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INTERPRETATION OF THE AEROMAGNETIC EXPERIMENTAL SURVEY IN THE EROMANGA/COOPER BASIN

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ABSTRACT

Developments over the last decade in the measurement, recording, processing and interpretation of the earth's magnetic field have significantly extended the scope of aeromagnetic surveys as a tool in the exploration for hydrocarbons. Two principal methods are used in the process of analysis and interpretation of the magnetic field: energy spectral analysis applied to the grid data, and automatic curve matching – applied to the located profile data. Effective interpretation of any data set depends on the use of appropriate methods in a systematic manner. The interpretation of aeromagnetic survey data over the sedimentary basin is carried out in several stages. It is important to establish the magnetic character of the sediments and basement rocks in planning an interpretation. It is necessary to determine the regional magnetic character of the area by applying energy spectral analysis to the total magnetic intensity data set. Application of the automatic curve fitting method to the line data provides results concerning the sedimentary section and deeper parts of the basin where control is provided by drill hole or seismic survey information (calibration with seismic).

An experimental aeromagnetic survey flown over parts of the Eromanga Basin and Cooper Basin as part of the South Australian Exploration Initiative in 1993 shows that magnetic layers in the sedimentary rocks make this an appropriate area for exploration using more detailed aeromagnetic surveys. It was possible to delineate basement highs and troughs in a weakly magnetic basement, to detect major structures within the basement, to follow magnetic horizons within the sedimentary section and to pick out fault and joint patterns in the sediments. While the resolution of structures obtained from interpretation of the aeromagnetic data is limited, it is clear from comparison that they are consistent with those derived from areas with closely spaced seismic lines. In areas where the basement is weakly magnetic and deeper than about 1.5 km, or where the aeromagnetic interpretation is being used to delineate magnetic layers within the sedimentary section, the methods discussed here are more effective when they are used to interpolate between widely spaced seismic lines.

INTRODUCTION

In 1993 an aeromagnetic survey (Fig. 1) was flown by the South Australian Department of Mines and Energy, and Santos Ltd. in an area (referred to as B5) west of Moomba in the northeastern part of South Australia. The B5 survey was conducted to test the contribution of a high-resolution aeromagnetic survey to the exploration for hydrocarbons in an area where the geology was well documented. The centre of the L-shaped area is 139° 30'E and 28° 10'S (Fig. 1). The survey was flown at a height of 70 m above ground level with a line spacing of 200 m in the northwest (an area 30 km by 30 km) and a line spacing of 400 m elsewhere (an area 30 km by 55 km); the tie line spacing was 1250 m. The flight line direction is 35° west of north. Total magnetic intensity (TMI) was measured with a noise level of less than 0.25 nT and the data were micro-levelled to provide the highest quality data possible. A gamma ray spectrometer recorded the gamma ray flux over the region.

Frears and Tucker (1994) brought together the results of a number of studies of the area covered by the survey. Their report included a list of magnetic susceptibility measurements of different lithological horizons of the Mesozoic sediments and the underlying basement. This report also included a series of "pseudo-depth slices", structural studies relating the magnetic anomalies from different depths and the structures corresponding to known oil and gas fields, and a compilation of basement faults determined from seismic data. There are also presented results of two separate studies estimating the depth of the underlying magnetic basement using conventional modelling of magnetic anomalies and Euler deconvolution. The susceptibility information shows that the magnetic layers determined from analysis of the magnetic anomalies correspond to magnetic sedimentary layers.

Two methods have been found to be exceedingly effective in defining geological structures within the sedimentary section: energy spectral analysis applied to the grid data, and automatic curve matching applied to profile data. Spectral methods are used to identify the depth of the principal magnetic units in a region. From this analysis the optimum parameters are set to get the greatest amount of detailed information from the automatic curve matching method.

THE PRINCIPLES OF SPECTRAL ANALYSIS

Energy spectral analysis provides a technique for quantitative studies of large and complex aeromagnetic data sets. The principles of the method are based on the fundamental work done by Bhattacharyya (1965, 1966a, 1966b), and

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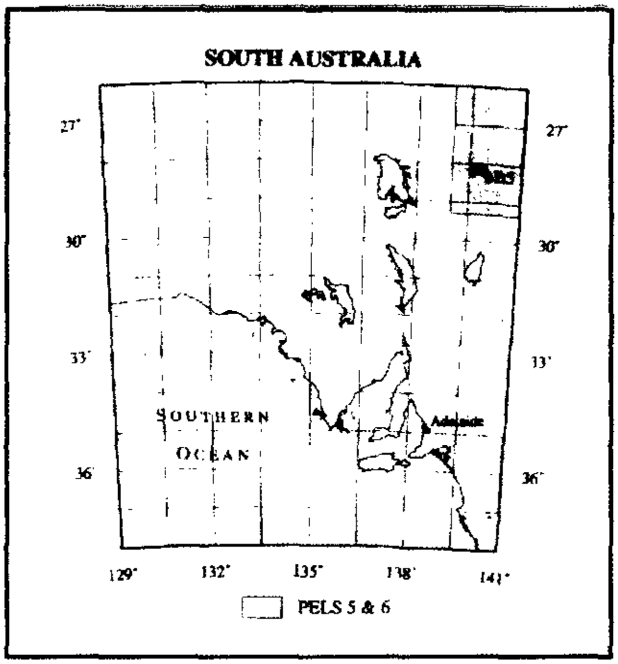

B5 area location map.

