Sediment Compaction and Magnetotelluric Data in the Eromanga Basin

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Abstract

Magnetotelluric data obtained in the Eromanga Basin can be interpreted using one-dimensional models to describe plane layers consistent with geological mapping. Interpretations are based on the results of non-linear inversions generating a minimum least- squares error between the observations and the model. However there is no statistical justification for selecting highly complex starting models. In particular adequate solutions can be generated using models based on 2, 3 or 4 layers over basement; additional layers defining fine structure can only be retained using external geological constraints. Solutions based on random starting models suggest gradations in resistivity (1-4 ohm m) consistent with sediment compaction. Major discontinuities in all models (4-30 ohm m) are assumed to indicate a basement contact at depths of 7-8 km.

Key words: magnetotellurics, resistivity, compaction, Eromanga Basin

Introduction

Magnetotelluric soundings provide one of the few alternatives to seismic profiling for structural analysis. Major geological units can be defined directly according to variations in electrical resistivity (eg Vozoff, 1972). However the data are normally presented in terms of apparent resistivity and individual stratigraphic units may then be difficult to identify. In particular major discontinuities are generated over lateral contacts and two-dimensional modelling is required for any interpretation.

Few of these complications are expected in sedimentary basins. Interpretations can be based on one-dimensional

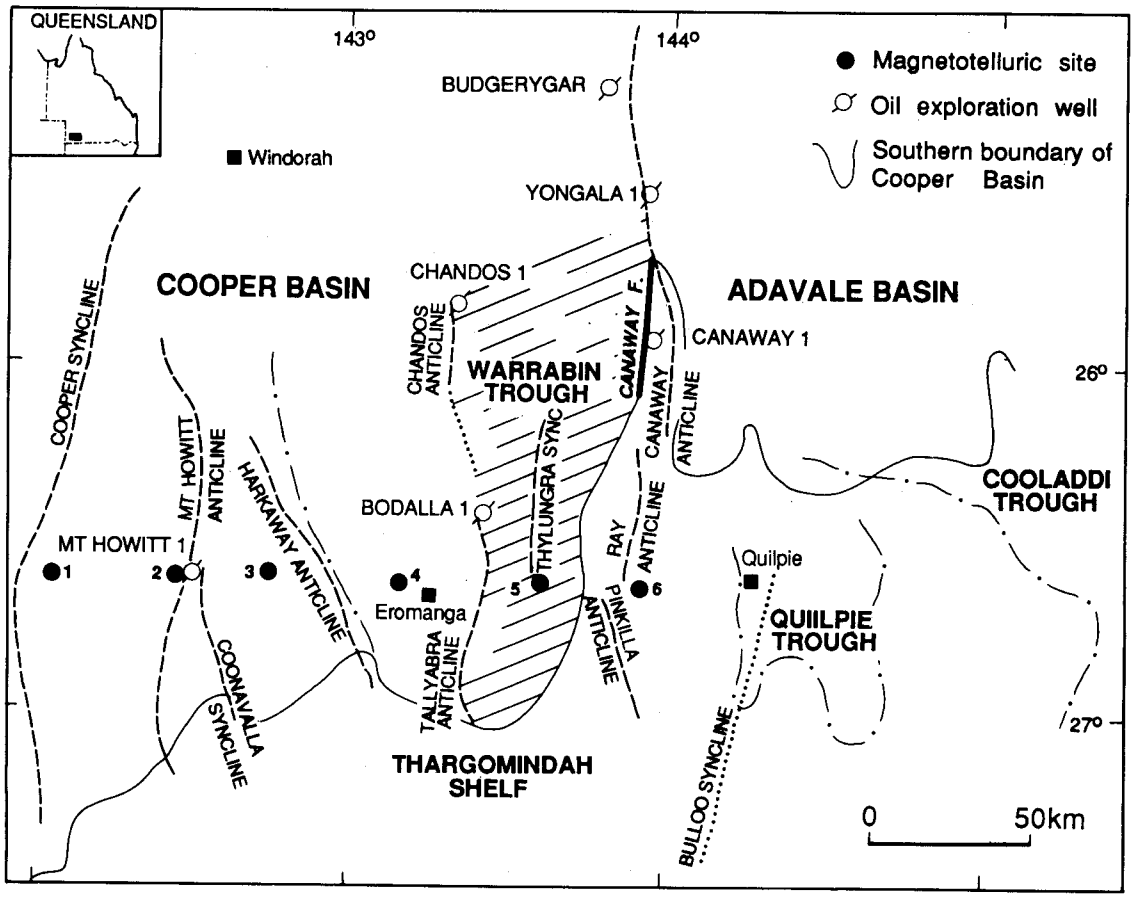

FIGURE 1
Magnetotelluric soundings over major structural units in the Eromanga Basin (50% subset of data reported by Spence & Finlayson 1983).

models with simple analytical solutions. Consequently magnetotelluric soundings are considered ideal for basement mapping involving homogeneous layers with abrupt vertical transitions in resistivity. However minor layers are poorly constrained and resistivities are averaged to represent the finer structures at shallow depth. New techniques are now required to interpret more subtle variations in resistivity.

