^{-1}. Current electrodes were 1 m long, 2 cm diameter aluminium rods, driven into the ground and watered with salt solution. Typical grounding resistances were 10–100 Ω.

With the exception of the signal processing, the use of this equipment for resistivity sounding is straightforward and follows conventional methods. For details see Constable (1983) or Constable *et al.* (1984). Signal processing consists of synchronous stacking, removal of drift caused by electrodes and low frequency telluric signals using the algorithm of McFadden & Constable (1983) and the calculation of Fourier coefficients at the signal frequency. Using this scheme, signal to noise improvement ratios of nearly 1000 have been achieved for measurements lasting 10 hr. This has allowed signals as small as 10^{-8} V m^{-1} to be recovered.

3 Australian experiments

3.1 GEOLOGY AND GEOPHYSICS OF THE FROME AREA

Fig. 2 is a sketch of the study area, showing the three main geological regions; the Adelaide Fold Belt, the Olary–Broken Hill Block and the Frome Embayment. Rutland *et al.* (1981) present a detailed geological description of the area.

The Adelaide Fold Belt consists of upper Precambrian (Adelaidian) geosynclinal sediments which have been folded and slightly metamorphosed in places. The Olary–Broken Hill Block is composed of Archaean granites and Proterozoic metamorphics. The fold belt and Olary–Broken Hill Block border a southern extension of the Great Artesian Basin (the Frome Embayment or eastern Arrowie Basin). The Cretaceous and Mesozoic sediments

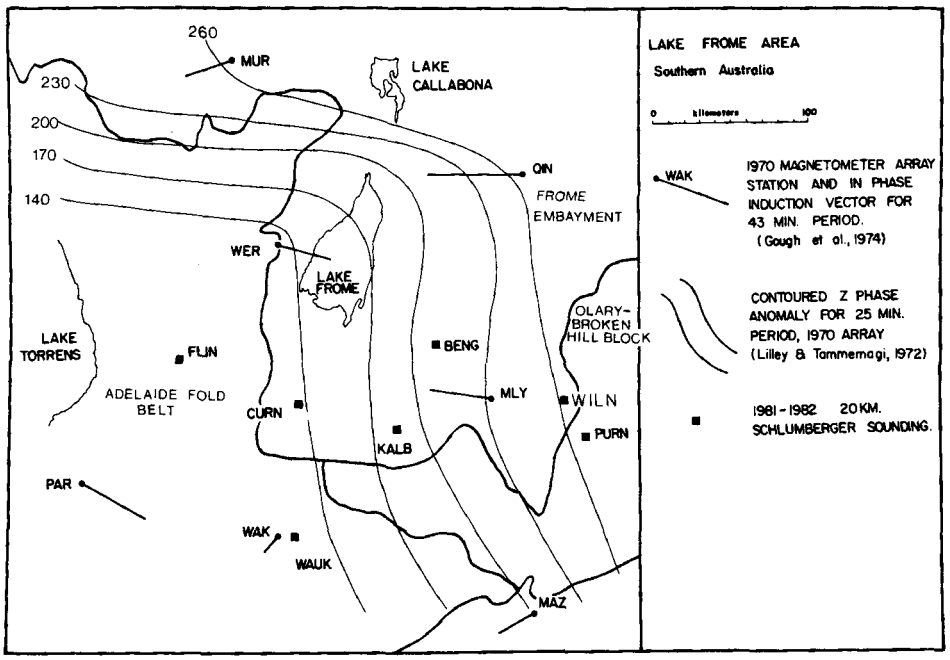

Figure 2. The study area showing the locations of the resistivity soundings and selected results from the 1970 GDS study. The contoured Z phase (units are degrees) is expected to follow conductive features and the induction vectors to point towards regions of increased conductivity.

extending south from the Great Artesian Basin overlie Cambrian sediments (the Hawker and Lake Frome Groups) which in turn lie disconformably on the Adelaidian sediments. The Cambrian and Mesozoic rocks are obscured by a surface cover of Tertiary and Quaternary sands in the embayment, and so the geology of that area is known only from drilling (Wopfner 1970; Kerr 1966; Youngs 1978). The thickness of the combined embayment fill increases to the north, from a thin Tertiary–Quaternary cover to a 2–4 km thickness of sediments at the southern edge of the Great Artesian Basin.