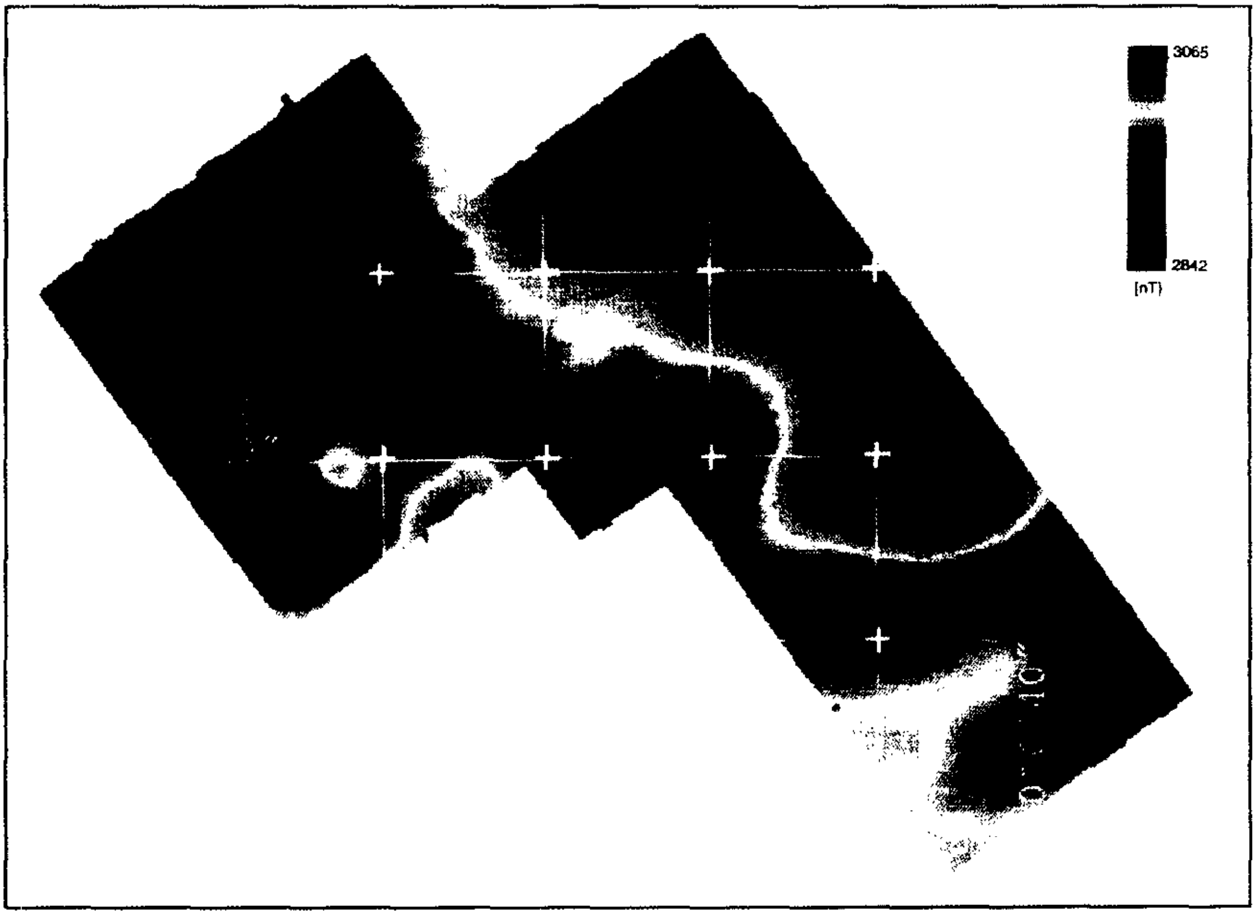

Fig. 1. *Aeromagnetic Survey of area B5: Image of total magnetic intensity field.*

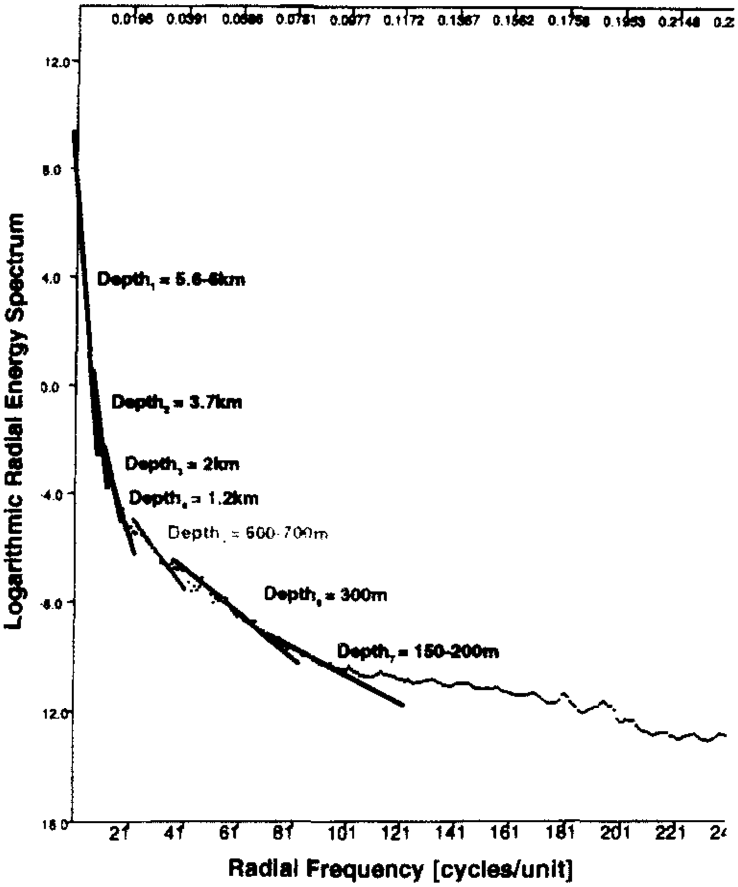

Fig. 2. Spectrum of total magnetic intensity field computed across the survey area B5.

