EXTENDED ABSTRACTS

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EXTENDED ABSTRACTS

15th BMR Research Symposium

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Gold search : micro to macro

R W Henley, BMR

Since the majority of gold deposits are hydrothermal in origin, the essential problem of gold transport and deposition is a geochemical one bounded by geological constraints. It is well established that gold is transported predominantly as a bisulphide solution complex so that a rational approach to regional exploration is through assessment of terrane evolution in terms of the temporal availability of reduced sulphur ($H_2S$). On the local or regional scale, reduced sulphur may be made available by such processes as magma degassing, high temperature sulphate reduction in hydrothermal fluids at depth, metamorphic desulphidation reactions in response to elevated heat flow, the latter relating to crustal tectonic evolution. Deposits of gold therefore are, in origin, a stochastic consequence of crustal evolution rather than randomly-occurring events. This framework provides not only a new perspective on regional exploration but a focus on key crustal-scale processes and data useful for targeting gold exploration and strategic research. The systematics of major and minor gas components in hydrothermal systems and their occurrence in fluid inclusions is a major study which forms part of the expanding Minerals Program at BMR.

Origins of Pb-Zn deposits, Canning Basin, WA

Part 1 : Isotopic and related studies

I B Lambert, Baas Becking Geobiological Laboratory

A variety of techniques (Table 1) has been applied in studies of diagenesis and ore genesis in the well-exposed, unmetamorphosed Upper Devonian carbonate reef complexes of the Lennard Shelf, northern Canning Basin (Figs. 1, 2).

The Pb-Zn deposits of this region are of the so-called Mississippi Valley Type. The largest of the deposits found to date is Pillara (Blendevale; Fig. 1), which contains an estimated 20 m.t. of ore grading 8.3% Zn and 2.5% Pb (Murphy & others, 1986). Here, marcasite, sphalerite, galena and calcite occur as veins and breccia cements, which formed during and/or after faulting of unaltered platform and atoll facies Pillara Limestone (Fig. 2). There is enrichment of Ag, As, Cd, Cl, Hg and Mn, and, more sporadically, Cu, Sb and Ba, in the ore. Other much smaller deposits studied are Wagon Pass (Buchhorn, 1986) and Narlarla (Ringrose, 1984). These occur as disseminated, veinlet and submassive colloform to granular mineralisation, dominated by complex intergrowths of galena, sphalerite and pyrite in dolomitised and chloritised silty packstone of marginal slope facies Napier Formation. There are enrichments of Cu, Ag, As, Cd, Cl, Hg, Sb, Tl and U in the Wagon Pass deposit and country rocks. The mineralisation post-dates the main dolomitisation and appears to be related to brecciation and formation of late dolomite, calcite and chlorite: lithological and structural permeabilities are considered to have been important factors in its generation. Exploration is continuing, particularly in the southeastern portion of the Lennard Shelf.

C, O and Sr isotope analyses have been conducted on unmineralised limestones provided by G. Kerans (former WAMPRI Senior Fellow) and A. Reeckmann (Esso). The isotopic compositions (Fig. 3) of the early-formed carbonates provide evidence for extensive marine cementation. Later cements commonly have lower $\delta^{18}O$ (and $\delta^{13}C$) values than the early cements (Fig. 3). These results, together with elevated $^{87}Sr/^{86}Sr$ ratios and fluid inclusion data (Part 2), indicate the influx of heated basinal brines. The high $\delta^{18}O$ values in the late dolomite cements (Fig. 3) must reflect high degrees of water:rock interaction deep in the basin.

Carbonate spars from the vicinities of Pb-Zn mineralisation exhibit wide ranges of C and O isotope compositions (Fig. 3) and high Sr isotope ratios, again attesting to the importance of basinal brines. The trend to low $\partial^{13}C$ values (with no decrease of $\partial^{18}O$ values) implies oxidation of organic carbon probably largely coupled with sulphate reduction; this is most evident in the mineralised zone at Wagon Pass, where there are minor amounts of calcite pseudomorphs after calcium sulphate minerals. The extensive dolomite developed in calcareous units in the Wagon Pass area, and its high $\partial^{18}O$ signature, can be traced basinwards in the underlying van Emmerick Conglomerate (a palaeo-aquifer).