The sediments of the embayment thicken to the west, and in some places terminate at a fault contact with the fold belt rocks. Faulting also occurs on the eastern margin. Thus the Frome Embayment is thought to be a graben structure formed by north–south trending block faulting.

During 1970, Gough, McElhinny & Lilley (1974) deployed an array of 25 Gough-Reitzel magnetic variometers across the Adelaide Geosyncline in South Australia to study the deep crustal and upper mantle structure of this feature. The GDS results showed a very pronounced conductive anomaly trending N–S down the eastern flank of the Flinders Ranges, a range of low hills which extends about 600 km north from the city of Adelaide and has a maximum elevation of 1165 m. During the recording of the magnetometer array, Tammemagi & Lilley (1973) positioned telluric recorders at nine of the magnetometer sites, allowing MT apparent resistivities to be calculated. Anomalously low resistivities were observed.

Fig. 2 also shows an example of data from the 1970 GDS experiment. The contoured Z phase anomaly is a useful parameter for delineating conductors, as it is expected to reverse across a conductive body and to follow the lines of induced current flow. The reversed in-

phase induction vectors have the property of pointing towards regions of high conductivity. Accurate estimates of the depth to conducting bodies are difficult to obtain from array data, but Gough *et al.* (1974) considered the anomalous conductor to be in the lower crust or upper mantle.

Telluric recorders were positioned at magnetometer stations PAR, WAK and MLY of Fig. 2 during the MT study of Tammemagi & Lilley (1973) (the other six telluric stations are off the edges of the figure). Two-dimensional interpretation by Tammemagi & Lilley (1973) produced a model featuring a 0.1–1 Ω m body buried between WAK and MLY. The top of this good conductor was considered to lie between 1 and 8 km below the surface on the basis of the MT results. This is at variance with the lower crust/upper mantle estimate of Gough *et al.* (1974). However, Tammemagi (1972) noted that anisotropy of the MT data could not be explained by 2-D induction and made accurate interpretation difficult.

Since the electrical sounding experiments described here were carried out, several more GDS studies in this area have been reported by Chamalaun (1985), White & Milligan (1985) and White & Polatajko (1985). These studies confirm the existence of the anomaly and establish its lateral extent more precisely.

3.2 ELECTRICAL SOUNDING

Fig. 2 shows the location of the 20 km electrical soundings conducted in the Frome Embayment area. One sounding was on the Olary–Broken Hill Block (PURN), two were on the Adelaide Fold Belt (FLIN and WAUK) and four were on the embayment sediments (CURN, KALB, BENG and WILN). The sounding data and interpreted models for five of these sites are shown in Figs 3–7.

The interpretation of the sounding data presented below was conducted as follows. Interactive forward modelling, using the linear filter method (Ghosh 1971) with the accurate, short filter of Guptasarma (1982), is used to determine quickly the minimum number of layers needed to fit the data with a 1-D model, as well as approximate values for the layer parameters. This model is then used as the starting point for an iterative model fitting scheme using the Marquardt (1963) algorithm, which produces a model which minimizes X^2, the sum of the squares of the residuals between the theoretical model response and the data. This minimization is dependent on the starting position, which one hopes the interactive modelling has placed near the global rather than a local minimum, and the number of layers in the parameterization. This latter constraint does not appear to be a severe one for the resistivity method, as there is usually some well-defined point at which the inclusion of additional layers does not significantly improve the fit.

Inversion is performed on the logarithms of the model parameters and apparent resistivity data. The use of the computerized data collection system results in measuring errors which are usually less than 1 per cent, but experience shows that the noise introduced by AB electrode effects (that is, non-1-D structure) is much larger. Hence the minimum data error has been set equal to 10 per cent of the (linear) apparent resistivities, to prevent the modelling routine placing unrealistic emphasis on fitting data with small measurement errors. If a layer parameter is very poorly constrained by the data, or if it is strongly correlated with another parameter, it is set to a reasonable value and held fixed during the inversion. The modelling scheme is described in more detail by Constable (1983).