Spector (1968, Spector and Bhattacharyya, 1966; Spector and Grant, 1970). Over the years many other scientists contributed to the development of this method (e.g., Hou and Shi, 1985).

The logarithm of the radial average of the energy spectrum (the square of the Fourier amplitude spectrum) is plotted versus the radial frequency. The slopes of the linear segments of the spectrum correspond to separate depth ensembles and provide parameters used for the design of numerous filters. The spectrum presented in Figure 2 shows a number of linear segments. The slope of each segment provides information about the depth to the top of an ensemble of magnetic bodies. The higher-frequency end of the spectrum is dominated by the anomalies derived from shallow magnetic bodies and magnetic noise; at the low-frequency end the main contributors to the energy spectrum are deep-seated magnetic bodies.

SPECTRAL ANALYSIS USING MOVING WINDOWS

The normal practice, which depends on the geology of the area investigated, is to apply the energy spectral method to the whole region or to the greater part of it, using a window which may be as large as 300 km by 300 km. From this the longest wavelengths of the anomalies in the region are determined. The process is repeated for smaller parts within the main area to establish local characteristics. In this way the magnetic units within the stratigraphy are discovered and more precisely defined. In some cases the region is covered systematically using smaller overlapping windows to follow structures across the area being studied (Kivior, 1996; Kivior and Boyd, 1998).

MAGNETIC CHARACTER OF THE ROCKS

A full account of the geology of this section of the Eromanga Basin can be found in The Geology of South Australia, Volume 2, The Phanerozoic (Drexel and Preiss, 1995). A typical cross-section showing the geological sequence and structure of the area, Figure 3, is taken from figure 9.11 of volume 2. This geological section which lies to the northeast of the aeromagnetic survey area summarizes the geological setting of the study area. The Middle/Upper Mesozoic sediments overlie the intracratonic Cooper Basin which contains Late Carboniferous to Middle Triassic sedimentary rocks. The Cooper Basin sediments overlie Cambro-Ordovician Warburton Basin strata. A more detailed account of stratigraphy and structure of the northwestern part of the survey area can be found in Oldham and Gibbins (1995).