Sulphides have different $\partial^{34}S$ ranges for each deposit studied (Fig. 4). Most of the $\partial^{34}S$ values are positive and there is increasing $^{34}S$-enrichment from Wagon Pass to Narlarla to Pillara. Iron sulphides can have quite different $\partial^{34}S$ values from associated galena and sphalerite, indicating that they formed separately. Sulphate reduction was clearly the main source of sulphide, and this evidently occurred under different conditions in different areas. Galena and sphalerite with the observed narrow ranges of $\partial^{34}S$ values could have formed following thermochemical sulphate reduction, which may require temperatures in excess of $150^{o}C$ (Trudinger & others, 1985). Alternatively, there could have been bacterial reduction of most of the sulphate in basinal brines, or in seawater trapped in the carbonate reefs, with isotopic homogenisation of the biogenic $H_2S$ before metal sulphide precipitation; the upper temperature limits of bacterial sulphate reduction are currently being investigated. The wide ranges of $\partial^{34}S$ values for iron sulphides are probably reflecting bacterial reduction of seawater sulphate within the reef complexes, under conditions which resulted in minimal isotopic homogenisation.

The Pb isotope compositions of galena from Pillara and Wagon Pass are also different (Vaasjoki & Gulson, 1986; Fig. 5). The Pillara Pb is radiogenic and its isotopic homogeneity probably reflects mixing of fluids which incorporated metals from various units in the thick sedimentary basin sequence of the adjacent Fitzroy Trough. The Wagon Pass and Narlarla leads exhibit a linear trend and are more radiogenic, implying that Pb from basin strata was mixed with more radiogenic Pb from Early Proterozoic basement rocks, particularly those in the coarse clastic aquifer unit beneath the deposits.

Colour alteration in conodont fossils and annealing of fission tracks in detrital apatites can be used as indicators of thermal alteration. Both techniques have been applied to host rocks for the Pb-Zn deposits and permeable strata along which metalliferous and dolomitising fluids migrated, and they showed that these strata have not been heated above about 70°C for long enough to be recorded by these indicators. This contrasts with fluid inclusion evidence for temperatures of up to 110°C (Part 2), and implies that there were multiple short-lived pulses of heated brines which did not result in long-term heating of the rocks they moved through. This is supported by the widespread evidence for fine zoning of sphalerite, galena and associated carbonates.

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Part 2 : Fluid inclusion studies

H Etminan, Baas Becking Geobiological Laboratory

Early carbonate cements are commonly too fine-grained for fluid inclusions to be visible, but spars contain minute single-phase inclusions. Later sparry cements from unmineralised areas formed mainly at temperatures between 40 and 110°C from fluids that were variably more saline than sea water. Together with isotopic features, these data imply that later carbonate cements formed from waters which incorporated brines from different depths in the basin; the general absence of hydrocarbons in the inclusions implies that the hotter brines were derived from organic-poor strata.

In sphalerites from the Pillara Pb-Zn prospect, homogenisation temperatures are between 70 and 110°C and freezing temperatures range from -15 to -32°C. Laser mass spectrometry revealed appreciable amounts of Ca (but no Mg) in the aqueous phase of the fluid inclusions, which accounts for the low freezing temperatures. Laser Raman and infra-red microprobe studies showed that aliphatic and aromatic hydrocarbons occur in fluid inclusions in the sphalerite and that purplish zones in this mineral have relatively high proportions of hydrocarbons. Gas-chromatograph analysis of hydrocarbons (C. Boreham) released from fluid inclusions by pyrolysis at 350° and 500°C revealed that they are characterised by marked odd to even predominance in the $C^{15}$-$C^{20}$ range, and pristane to phytane ratios greater than 1: in these features they closely resemble Ordovician oils of the Canning Basin (e.g. Great Sandy). This provides further evidence for the derivation of metalliferous brines from deep basinal strata. Oil inclusions also occur in barite which formed penecontemporaneously with Pb-Zn mineralisation within the Canning Basin. Numerous biological marker compounds have been noted in these, including mature distributions of steranes and hopanes, and the hydrocarbons appear to be different from the Ordovician oils (C. Hoffmann).

The fluid-inclusion characteristics of some Pillara calcite (and of Wagon Pass dolomite) are comparable to those of Pillara sphalerite. Furthermore, Figure 6 shows that the fluid-inclusion data on the Lennard Shelf are similar to those for major Mississippi Valley Type (MVT) deposits. The atomic ratio of K/Na (0.02 to 0.07) of fluids extracted from minerals in the Lennard Shelf Pb-Zn deposits are higher than in most oilfield brines and are comparable to values from other MVT deposits. The available fluid inclusion and isotopic data on the mineralised areas are consistent with major contributions of brines which ascended from or through zones of saline waters of marine and meteoric derivation. Potassium was probably enriched by interaction with K-rich minerals in the basin strata, and it may have played an important role in release of metal ions to the basinal brines.

