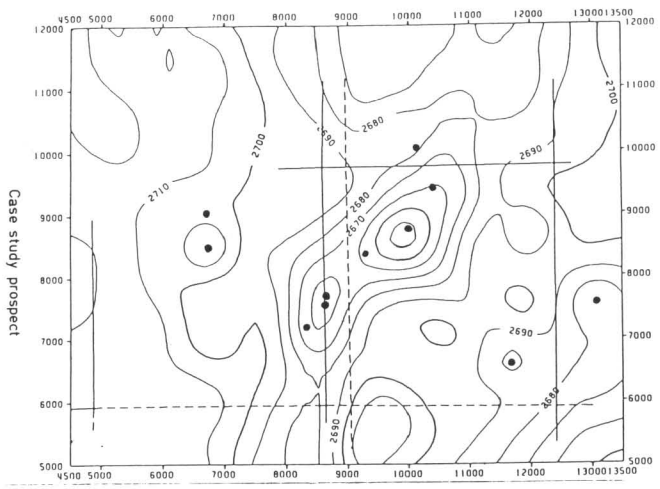

Fig. 4 Top of reservoir from logs and seismic.

wellbore are almost identical, in phase and amplitude to the VSP traces.

Recall that Fig. 1 is a contour map of the top of the reservoir formation as determined from log data only. In Fig. 4 the top of the reservoir formation as determined from the reprocessed (or calibrated) surface seismic data is displayed. Two-way transit times from the seismic data have been converted to depths from the transit time–depth relation observed at the wells. The combined seismic-log map not only shows much greater resolution in terms of the shape of the anomaly, but also indicates that the structural high is along the line of the wells and not to the south-east as indicated by the log map.

The following conclusions can be reached:

(1) It is feasible to combine seismic and well log data to produce a reservoir description that is superior to using either data set alone.

(2) The VSP can provide the missing link between the petrophysical properties in the borehole and the surface seismic data.

(3) The linking of the surface seismic sections to borehole answers should allow a Reservoir Description Study to be involved in the initial stages of field development.

A. James and L. Nutt, Schlumberger, PO Box 7098, Cloisters, Perth, WA 8000.

Interpretation of satellite magnetometer data

B. David Johnson and Michael A. Mayhew

Introduction

The MAGSAT satellite mission (Langel *et al.* 1982) obtained vector magnetic field measurements at altitudes ranging from 350 to 500 km above the earth's surface for a period of 7 months from November 1979 to June 1980. The satellite flew in a sun-synchronous near-polar orbit to achieve maximum coverage over the earth's surface and to minimize the effects of rapidly time-varying magnetic fields. The isolation of the crustal source anomaly components has proved to be a complex task involving the development of new geomagnetic field modelling techniques, improved methods for accounting for time-varying components and interactive techniques for critically selecting optimal data sets (Johnson & Dampney 1983).

Geomagnetic field sources

The magnetic field measured at satellite altitudes is a combination of effects due to several sources. The main field is due to electrical currents flowing in the outer core of the earth. This is normally modelled as a spherical harmonic sequence, up to at least order 13 (the transition between core and crustal field wavelengths), with linear coefficients to account for time variations of the order of a decade. More rapid time variation components arise from electrical current systems in the ionosphere and the magnetosphere. The former effects are very large near to auroral latitudes whereas the latter are quietest for dawn–dusk orbits. Field models are now available for the duration of the MAGSAT mission which adequately describe the main field plus the time varying components. MAGSAT data now dominates the International Geomagnetic Reference Field Models (Peddie & Fabiano 1982).

The remainder of the satellite observed magnetic field appears to come from the crust of the earth, where the temperatures lie below the Curie point for magnetic minerals.

The relative amplitudes of the anomalies from the various sources, when observed at satellite altitudes, demand that careful attention be paid to the problems of correctly separating the various effects. The vexing problem of separating the core and crustal anomaly fields remains essentially unsolved and is deserving of continued research.

Crustal-source anomaly map

Figure 1 shows a map of the crustal-source magnetic field superimposed on a map of the Solid Geology of Australia (Bureau of Mineral Resources 1979). The data set is obtained from the global anomaly map (Langel, Phillips & Horner 1982) which presented averages of the scalar magnetic field, taken over $2° \times 2°$ latitude/longitude bins and over all elevations, after field model and linear trends have been removed. This data set was filtered by frequency domain techniques to remove high frequency effects due to between-orbit differences and along-orbit noise (Johnson *et al.* 1984). Both the global map and the filtered Australian map show extensions of

east–west contour trends which may be due to the averaging process, incorrect linear trends being removed, and field modelling problems. Further work is in progress to produce a truly crustal source anomaly map.