The models produced from the data are given in Table 1 as layer resistivities (Ω m) and thickness (m). Fractional linear errors (denoted by ±%) are given for the layer parameters, but because these depend on linear approximations and correlations between parameters they provide only an approximate indication of the uncertainty in the parameters. Relative

Table 1. Model parameters. The parameter errors are dependent on linear approximations and correlations between parameters, and so only provide approximate or relative estimates of parameter uncertainty. Parameters marked * have errors too large to be easily estimated.

SOUNDING:	PURN	FLIN	CURN	BENG	WILN
System Variance	2.720	1.370	1.290	0.096	0.482
Resistivity:					
layer 1	21.5*	68.3*	9.51 ± 4%	7.04 ± 5%	92.7 ± 14%
layer 2	3.26 ± 7%	12.5*	2.63 ± 13%	2.11 ± 6%	7.14 ± 2%
layer 3	10000*	801 ± 4%	285 ± 37%	5.26 ± 9%	8.91 ± 6%
layer 4				181 ± 13%	10000*
Thickness:					
layer 1	0.62 ± 53%	1.31*	30.7 ± 12%	2.61 ± 7%	1.22 ± 5%
layer 2	10.1 ± 8%	4.89*	165 ± 16%	14.9 ± 18%	64.1 ± 28%
layer 3				88.5 ± 7%	359 ± 6%

goodness of fit is determined by the system variance (X^2 divided by the number of degrees of freedom). If the system variance is much greater than 1.0, then the model has too few parameters or (as is more likely) the data errors have been underestimated. If the system variance is much less than 1.0, the model has too many parameters or the data errors have been overestimated.

3.2.1 Olary–Broken Hill Block – Fig. 3 shows the data for the PURN (Purnamoota) sounding, with the three layer best fitting model. The layer 3 (bedrock) resistivity is not

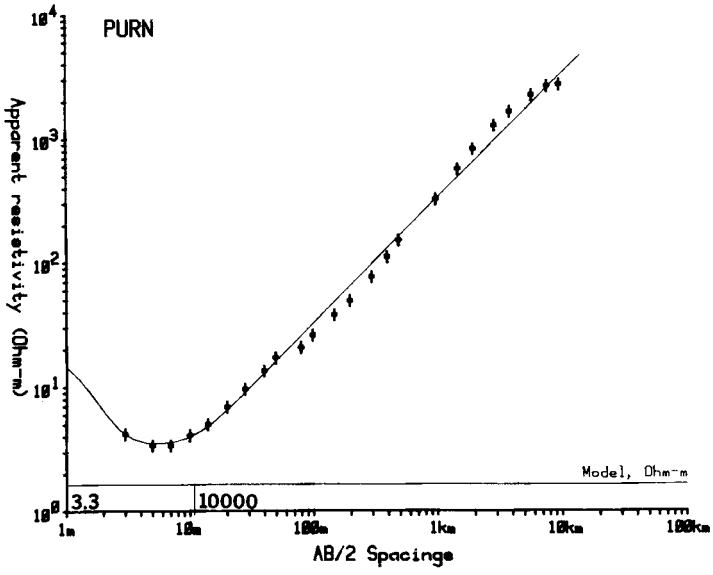

Figure 3. Purnamoota resistivity data. Error bars are ± 10 per cent of the (linear) data. The solid line is the response of the model, which is given in Table 1.

resolved by the data and so was held fixed at $10^4\ \Omega$ m during the inversion, but forward modelling shows it to be no less than 5000 Ω m. Because the apparent resistivity curve for layered structure cannot rise more steeply than 45°, the conductive overburden (in this case *10 m of 3.3 Ω m colluvium and alluvium) prevents the resistivity curve attaining the value of* the bedrock resistivity. The conductance, (integrated conductivity-thickness product) of the surface layer is 3.1 S. The reduction in slope of the resistivity data at $AB/2 = 8$ and 10 km suggests a levelling off at about 5000 Ω m or even a drop in resistivity, but the effect is too small to justify inclusion of another layer in the model. According to the GDS and MT studies, this sounding is not over the region of anomalous conductivity. The sounding fixes the minimum transverse resistance (integrated resistivity-thickness product) of the crust at $5 \times 10^7\ \Omega m^2$.