TABLE 1 : METHODS OF APPROACH & TECHNIQUES

PETROGRAPHY

GEOCHEMISTRY: MINOR & MAJOR ELEMENTS, GC & GCMS

FLUID INCLUSIONS: MICROTHERMOMETRY, LASER RAMAN, LASER MASS, I.R. MICROSPECTROSCOPY, IONS IN SOLUTION, GC & GCMS

FISSION TRACK ANNEALING

MINERAL CHEMISTRY : CATHODOLUMINESCENCE & ELECTRON PROBE

EXPERIMENTAL WORK: SULPHATE REDUCTION

ISOTOPE GEOCHEMISTRY: OXYGEN, CARBON, SULPHUR, STRONTIUM, LEAD

CONODONT COLOUR ALTERATION

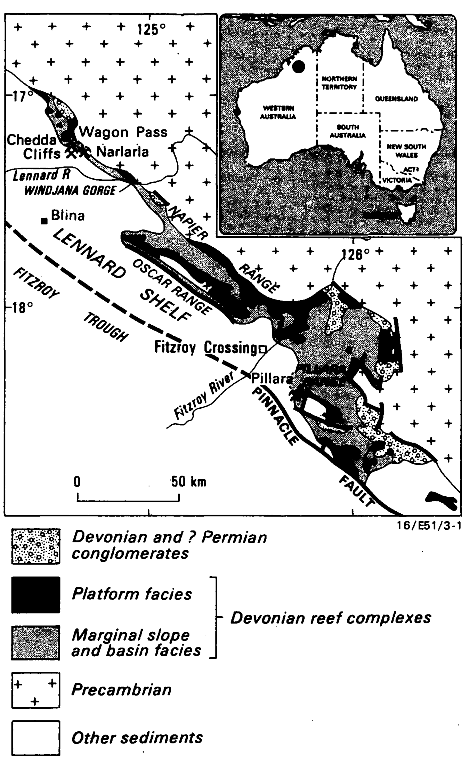



Figure 1: Localities and simplified geology, northern Canning Basin. Slightly modified after Playford (1980)

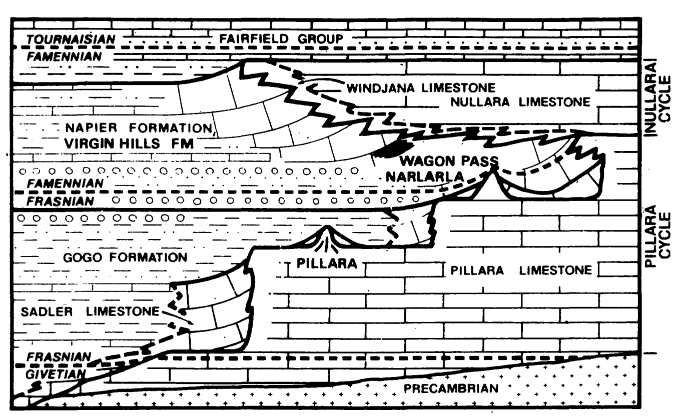



Figure 2: Simplified section through upper Devonian reef systems, Lennard Shelf. From Playford (1980)

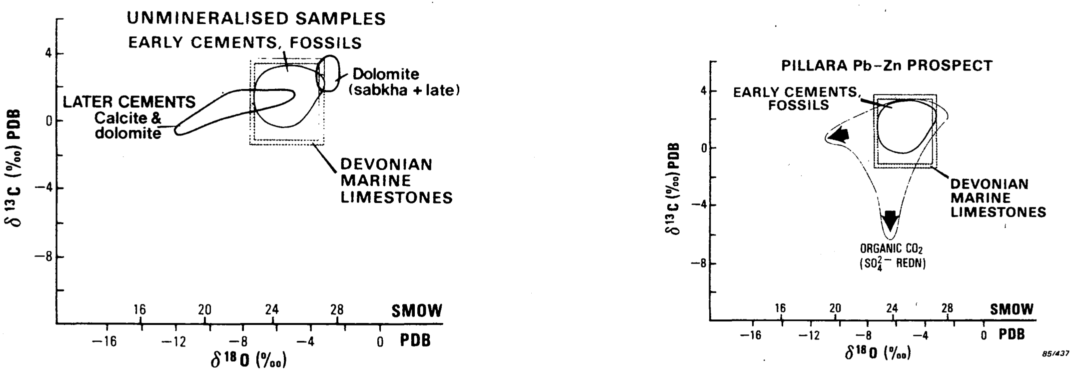



Figure 3: O and C isotope data for unmineralised carbonates, and carbonates from Pillara Pb-Zn deposit. Wagon Pass trends are similar to, but more extreme than, those shown for Pillara