Geological correlations

Correlations between gross structure and crustal anomalies for Australia have previously been found in an analysis of POGO data (Mayhew *et al.* 1980). The MAGSAT data are at considerably lower altitude, have a better sampling rate and have derived superior main field models. These effects contribute to an increased resolution and knowledge of the geologically related anomalies. The Australian correlations between geology and satellite anomalies are particularly good due to the scale and orientation of the major tectonic units.

In southeastern Australia, the crustal magnetic anomalies are relatively subdued. This is interpreted as reflecting the presence of a high heat-flow gradient. This has been confirmed from the analysis of xenoliths, from which a vertical temperature profile has been derived for south-eastern Australia (O'Reilly & Griffin 1985).

The eastern margin of the Precambrian shield area is shown by a zone of steep gradients from the south coast, east of Adelaide, to the southern edge of the Mt Isa Block. The cratonic blocks that make up the Precambrian of Australia are all indicated by large positive anomalies. The Yilgarn Block is of particular interest as it appears to have a fundamental boundary within it giving rise to the northwest–southeast trending gradient. The Gawler Block has the largest positive anomaly situated over it and is well defined to the south and east. The Mt Isa Block also shows up as a large positive anomaly.

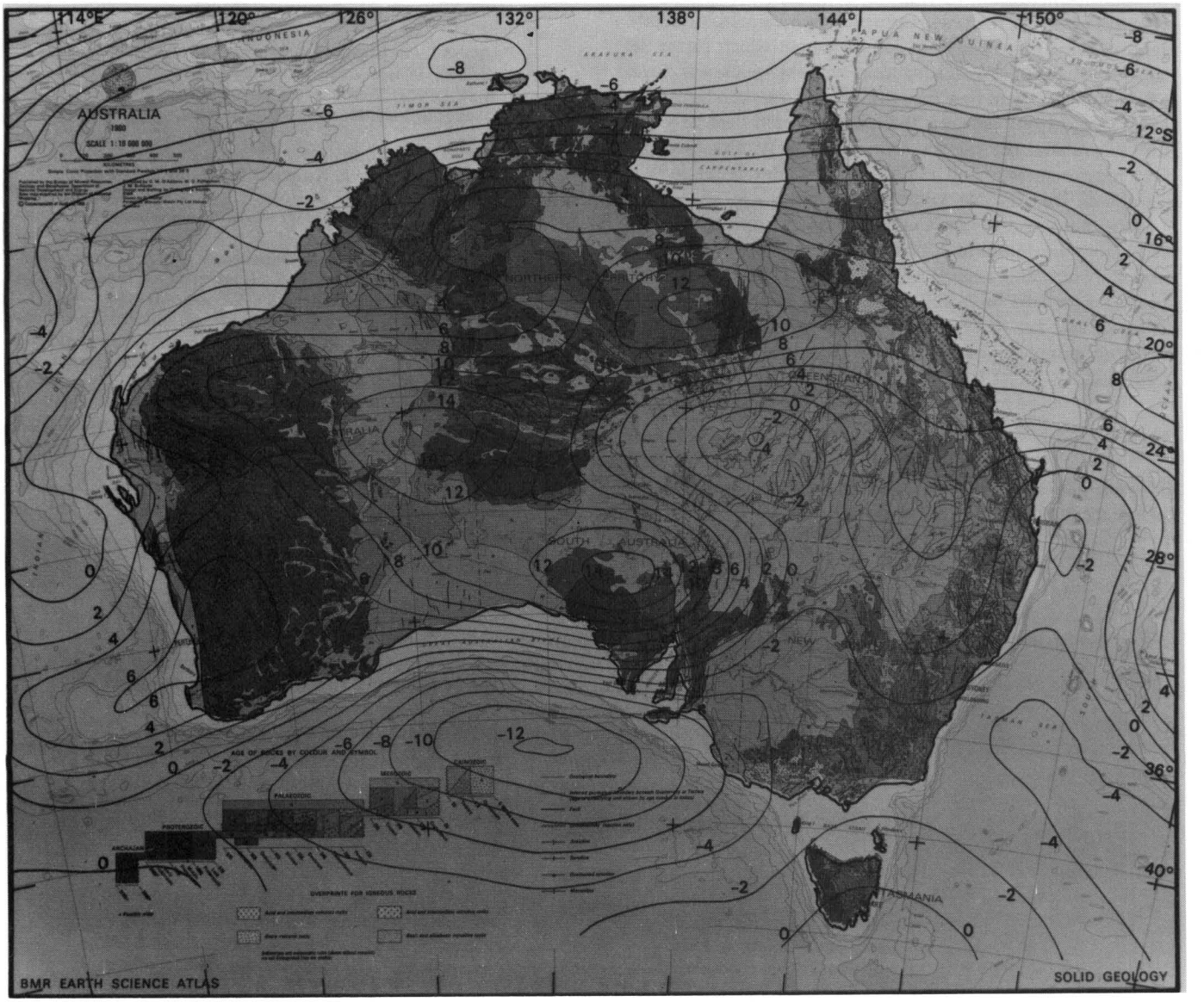

Fig 1

Inversion techniques

Inversion techniques have been developed which give the horizontal distribution of the vertical integral of magnetization. This is normally interpreted as a variably-magnetized constant-thickness layer. These inversion techniques require large mainframe computer calculations. Care also needs to be taken to maintain maximum resolution and yet have stable solutions. The magnetization solutions reflect the zero-level ambiguity inherent in the spherical harmonic modelling. The solutions, however, provide useful constraints on the areal distribution of the magnetized sources and the levels of magnetization required.

Heat flow and Curie isotherm modelling

The equivalent source solutions can be transformed into a constant-magnetization varying-thickness model provided that estimates are given for heat production as a variable of depth. Hence a Curie point isotherm can be sought which forms the base of a constant-magnetization variable-thickness layer (Mayhew 1985). Heat flow modelling techniques can be used to make comparisons between the magnetic field derived Curie isotherm model, the surface heat flow and temperature gradient measurements (Cull 1982; Cull & Conley 1983) and the xenolith-derived vertical temperature profiles.