Complex models have been constructed to explain magnetotelluric data obtained in the Eromanga Basin (Spence and Finlayson, 1983). The data are consistent with fine layering in the sediments revealed by well-log analysis. Consequently interpretations have been based on one-dimensional inversions incorporating multiple layers. Statistical theory can be used to justify several minor layers in the Eromanga Basin but many different combinations are possible and more general geological constraints must be considered for greater precision.

Eromanga Basin

Magnetotelluric data were obtained during 1980 by the Bureau of Mineral Resources for 12 sites in the central Eromanga Basin (Figure 1, Spence and Finlayson, 1983). Pseudosections of apparent resistivity were constructed demonstrating the continuity in the response along a single EW traverse. Three principal layers were identified. Low resistivities (< 4 ohm m) were obtained at periods less than 10 s followed by an increase (10-400 ohm m) at periods of 10-100 s. Resistivities in the range 750-3800 ohm m were assumed to represent the basement extending to depths of 40-60 km. Lower resistivities observed for some sites at longer periods (> 700 s) were attributed to high temperatures with partial melting in the upper mantle.

Low resistivities at shallow depth can be assumed to indicate total saturation in sediments of high average porosity. In these circumstances individual units representing gradations from the Eromanga Basin (Jurassic/Cretaceous) to the Cooper (Permo/Triassic) and the Adavale Basins (Devonian/Carboniferous) are difficult to detect. Only one major discontinuity can be consistently identified along the traverse corresponding to a basement of granodiorite/basalt/schist (Lower Palaeozoic) at depths of 2-3 km. More sophisticated interpretations were presented (Spence and Finlayson, 1983) based on the one-dimensional inversion algorithms described by Jupp and Vozoff (1975). Several layers were incorporated in the starting models based on well-log data and the results were assessed for statistical significance. All layers were retained in the solution and all were attributed to major geological units. However the validity of each starting model must now be established. In particular the solution statistics may be influenced by the number of layers adopted for each inversion.

Adequate solutions can be generated for the Eromanga data using models based on 3-4 layers (Figure 2). These models generate a sufficient solution (indicated by a local minimum in the error space) and additional layers can not be justified from statistical analysis alone (there is no global minimum). However within each group of models there is considerable freedom in the selection of a starting value for each parameter in the inversion. Consequently systematic trends may be identified using multiple solutions.

Bias can be removed in selecting representative models for inversion by allowing random perturbations to each parameter prior to any calculation. Multiple inversions can then be used to emphasise the dominant features preserved in all solutions. For the Eromanga Basin only the basement contact appears to be well defined; a major discontinuity is required in all solutions (Figure 2). Fine structure within the sediments appears to be poorly constrained; there appears to be a resistivity/thickness ambiguity but some systematic progression can be suggested in the locus resulting in a continuous resistivity profile (Figure 3).

Sediment Compaction

Continuous resistivity profiles are consistent with models based on sediment compaction related to variations in basin formation and burial history. Consequently a more appropriate model of the substructure of the Eromanga Basin can be suggested including an exponential increase in resistivity with depth to the basement, rather than the several dicrete layers previously modelled.