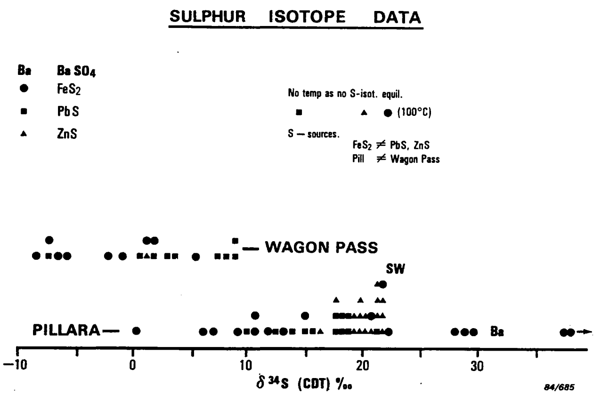



Figure 4: S isotope data for Pillara and Wagon Pass deposits

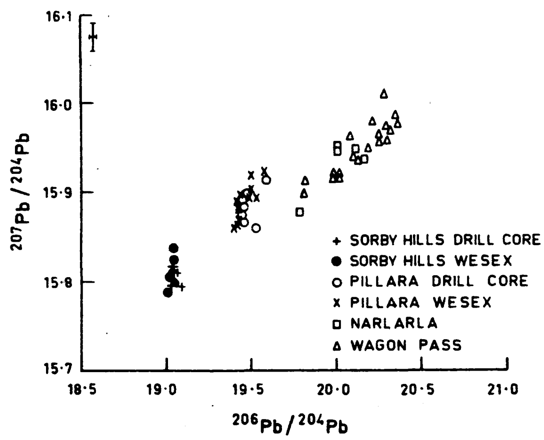
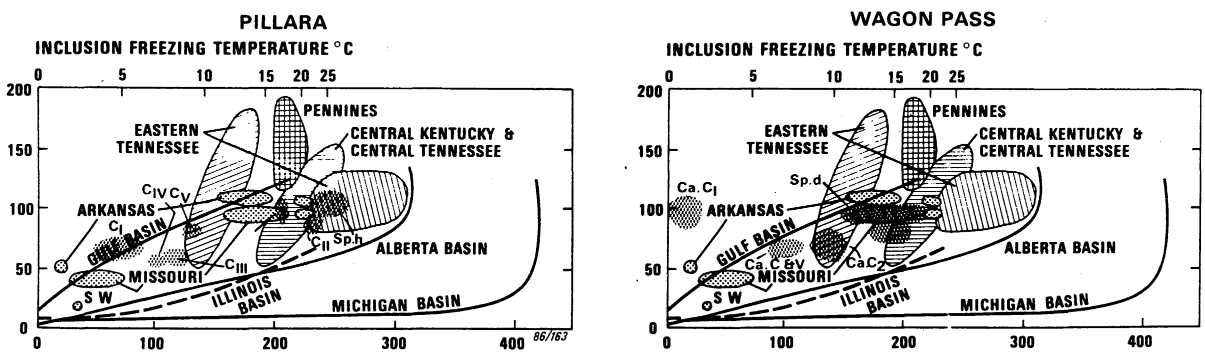



Figure 5: Pb isotope data for Lennard Shelf deposits, compared with other carbonate-hosted Pb-Zn deposits From Vaasjoki & Gulson (1986)




| | |
|---|---|
| SPHALERITE (Sp.h) | CALCITE IN VEIN TYPE III ($C_{III}$) |
| CALCITE IN VEIN TYPE I ($C_I$) | CALCITE IN VEIN TYPE IV ($C_{IV}$) |
| CALCITE IN VEIN TYPE II ($C_{II}$) | CALCITE IN VEIN TYPE V ($C_V$) |

| | |
|---|---|
| SPARRY DOLOMITE (Sp.d) | CALCITE CEMENTS (Ca.$C_I$) |
| CALCITE CEMENTS & VEINLETS (Ca.C &V) | CALCITE CEMENTS (Ca.$C_2$) |

Figure 6: Comparison of fluid inclusion data from Pillara and Wagon Pass with major MVT deposits; temperature-salinity relations for waters from North American basins are shown for comparison. Modified after Hanor (1979)

Distribution of precious metals in Precambrian basic-ultrabasic suites

## Part 1 : Platinum group elements potential of layered intrusions in the Pilbara Block, Western Australia

A Y Glikson, S-S Sun, & D A Wallace, BMR

The distribution patterns of platinum group elements (PGE) and related chalcophile metals in basic-ultrabasic magma systems depend critically on the behaviour of sulphur and thereby the origin of sulphides - the principal collectors of the PGE. Undepleted (fertile) mantle peridotite is thought to contain about 300 ppm S. PGE levels in mantle nodules (Pt - 7 ppb; Pd - 4.5 ppb; Ir - 4.2 ppb; Au - 1.2 ppb) are consistent with model mantle abundances, deduced from the composition of modern and ancient volcanic compositions. Small degrees of partial melting of such mantle sources would normally result in S-saturated liquids and consequently the separation of residual immiscible sulphide droplets. The latter are effective collectors of the PGE, with mineral/melt distribution coefficient (Kd) values above $10^3$, depleting the magmas in the trace and metal chalcophile elements. Where remelting of PGE-enriched S-depleted residual mantle which underwent a previous melting event takes place, the PGE are progressively concentrated in the liquids until crystal fractionation and/or assimilation and magma mixing result in S-saturation once again.