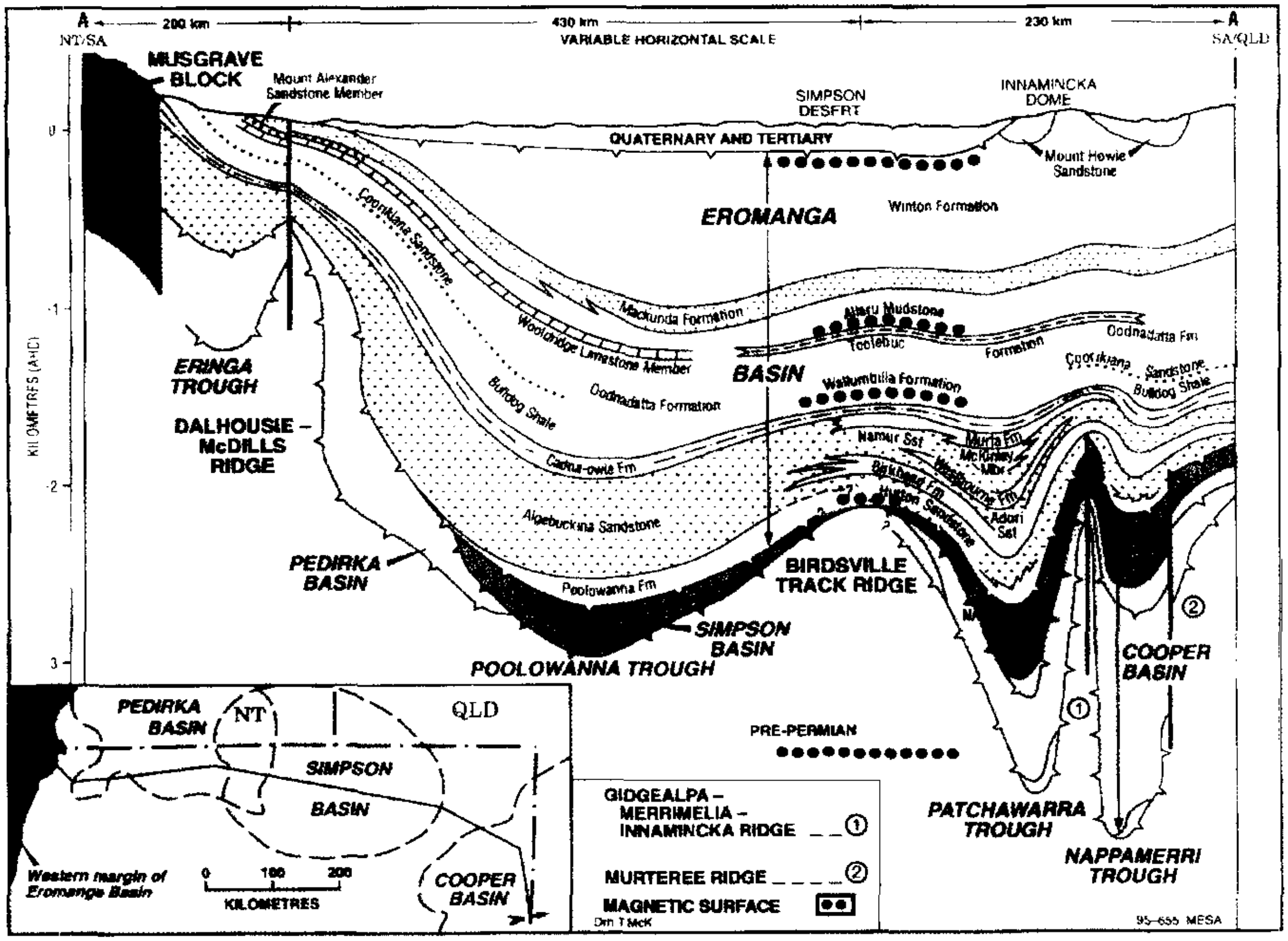

Fig. 3. Typical geological cross-section through the Cooper/ Eromanga Basins; based on figure 9.11, Geological Survey, South Australia. Bulletin, 54 Vol. 2.

Until recently there has been little interest in magnetic layers within the sedimentary section and it is often assumed that the sediments are not significantly magnetic. Consequently in many sedimentary basins very little is known about the presence or nature of magnetic minerals in the sediments. Even in this area where there has been a substantial effort to collect information (Frears and Tucker, 1994), this is limited to the knowledge that certain horizons are of more than average magnetic susceptibility over thicknesses of several tens of metres. This information is important when it comes to correlating sedimentary formations and the magnetic layers determined from interpretation of the aeromagnetic data. While it may seem obvious, it is important to appreciate that results of the kind described here can only be obtained from magnetic surveys when there are magnetic layers in the sedimentary section!

In the B5 survey area the magnetic susceptibilities of the sediments from core in a number of wells, reported by Frears and Tucker (1994), provide information about the magnetic layers determined from the analysis of the aeromagnetic data. The magnetic susceptibility of sediments is generally of the order of between 20 and 50 (SI units E-5). [E-5 means… "times 10 to the minus 5."] At the level of the Mackunda Formation there is a section about 400 m thick in which susceptibility values of 200 (SI units E-5) are recorded. At the level of the Cadna-owie Formation susceptibility values of 200 (SI units E-5) are measured over an interval which varies in thickness from 200 m to 400 m in different wells. Over a short range of depths at the base of the Mesozoic sediments susceptibilities of 300-500 (SI units E-5) are reported.

SPECTRAL ANALYSIS OF THE TMI DATA COMPUTED OVER THE B5 AREA

The energy spectral analysis method was applied to TMI grid data over an area covered by a 200 m flight line spacing survey. The TMI grid was computed at a 50 m by 50 m grid cell size using the cubic spline algorithm. As mentioned above, the spectral analysis of gridded magnetic data provides approximate average depth values to the top of an ensemble of magnetic sources within the analyzed map-window. The analyzed area lies on the eastern side of the Birdsville Track Ridge shown on Figure 3; the results are