3.2.2 Adelaide Fold Belt – The two sounding experiments carried out on the fold belt were in the Flinders Ranges proper (FLIN) and about 100 km to the east of them at Waukaringa (WAUK). Sounding FLIN is about 40 km to the west of the anomaly centre, and the GDS and MT results suggest that sounding WAUK is directly over the conductive body.

The data and least squares 3 layer model for FLIN are shown in Fig. 4. The bedrock resistivity (ρ_3) is 800 Ω m. Unlike the PURN sounding, the curve for FLIN attains the value of bedrock resistivity, because at FLIN both ρ_3 and the conductance of the overburden (0.41 S) are lower. Large AB electrode effects were expected for the FLIN sounding, as the rocks of this area are interbedded sandstones and siltstones which have been extensively folded. However, although some AB noise is evident, it appears to be smaller than was expected.

Forward modelling may be used to determine constraints on particular parameters, by varying a parameter until an unacceptable fit to the data is observed. In this way it can be shown that a significant change in resistivity (a factor of 5) above a depth of 7 km is inconsistent with the data. A layer of resistivity 0.1 Ω m could occur at a minimum depth of about 10 km.

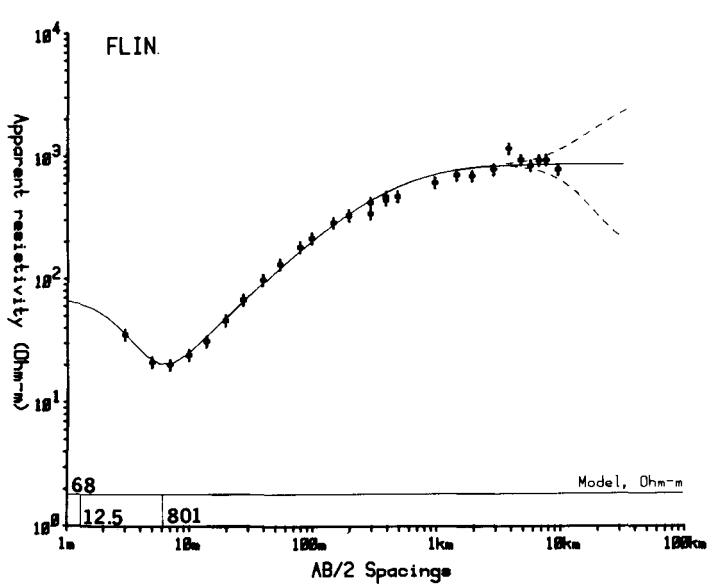

Figure 4. Flinders resistivity data. Data errors are ± 10 per cent. The broken lines show the effect of placing a resistivity contrast of 5 (4000 or 160 Ω m) at a depth of 7 km.

The form of the WAUK sounding curve is similar to that of FLIN, with a low conductance surface layer ($S = 0.60$ S) underlain by bedrock of moderate resistivity (200–300 Ω m). However, large electrode effects during the WAUK sounding reduced the resolution of the experiment for detecting deep layers, which is unfortunate because of this station's position near the centre of the anomaly. The most that may be said is that a very conductive layer (1 Ω m or less) shallower than 5 km is not suggested by the sounding data.

The bulk resistivity of the Adelaide fold belt is thus determined to be 200–800 Ω m. A conducting layer shallower than 7 km is not likely to exist under the Flinders Ranges, and although the WAUK sounding was degraded by AB electrode effects, the data suggest that a conductive layer must be deeper than 5 km to occur in that area.