Economic concentrations of the PGE result from concentration or introduction of sulphur into PGE-high magmas, inducing S-saturation under physical conditions which allow scavenging of large volumes of magma of their PGE within magma chambers. Chromite is another important phase with which PGE are associated, forming in conjunction with multiple magma injections, turbulent magma mixing, single or double diffusive convection cells and consequent cyclic layering of cumulus phases. Because of the diversity of geological/petrological situations under which S-saturation of PGE-high magmas is achieved, no single model for PGE concentration applies. Nevertheless, the major PGE deposits of the Bushveld and Stillwater Complexes occur in conjunction with high-Mg siliceous basic magmas which show evidence of S-under-saturation and high primary PGE levels (Bushveld - 12% MgO; Pt - 40 ppb; Pd - 12 ppb). For this reason, attention has been focused in recent years on high-Mg siliceous, high-PGE S-under-saturated "boninite" volcanics of arc-trench environments and Precambrian environments where similar petrogenetic processes take place, as potential host rocks of PGE deposits (Hamlyn & others, 1985; Hamlyn & Keays, in press).

The Australian Precambrian Shield includes a large number of layered basic-ultrabasic intrusions which in terms of their dimensions and magmatic differentiation constitute potential hosts for PGE mineralisation. Principal examples are the Windimurra intrusion (northwest Yilgarn), Giles Complex (central Australia), Fraser Range (Western Australia) and Mt Hay-Mt Chapple (central Australia) basic granulite complexes, Lamboo Complex (Kimberleys) and hosts of small to medium-size intrusions throughout the Yilgarn and Pilbara Blocks (Fig. 1). The BMR project "Precious and trace metal disperson models of Precambrian mafic-ultramafic suites" aims at (1) the geochemical characterisation of intrusions and associated volcanics in terms of PGE and trace metal disperson models and mineralisation potential, and (2) classification of these bodies on the basis of petrological, geochemical and isotopic criteria. The PGE study of these intrusions and associated units constitutes a collaborative effort with Dr R R Keays and Dr P R Hamlyn within the framework of AMIRA.

Reconnaissance PGE background-level studies of Kimberleys and Pilbara intrusions indicate broad distinctions between the two provinces, including generally high Au (above 3 ppb) and commonly elevated Pd (above 3 ppb) in the Lamboo Complex of the Kimberleys (Fig. 2). The current phase of the project is aimed at intrusions in the Pilbara Block, in part in view of the occurrence of PGE mineralisation at the Munni Munni Complex (see following abstract by D Hoatson). Other bodies currently under investigation include the Mt Sholl, Andover (both in the western Pilbara) and Soanesville layered complexes.

The Andover Complex covers an area of about 150 $km^2$ and consists of a series of dunite, peridotite, pyroxenite and gabbro horizons which, together with minor anorthosite, form a succession about 2 km thick. The sequence is anticlinally folded about an E-W trending axis. The complex includes a deposit of massive titaniferous magnetite containing 0.99% $V_2O_5$. The Soanesville sill-complex includes (1) layered peridotite-bronzitite-norite sills (2) peridotite-pyroxenite lenses, and (3) peridotite lenses. Chromite occurs as discontinuous seams within the latter intrusions and fairly high PGE tenors (800 ppb) were detected in Cu-Zn sulphides in one of these lenses.

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## Part 2 : Platinum group geochemistry of the Munni Munni layered intrusion, west Pilbara Block, Western Australia

D M Hoatson, BMR

The Munni Munni mafic-ultramafic Complex (Sm-Nd model age 2800 Ma, S. Sun unpub. data), covers an exposed area of 9 x 4 km, and is composed of a lower 1850 m thick ultramafic zone (UZ) and an overlying gabbroic zone (GZ) which has a minimum thickness of 3630 m (Fig. 3). Aeromagnetic and gravity data indicate that the overall dimensions of the complex, which extends beneath Archaean Fortescue sediments and volcanics to the southwest, are 25 x 5 km. The UZ includes cyclic sequences comprising basal dunite followed by lherzolite, olivine websterite, clinopyroxenite and websterite. Norite, orthopyroxenite and chromitite are confined to the UZ-GZ interface. The bulk of the GZ consists of gabbronorite displaying a pronounced tholeiitic chemical trend, with inter-layered anorthositic gabbro and gabbronorite forming the highest stratigraphic levels. Broad petrological variations through both zones are represented with ascending stratigraphy by the cumulus mineral parageneses of: olivine, olivine-clinopyroxene, clinopyroxene-olivine, clinopyroxene, orthopyroxene-chromite and plagioclase. This sequence differs from other major intrusions where crystallisation of orthopyroxene generally precedes that of clinopyroxene.