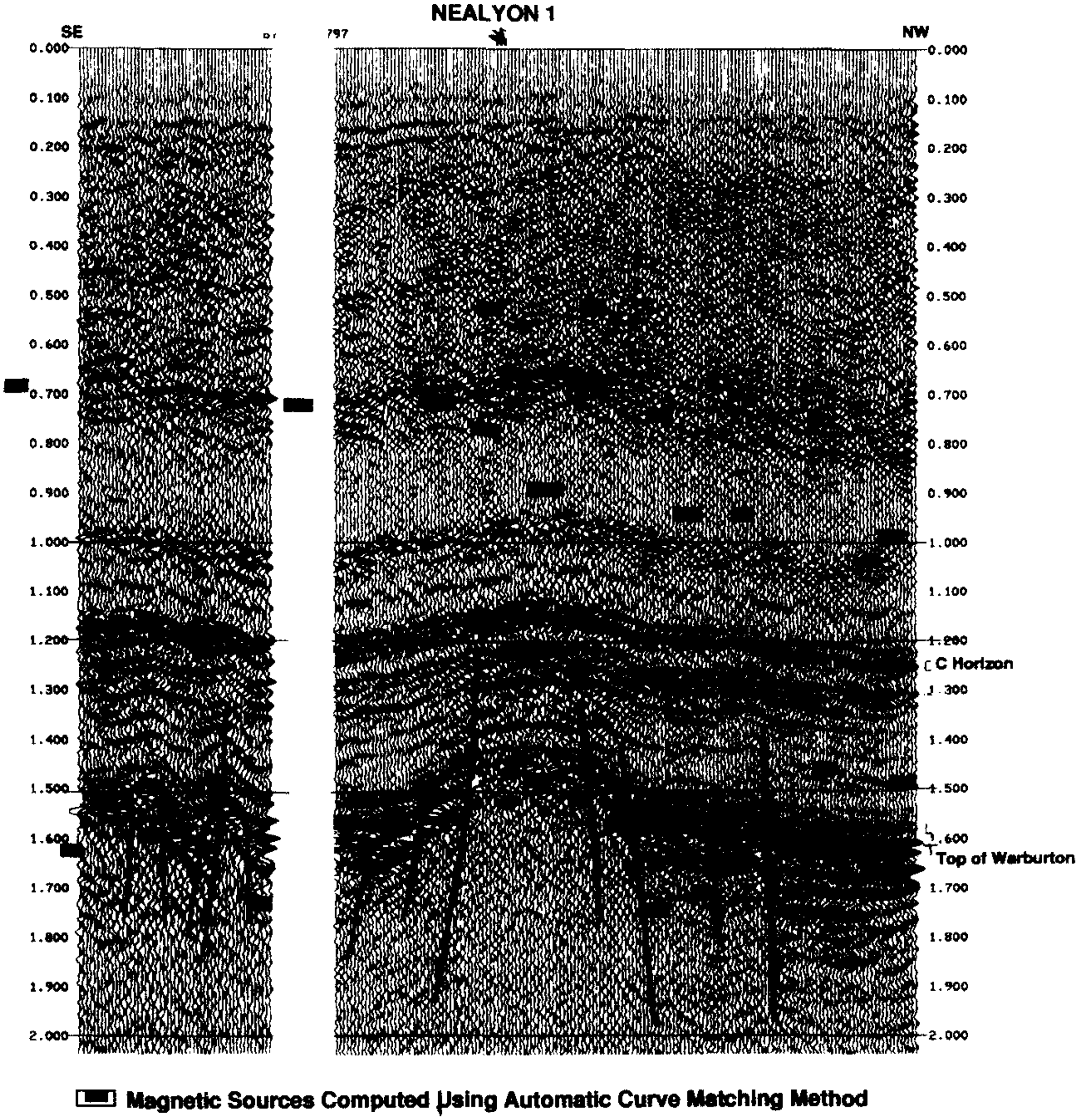

Fig. 4. Seismic section with superimposed magnetic sources detected using automatic curve matching method.

projected onto the section as the survey area lies some distance off the line of the geological section. The survey covers a length of only about 30 km of this section. As the dips of the sediments are low in this part of the area it is appropriate to use this method.

The analysis of the spectrum of TMI computed over the B5 area has established that there are magnetic horizons within the Mesozoic sediments at depths below the land surface of 180 m, 600 m, 1200 m and 2000 m. There are detectable magnetic sources at depths of 3600 m and 5700 m within the pre-Permian basement which consists of the rocks of the Warburton Basin. The results are shown diagrammatically by projecting the results (solid dots) onto the geological cross-section of the Cooper/Eromanga Basin presented in Figure 3.

Precise correlation of the magnetic layers with the stratigraphy depends on having the necessary information about the magnetic properties of the sediments as discussed above. Susceptibility measurements from cuttings and core from various wells in the region confirm that magnetic sediments occur at about the level of the Mackunda Formation and in the Cadna-owie Formation.

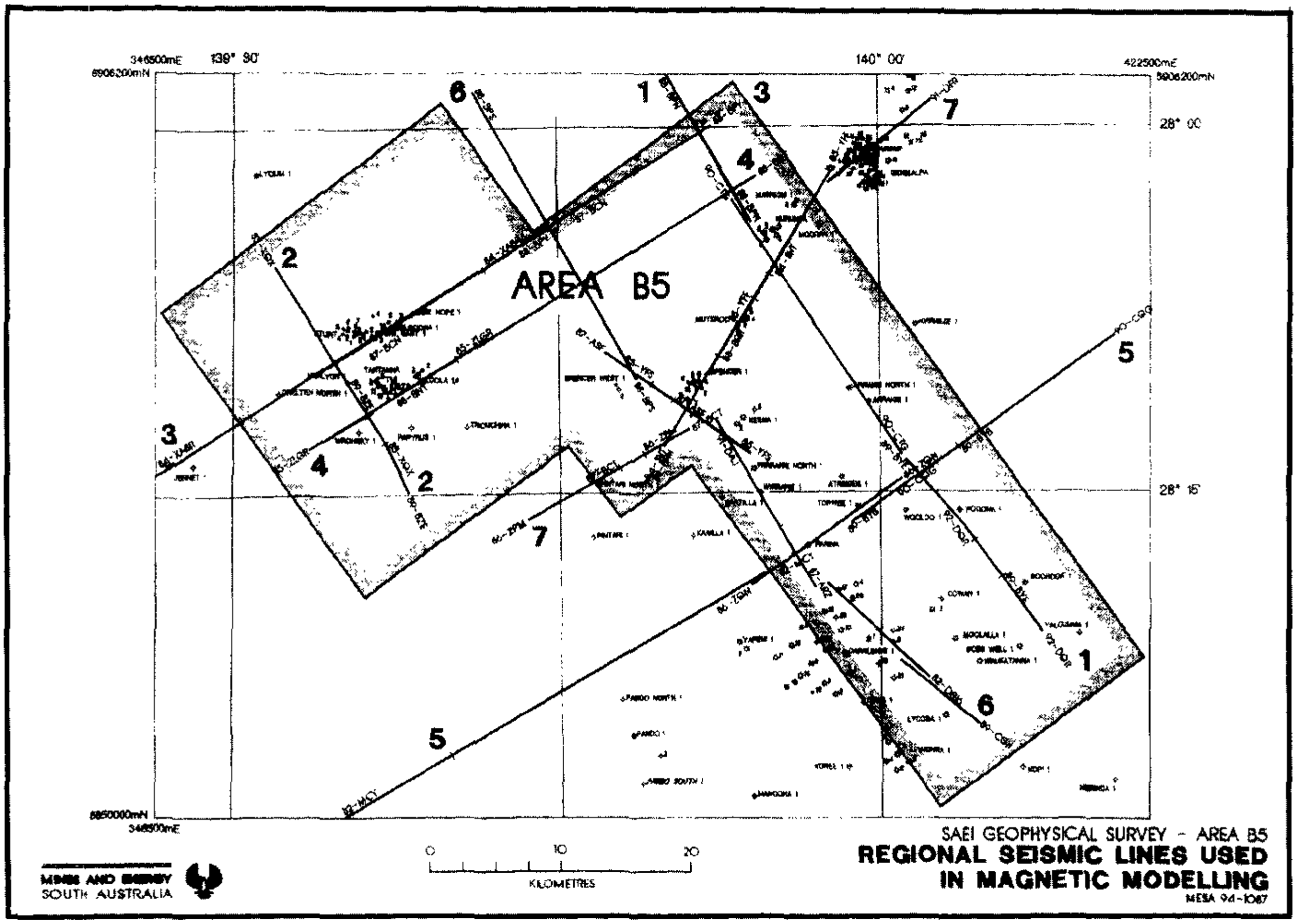

Fig. 5. Regional seismic lines (after Frears and Tucker, 1994) used to calibrate magnetic basement depths shown in Figure 6.