3.2.3 Frome Embayment – Four soundings were conducted on the Frome Embayment, CURN, KALB, BENG and WILN. The CURN (Curnamona) sounding data are shown in Fig. 5. The sounding is situated to the SW of the embayment where the bedrock is probably Adelaide Fold Belt. The two upper layers of the model represent 196 m of surface sediments with a resistivity of 2.5–10 Ωm and conductance of 65.9 S. The layer 3 resistivity (285 Ωm) is consistent with the FLIN/WAUK results for fold belt rocks, which probably undielie the sediments in this region.

Because the sounding curve is still rising at the greatest electrode spacings, the depth of investigation is shallower than that of FLIN, for example. It is not possible to include a conducting layer at a depth shallower than 4 km without significantly affecting the fit to the data.

The KALB (Kalabity) sounding, which was terminated at 1 km because of technical difficulties, showed the thin sediments at the southern edge of the embayment to have a conductance of 5S. A moderate value for the basement resistivity (~ 80 Ωm) suggests that the basement (Olary–Broken Hill Block) is extensively weathered.

Data collected at BENG (Benagerie) are shown in Fig. 6. It appears that the latter section of the curve is afflicted by AB electrode effects, as it is not possible to fit these data by

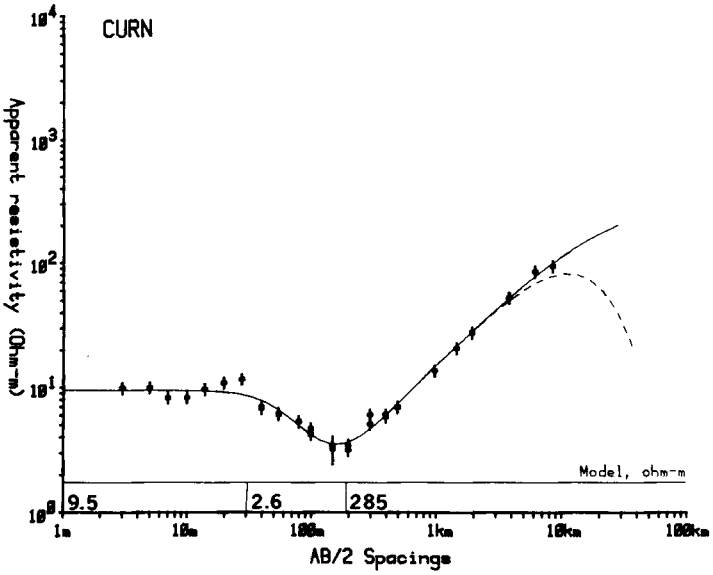

Figure 5. Curnamona sounding. The broken line shows the effect of placing a very conductive layer (1 Ω m) at a depth of 4 km.

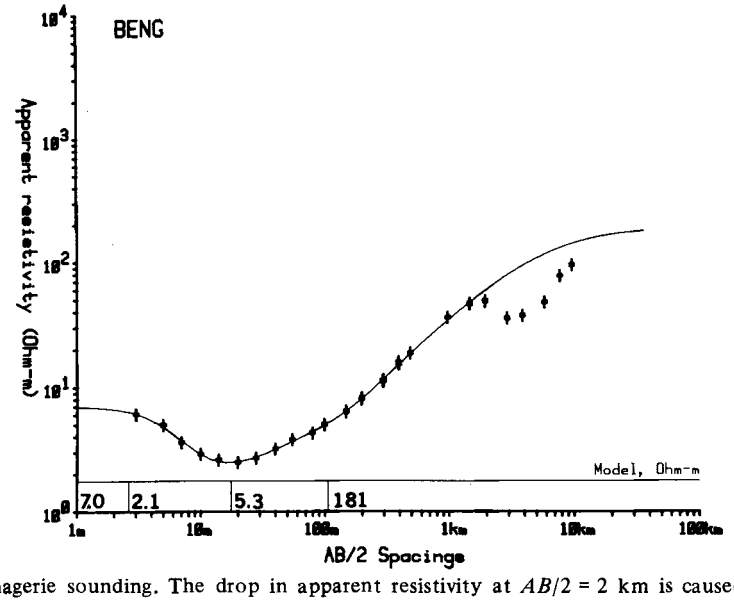

Figure 6. Benagerie sounding. The drop in apparent resistivity at $AB/2 = 2$ km is caused by electrode effects, as it is not possible to fit these data using 1-D models.