Radiochemical neutron activation and XRF-AAS analyses indicate tht PGE-Ni-Cu mineralisation in porphyritic websterites below the UZ-GZ contact involves enrichment factors of $10^3$ for the PGE (from background levels of approximately 3 ppb to 3 ppm Pt + Pd). The mineralisation is believed to have resulted from magmatic processes involving crystal fractionation and/or interaction-mixing of chemically-distinct magma types. The importance of a magmetic mechanism rather than hydrothermal processes is indicated by (1) the consistency of the regional PGE-Ni-Cu variation trends below and above the mineralised horizon, (2) the paucity of other mineralised horizons through the stratigraphic sequence and (3) the lateral extent (about 12 km strike length) and lithological control of the mineralisation.

It is inferred that, during magmatic differentiation of a S-under-saturated magma of the UZ, Pt, Pd, Au and Cu were progressively concentrated in the residual silicate liquid. Emplacement of the S-rich GZ tholeiitic magma resulted in turbulent mixing of the two magmas, with rapid S saturation and precipitation of sulphide droplets in the UZ-GZ contact region. The sulphides acted as efficient collectors for the chalcophile elements Pt, Pd, Au and Cu since they are depleted in the basal gabbronorites. The Pt+Pd/S ratios are a factor of approximately 10 greater in the S-under-saturated UZ relative to the GZ. Iridium and Ni however display antipathetic relationships with S, but appear to correlate with olivine in the UZ peridotites (Fig. 4). The basal contact of the UZ also displays S-saturation, but unlike the main mineralised horizon, S was probably introduced by assimilation of the S-bearing volcanic and/or granite country rocks, with sulphide precipitation induced by super-cooling along the contacts. The marginal UZ rocks have low PGE levels (92 ppb Pt+Pd) relative to the mineralised websterites at the UZ-GZ contact. The incompatible lithophile elements Cs, Th and Zr which remain in the melt rather than entering the cumulus phases, display increasing concentration trends towards the base of the ultramafic zone and the mineralised websterites. These distributions parallel the trends of the PGEs and S, and reflect a higher melt to cumulus ratio, i.e., a greater porosity for the mineralised rocks.

The Munni Munni data have shown that variations in Pt+Pd/S, Cu/S ratios and trends of the incompatible elements Cs, Th, and Zr, are valuable in understanding the S evolution and therefore the PGE potential of the magmas. These chemical data should be used in association with field evidence which can indicate a mechanism for PGE precipitation (eg, magma mixing as shown by hybrid rock types, unconformities between magma types, lateral variation of rock types, marked disruption in cumulus parageneses, occurrence of porphyritic and pegmatoidal textures, and other criteria.

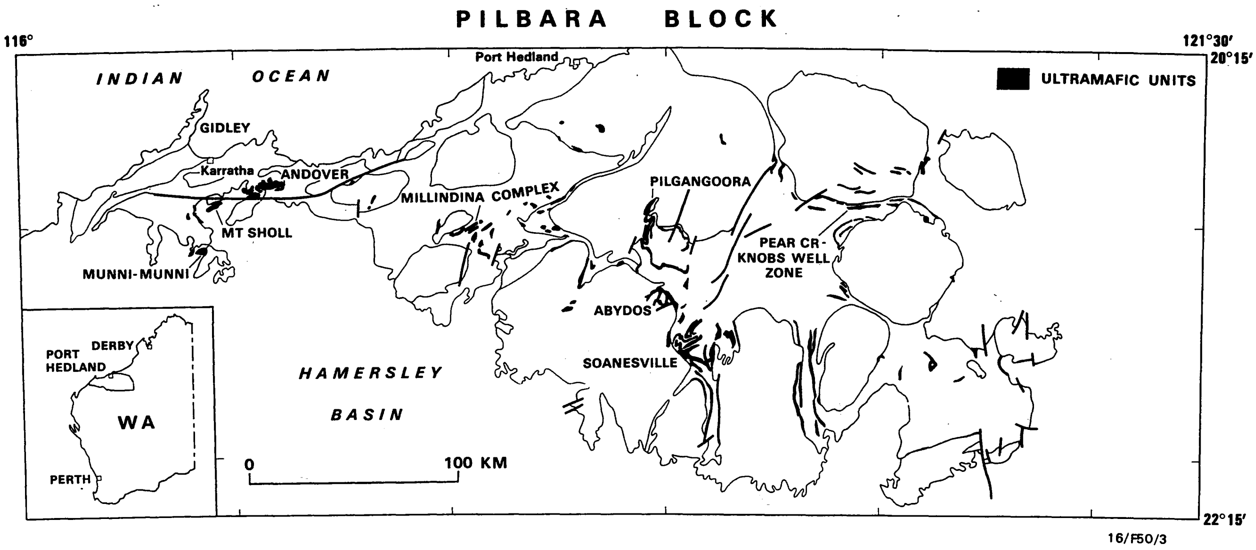


Figure 1 Geological sketch map showing the distribution of some basic-ultrabasic intrusions in the Pilbara Block Western Australia.