The magnetic horizon at a depth of 180 m corresponds to the Tertiary unconformity at the top of the Mesozoic. The discrimination of whether the magnetic layer is in the basal layers of the Tertiary sediments or in the weathered layers at the top of the Mesozoic is beyond the accuracy of the spectral method. A second magnetic horizon which lies at a depth of about 600 m below the land surface in the survey area corresponds to the Mackunda Formation which as noted above contains magnetic sediments, and a third magnetic interface was detected near the level of the Cadna-owie Formation. The magnetic interface at a depth of about 2 km corresponds to the base of the Eromanga Basin sediments which lie on top of the sediments of the Warburton Basin. The deeper magnetic boundaries lie within or below the underlying Warburton Basin sediments but there is no seismic or drilling information from this depth to check these depths.

Finer detail of the distribution of magnetic layers within the sedimentary section is obtained by employing the method of a moving window. After initial data analysis was applied using a window of 15 km the energy spectral method was applied again using what was effectively a 7.5 km square "moving window" to compute the depth to one of the magnetic horizons established in the initial analysis of the results. From the depth obtained from the "moving window" a map of a magnetic horizon about the depth of the Cadna-owie Formation was produced. In places this horizon corresponded closely to that determined from seismic surveys.

AUTOMATIC CURVE MATCHING

The automatic curve matching method was applied to the original flight-line data to which corrections had been made for the diurnal variation of the magnetic field. The method works by identifying a magnetic anomaly on a profile and comparing the observed anomaly with one that is computed for a prism, varying the parameters and accepting the model which provides the best fit. Analysis of magnetic anomalies along the profile (Shi, 1991, 1993; Shi and Boyd, 1993) has the advantage of a higher resolution of detected structures than the energy spectrum.

There are four main outcomes from the application of the automatic curve matching method to the profile data in the B5 area:

(i). The results shown on Figure 4 have been constructed

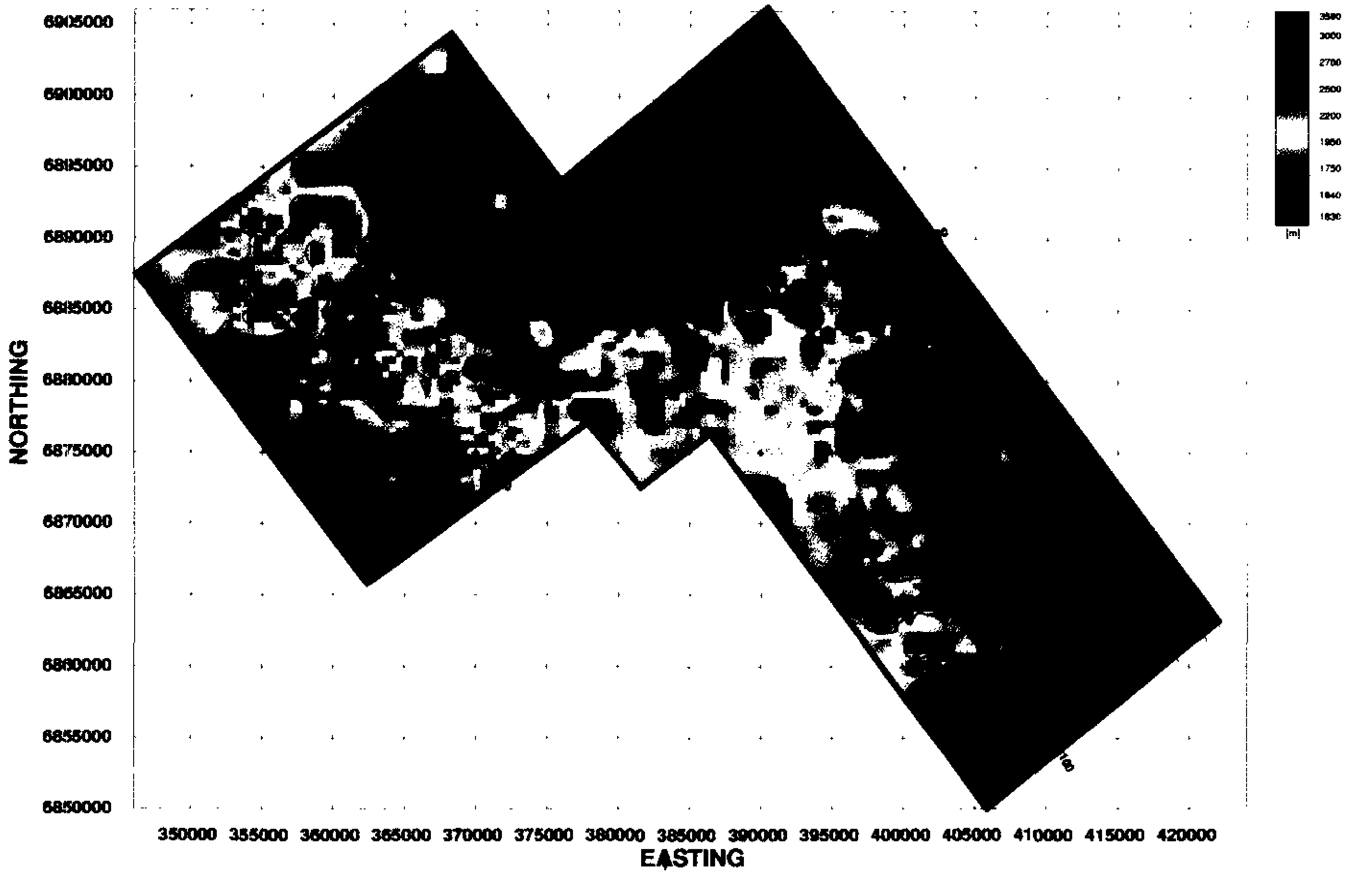

Fig. 6. Area B5: Depth to magnetic basement computed using automatic curve matching method.

from the depths obtained on three flight lines, one coinciding with three seismic lines and the two adjacent lines which were about 400 m on either side; depths were projected from the adjacent aeromagnetic lines onto the seismic line. There are two very well defined magnetic horizons in the top kilometre of the sediments. The uppermost, at a depth of between 150 m and 200 m, occurs at the unconformity between the Tertiary and Mesozoic sediments and has been omitted from the diagram. The lower one occurs at a depth of about 600 m and corresponds to the Mackunda Formation which occurs at about 700 ms two way time on the section. The first layer may provide information about the low-velocity upper layers which may assist in making better static corrections for the seismic surveys. The lower layer would in less well-surveyed areas provide some information about folds and other structures in the sediments.

(ii). The resolution of the depth estimates decreases for bodies at greater depths. The depth estimates which occur at between 1500 ms and 1600 ms on the seismic section (Fig. 4) correspond to the sediments at the bottom of the Eromanga Basin and the top of the rocks in the Warburton Basin which are considered, at present, as the basement for almost all the known hydrocarbon accumulations. The basement uplift under the Nealyon 1 well is clearly indicated in the depths derived from the aeromagnetic data. With some control provided by widely spaced seismic lines the magnetic results were used to interpolate structures between the seismic lines (Fig. 5). Based on about 2000 individual depth estimates a map of magnetic basement has been constructed (Fig. 6). This map of the magnetic interface corresponds with the basement surface map (Fig. 7) constructed from all available seismic data in the area.

(iii). The automatic curve matching method can also be used to show the position of the magnetic bodies which occur within the Mesozoic sediments. Some of the bodies correspond with faults determined from seismic surveys (Fig. 8); others may be due to areas of joints or to small-throw faults which would not be detected by seismic but which might play a significant part in the migration of fluids through the sediments. Similar observations of the magnetic response to faults have been observed elsewhere (Peirce et al., 1998).

(iv). It has been suggested that the distribution of magnetic material within the sediments may also be of significance either as part of alteration haloes (similar as detected by "moving window") produced by the interaction of hydrocarbons and iron in the sediments or as indicators of facies variations within the sediments.