layered earth modelling. For this reason, the last six data were not included for the modelling, the results of which are given in Table 1. The surface sediments have resistivities between 2.1 and 7.0 Ωm and a total conductance of 24.3 S. The layer 4 resistivity of 181 Ωm again suggests that the basement (Olary–Broken Hill Block) has a deep weathering profile, although it may be simply that the distortion of the curve is lowering the estimate. This distortion makes it inappropriate to consider a deep conductor, but it may be noted that the curve is still rising at the greatest electrode spacings.

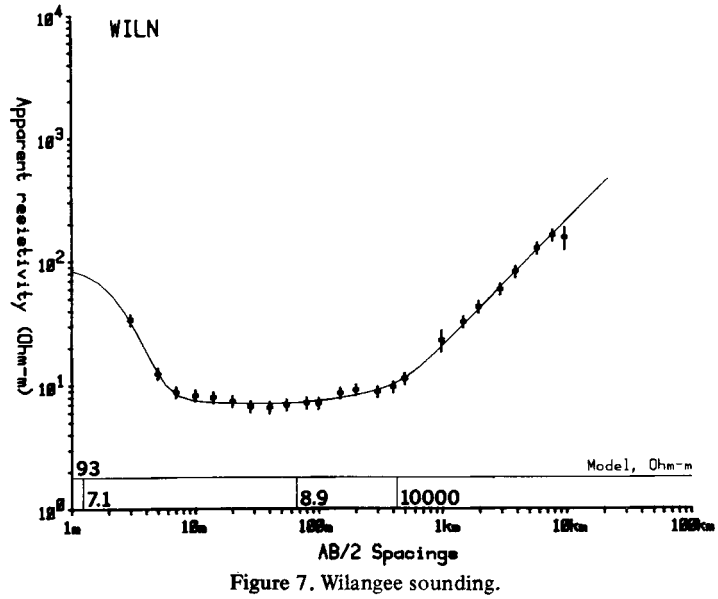

Figure 7. Wilangee sounding.

The sounding at WILN (Wilangee) is situated on the eastern edge of the Frome Embayment. The sounding curve and model are given in Fig. 7 and Table 1. The model features more than 400 m of 7–9 Ω m sediments overlying a basement (Olary–Broken Hill Block) with resistivity > 500 Ω m. The conductance of the overburden is 49.2 S. This sounding is close to and parallel with the faulted edge of the (more resistive) Broken Hill Block. It would appear that this feature is far enough away to have had little effect on the sounding, as the ascending part of the curve would rise more steeply than 45° if electric current were trapped in the vicinity of the sounding array by the faulted margin. A conductive zone associated with a continuation of faulting in the basement might also distort the curve in a less apparent manner, although again there is no evidence of this.

4 Discussion

The electrical soundings do not support the notion of a very conductive body buried less than 5 km deep, but certainly would allow such a feature to exist deeper, as proposed by Gough *et al.* (1974). However, attention is drawn to the extremely conductive sediments of the embayment, which could offer an alternative explanation for the low MT resistivities and the conductive anomaly observed by the magnetometer array. These sediments, with resistivities as low as 2 Ω m, have thicknesses (measured using the electrical soundings) of up to 400 m in the southern part of the Frome Embayment, and conductances up to 65 S. The depth to magnetic basement map produced by Gerdes (1982) suggests that the same sediments are 1–2 km thick further north near Lake Frome. It is possible that induction in these surface sediments is directly responsible for the observations, but a more likely mechanism is current channelling between larger conductive bodies. Immediately to the north of the study area lies the Great Artesian Basin, approximately half a million square kilometres in area with sediment thickness of 3–5 km. To the south-west lie Spencer's Gulf and the Southern Ocean.