In the cratonic areas the Curie isotherm is probably reached well below the Moho and, since the mantle is thought to be essentially non-magnetic (Wasilewski *et al.* 1979) then the base of the magnetized layer will occur at the Moho and will not reflect surface heat-flow. Cratonic blocks with unusually small magnetic anomalies may reflect abnormal high temperature gradients.

Magnetizations

Forward modelling on isolated anomalies has shown that the source magnetizations need to be of the order of 5 A/m and commonly involve the entire crust (Johnson 1985). These minimum values are higher than expected and thus some form of enhancement effect is needed. One possible mechanism is the acquisition of viscous remanence which occurs when material is subject to a magnetic field and is at a sufficiently high temperature.

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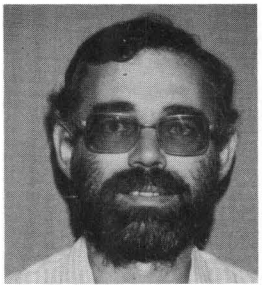

Dave Johnson graduated from Durham University with a BSc in geology followed by an MSc in geophysics. He then moved to Hobart where he completed a PhD studying the crustal structure of Tasmania. Since that time he has been lecturing at the University of New South Wales and at Macquarie University, where he is currently Senior Lecturer. His research interests include potential field modelling techniques, plate tectonic synthesis and computer graphic techniques. He is an active member of ASEG, SEG, EAEG, AGU, IAMG, ACGA, and helped to organise the ICOGEO conferences and establish the ASEG.

B. D. Johnson, Centre for Geophysical Exploration Research, Macquarie University, North Ryde, NSW 2113.

Mike Mayhew graduated from Ohio State University in mathematics and then received a PhD in marine geophysics from Columbia University. He became a Senior Resident Research Associate at the NASA Goddard Space Flight Center where he pioneered the inversion work on satellite data and played a role in the MAGSAT planning stages. He has since continued his association with NASA and MAGSAT both as a consultant and more recently as a Program Director (Experimental and Theoretical Geophysics) at the National Science Foundation in Washington. He is an active member of AGU, AAAS, the Potomac Geophysical Society, and the Geological Society of Washington.

M. A. Mayhew, National Science Foundation, USA.