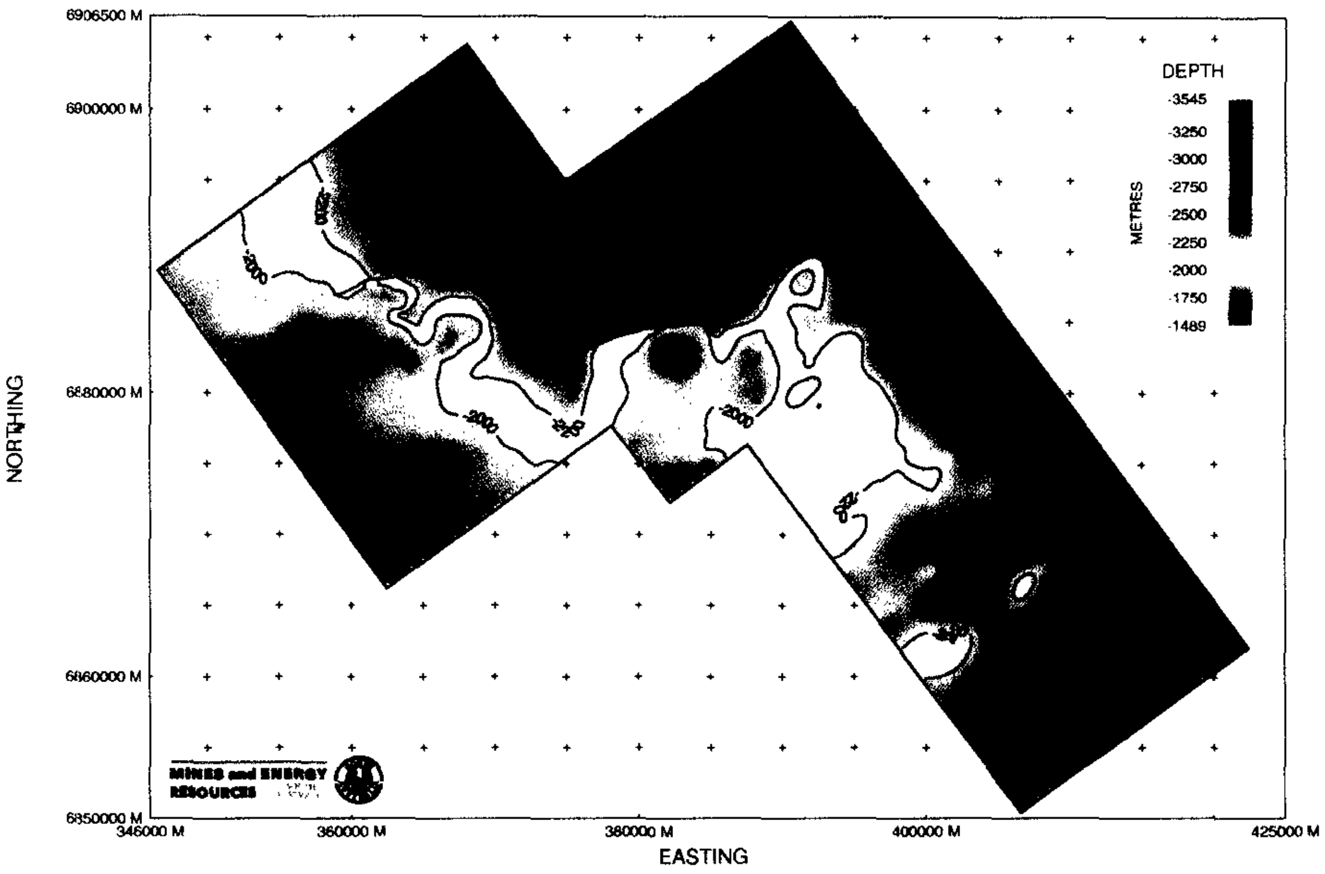

Fig. 7. Area B5: Depth to basement derived from numerous seismic surveys (after Mines and Energy, South Australia).

CONCLUSIONS

Modern high quality aeromagnetic surveys with a low noise level and with data collected on closely spaced flight lines, supported by a small amount of control concerning the depth to economic basement from widely spaced seismic lines can provide information which could assist with the planning of subsequent exploration programs. The results obtained show details about the basement structure, magnetic horizons, folds and other structures within the sediments, and also fault and joint patterns both within the sedimentary section and underlying basement.

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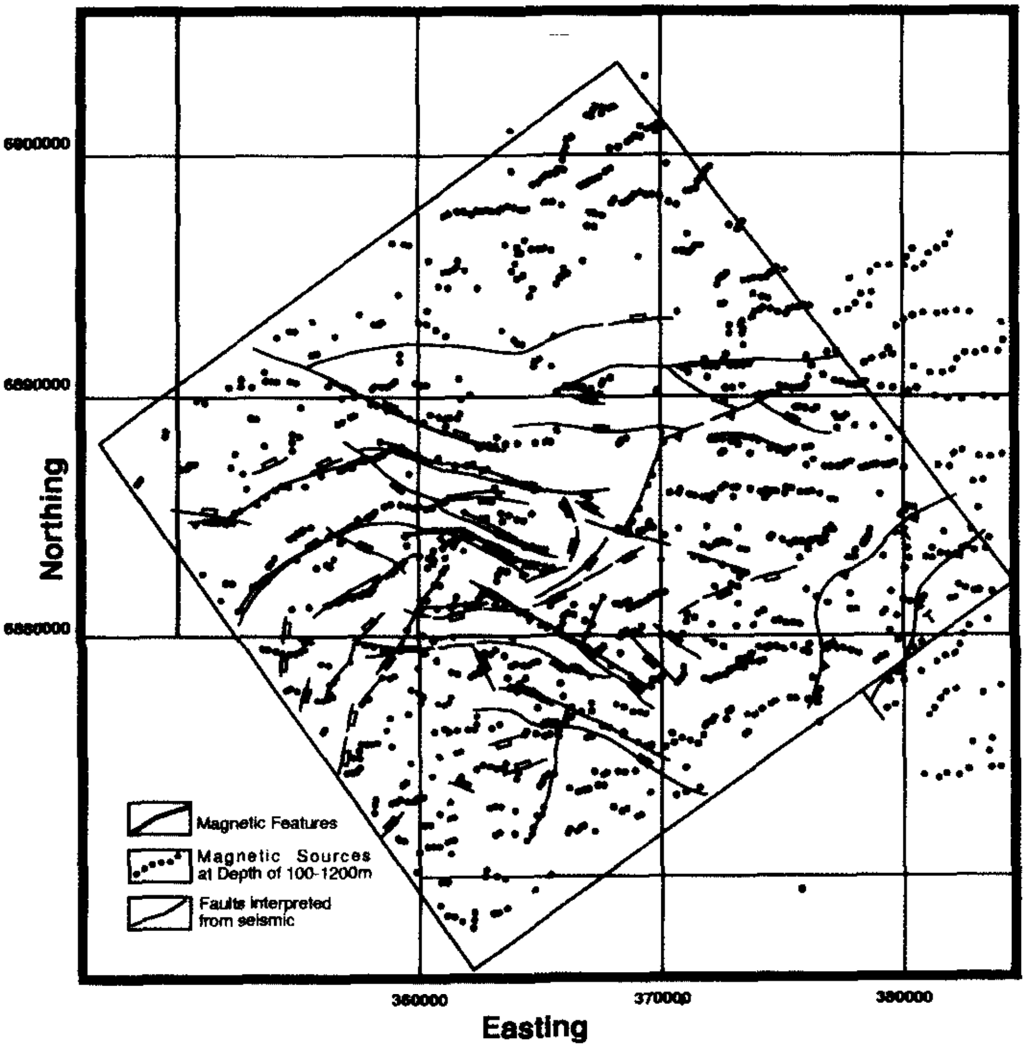

Fig. 8. Interpretation of aeromagnetic data using automatic curve matching method. Magnetic features are superimposed on the basement faults derived from seismic surveys.

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