Woods & Lilley (1980) observed peak current densities of 10^{-5} A m^{-2} in the north-western Great Artesian Basin (Eromanga Basin), thought to be associated with current channelling. Simple modelling shows that such a current density in the Frome Embayment sediments would produce vertical magnetic fields of about ± 5 nT (Constable 1983), which are comparable in magnitude to the Z field variations observed by Gough *et al.* (1974). Current channelling would easily account for the 1–2 decades of anisotropy observed in the MT data of Tammemagi & Lilley (1973). Indeed, the same currents measured by Woods & Lilley (1980) may be flowing down the western margin of the Great Artesian Basin and into the Frome area.

Jones (1983) suggests examining the ratio of the length (l) of the 2-D part of a 3-D structure, to the skin depth in the host material (δ_h). If this ratio is greater than a certain value, the non-2-D effects will be small near the centre of the 2-D feature and may be ignored. For a 2-D channel connecting two large, very conductive bodies, l/δ_h must be greater than about 3 for the 'E polarization' mode and much greater than 1 for the 'B polarization' mode before the 2-D approximation is valid. Although the Great Artesian Basin is about 600 km from the Southern Ocean, most of the experiments were carried out within about 200 km of the basin's southern margin. Thus 200 km is taken as the length scale. If the Olary–Broken Hill Block, believed to underlie most of the embayment, is taken as the host material, δ_h is at least 270 km at 60 s periods and 1500 km at 2000 s. Thus l/δ_h is at most 1 at 60 s and 0.1 at 2000 s. Hence, Jones' criteria suggest current channelling will be a problem at the frequencies used in the 1970 GDS and MT experiments.

The recent GDS work by Chamalaun (1985), White & Milligan (1985) and White &

Polatajko (1985) establishes the lateral position of the anomaly well, showing the southern end to swing to the west across the Adelaide Fold Belt and possibly into the head of Spencer Gulf. However, the GDS method has poor depth resolution, and these recent studies have not really improved the estimates of the conductor's depth. A little support for the current channelling hypothesis is gained from the GDS studies because they show the conductor cuts across several geological structures. This suggests that the current flow is not intrinsically associated with a particular geological feature, but may be being forced to take the path of least electrical resistance.

The above does not disprove the existence of a conductive body in the lower crust or upper mantle. It does, however, cast some doubt on the previous interpretation of the GDS and MT data. It is possible that reinterpretation of the GDS data along the lines suggested by Jones (1983), to give 'anomalous induction vectors' and to separate spatial and temporal variables, would assist interpretation. Finally, detailed numerical or analogue electrical models of the upper 5 km of the embayment region could be constructed using the Schlumberger results and the depth to magnetic basement. Forward computations using such models might show how much the GDS data are being influenced by surface structure.

5 Conclusions

Using the computer controlled electrical sounding system constructed at ANU, along with synchronous stacking and the drift removal algorithm of McFadden & Constable (1983), signal to noise improvement ratios of nearly 1000 have been achieved. This has made possible the 200 km electrode spacing Schlumberger soundings reported by Constable *et al.* (1984), and facilitated the seven 20 km Schlumberger soundings reported here.

These seven soundings, situated over a previously delineated conductivity anomaly, show the surface sediments of the Frome Embayment to have very low resistivities. This raises the question of whether the GDS and MT experiments conducted in this area are being influenced by current channelling in the surface sediments rather than by a deeply buried conductor. Application of Jones' (1983) criteria of 2-D length to host rock skin depth ratios suggest that this could be the case. However, further work is required before a truly definitive answer to this question can be obtained.

Acknowledgments

Many people have contributed to this work. The author would like to thank Dr M. McElhinny, who suggested and initiated the research as well as assisting with the field-work, Mrs C. Constable, Dr P. McFadden and Professors D. Jones and R. Merrill, who also assisted with the field-work, Messrs E. Penikis, D. Edwards and F. Burden who assisted with the equipment construction, and Dr F. E. M. Lilley for helpful discussion.