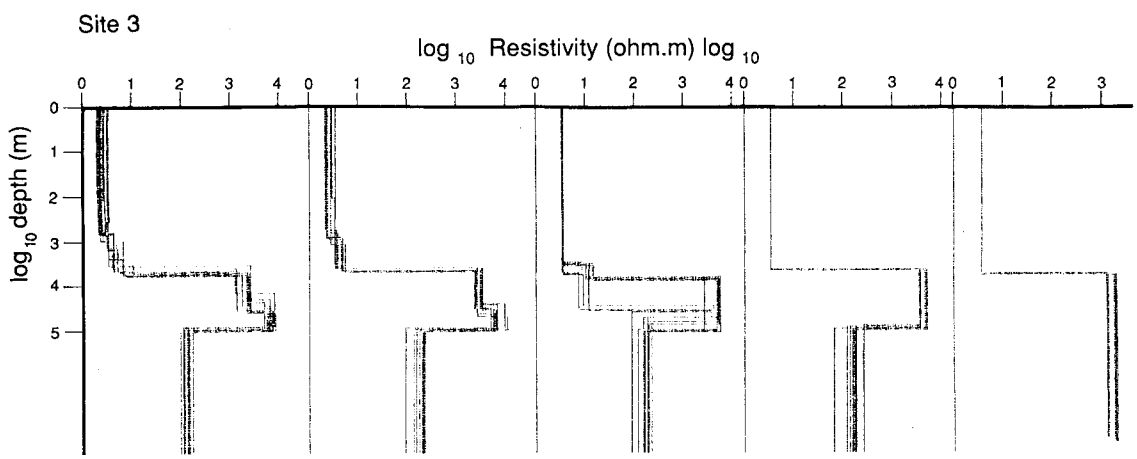

FIGURE 2
Alternative solutions for 1D models incorporating 2-6 layers at Site 3 (Figure 1). Basement discontinuity required in all solutions. Compaction indicated by curvature in the locus of solutions for the upper layers.

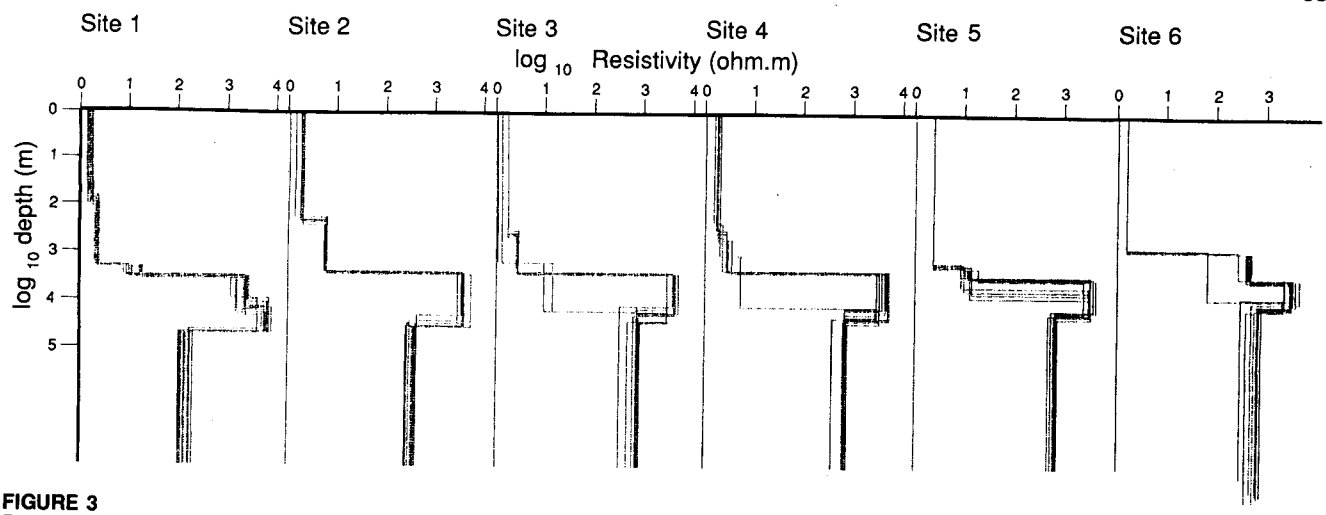

FIGURE 3
Best fit solutions at each site (dominantly 4 layers) representing trends in resistivity for the Eromanga Basin.

Porosity is a measure of the percentage of pore space in the total volume of rock. The mechanism of porosity reduction is mainly achieved by compaction. The porosity of sediments is found to decrease exponentially with depth. Since porosity is inversely proportional to the formation resistivity factor of a rock (Atkins and Smith, 1961), it follows that the resistivity of the sediments will increase exponentially with depth.

Magnetotelluric soundings for exponential distributions of resistivity have been considered by Kao (1982). Analytical solutions were generated using modified Bessel functions.

However Kao (1982) has demonstrated that equivalent results can be obtained using plane layered models. In these circumstances the total error can be related to the number of layers used to approximate the exponential section (but only marginal improvements are obtained with more than 2-3 layers). Consequently systematic variations in resistivity may be wrongly interpreted using discrete layers.

Conclusions

Magnetotelluric data obtained in the Eromanga Basin can be interpreted using multiple layers consistent with the results of well-log analysis. Many of these layers have no statistical significance and any fine-structure remains contentious. Equivalent precision can be obtained using models based on 3-4 layers. However random starting models result in a range of solutions with resistivities defining a complex vertical profile.

More appropriate models can be suggested for the resistivity profiles observed in sedimentary basins. In particular an exponential increase in resistivity can be anticipated for sediments subject to compaction with depth. Kao (1982) has demonstrated that there is no improvement in accuracy over the conventional 3-4 layer models. However individual layers may then result from mathematical approximations unrelated to geological constraints.

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