References

Chamalaun, F. H., 1985. Geomagnetic deep sounding experiment in the central Flinders Ranges of South Australia, *Phys. Earth planet. Int.*, **37**, in press.

Constable, S. C., 1983. Deep resistivity studies of the Australian crust, *unpublished thesis*, Australian National University.

Constable, S. C., 1985. Electrical studies of the Australian lithosphere: a review, *Aust. J. Earth Sci.*, submitted.

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

Gerdes, R. A., 1982. The interpreted depth to magnetic basement map of South Australia, *Q. geol. Notes, geol. Surv. S. Aust.*, **83**.

Ghosh, D. P., 1971. Inverse filter coefficients for the computation of apparent resistivity standard curves for a horizontally stratified earth, *Geophys. Prospect*, **19**, 769–775.

Gough, D. I., Lilley, F. E. M. & McElhinny, M. W., 1972. A polarization-sensitive magnetic variation anomaly in South Australia, *Nature Phys. Sci.*, **239**, 88–91.

Gough, D. I., McElhinny, M. W. & Lilley, F. E. M., 1974. A magnetometer array study in southern Australia, *Geophys. J. R. astr. Soc.*, **36**, 345–362.

Guptasarma, D., 1982. Optimization of short digital linear filters for increased accuracy, *Geophys. Prospect*, **30**, 501–514.

Jones, A. G., 1983. The problem of current channelling: a critical review, *Geophys. Surv.*, **6**, 79–122.

Kerr, D. S., 1966. The hydrology of the Frome embayment in South Australia, *Bull., S. Aust. Dep. Mines geol. Surv.*, **41**.

Lilley, F. E. M. & Tammemagi, H. Y., 1972. Magnetotelluric and geomagnetic depth sounding methods compared, *Nature Phys. Sci.*, **240**, 184–187.

Marquardt, D. W., 1963. An algorithm for least-squares estimation of non-linear parameters, *J. Soc. ind. appl. Math. numer. Anal.*, **11**, 431–441.

McFadden, P. L. & Constable, S. C., 1983. The estimation and removal of a linear drift from stacked data, *J. Geophys.*, **53**, 52–58.

Rutland, R. W. R., Parker, A. J. Pitt, G. M. Preiss, W. V. & Murrell, B., 1981. The Precambrian of South Australia, in *Precambrian of the Southern Hemisphere*, pp. 309–359, ed. Hunter, D. R., Elsevier, Amsterdam.

Tammemagi, H. Y., 1972. A magnetotelluric study in south-eastern Australia, *unpublished thesis*, Australian National University.

Tammemagi, H. Y. & Lilley, F. E. M., 1973. A magnetotelluric traverse in southern Australia, *Geophys. J. R. astr. Soc.*, **31**, 433–445.

Van Zijl, J. S. V., 1977. Electrical studies of the deep crust in various tectonic provinces of southern Africa, in *Am. Geophys. Un. Monogr.*, **20**, 470–500, ed. Heacock, J. G.

Van Zijl, J. S. V. & Joubert, S. J., 1975. A crustal geoelectrical model for South African Precambrian granitic terrains based on deep Schlumberger soundings, *Geophysics*, **40**, 657–663.

White, A. & Milligan, P. R., 1985. Geomagnetic variations across the southern Adelaide Geosyncline, South Australia, *J. Geomagn. Geoelect.*, in press.

White, A. & Polatajko, O. W., 1985. Electrical conductivity anomalies and their relationship with the tectonics of South Australia, *Geophys. J. R. astr. Soc.*, **80**, 757–771.

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

Wopfner, H., 1970. Early Cambrian palaeogeography, Frome Embayment, South Australia, *Bull. Am. Ass. Petrol Geol.*, **54**, 2395–2409.

Youngs, B. C., 1978. Stratigraphic drilling in eastern Arrowie basin, 1975–1976, *Q. geol. Notes, S. Aust. geol. Surv.*, **66**, 16–20.