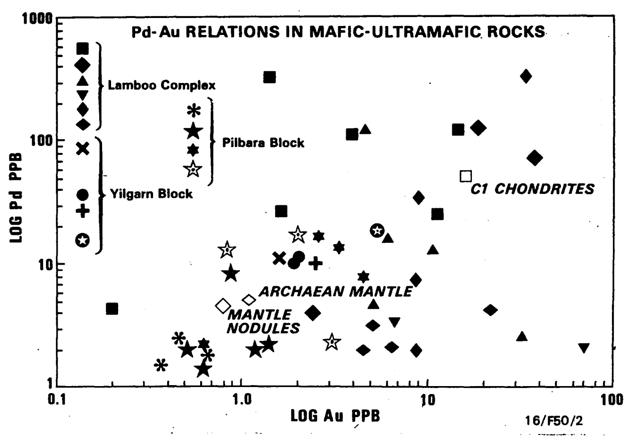


Figure 2 Log Pd versus log Au plots for basic and ultrabasic rocks from the Lamboo Complex (Kimberley) and the Pilbara Block, Western Australia.

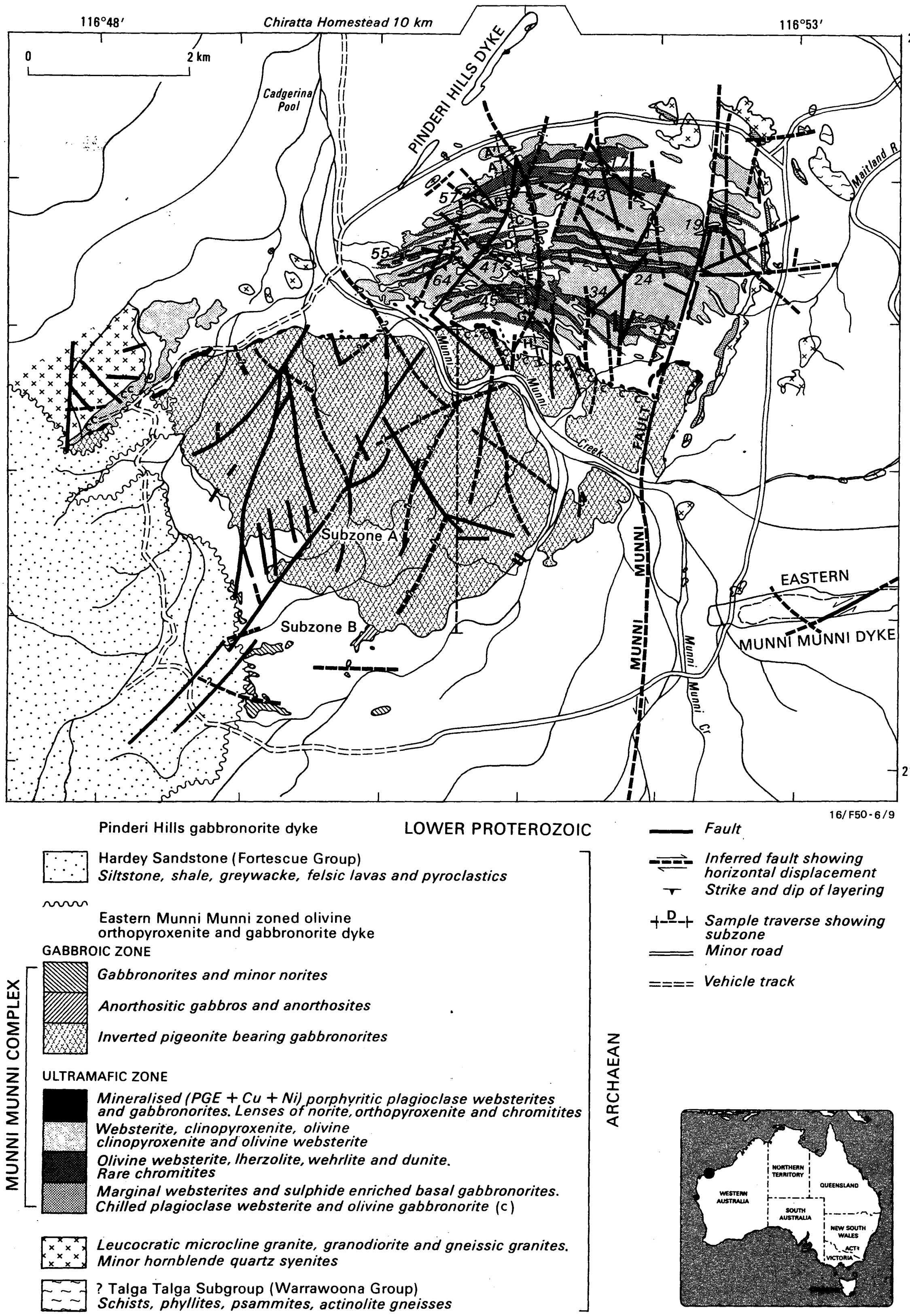


Figure 3. Geological sketch map of the Munni Munni Complex, western Pilbara Block, Western Australia.

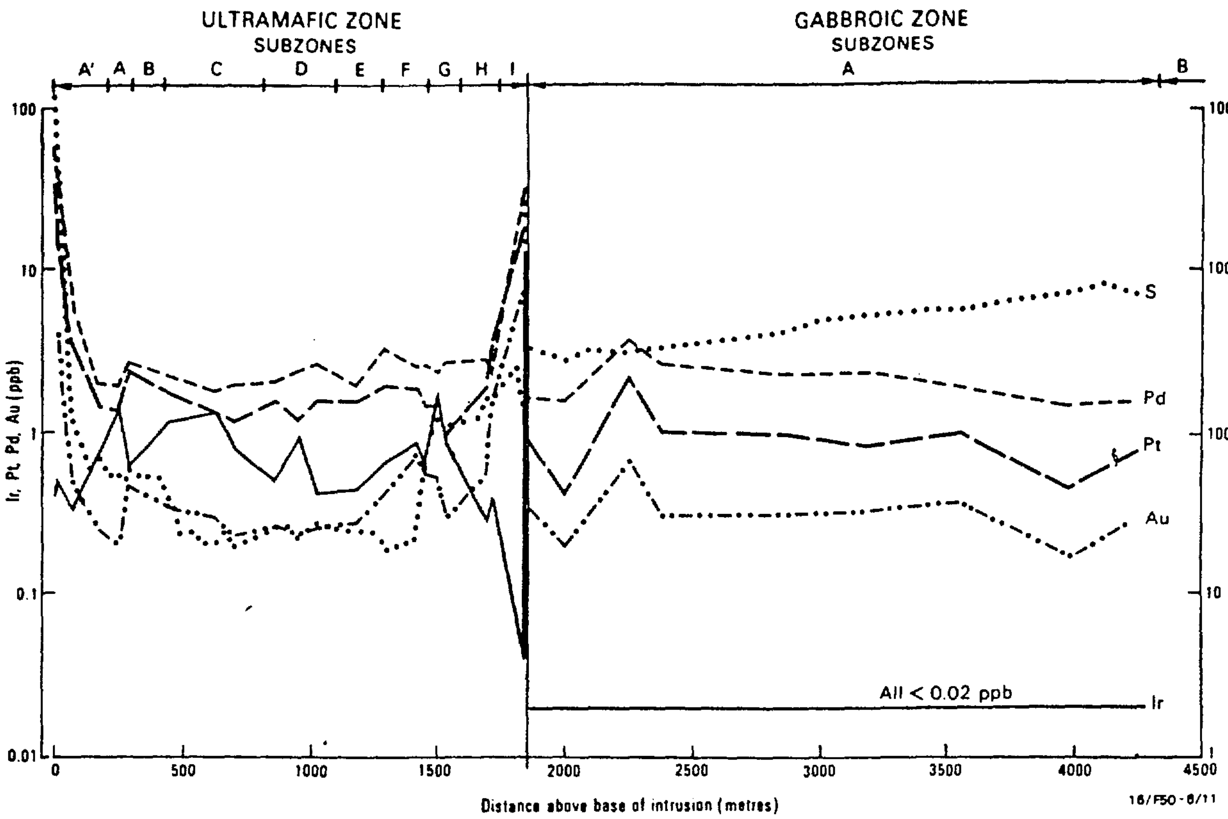


Figure 4 A precious metal profile through the magmatic sequence of the Munni-Munni Complex, western Pilbara Block, Western Australia.

Origin of Argyle diamonds: evidence from crystalline inclusions and carbon isotopic compositions

A L Jaques[1], A Hall[2], J W Sheraton[1], C B Smith[2], S-S Sun[1], R Drew[1], & C Foudoulis[3].

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Syngenetic inclusions provide important information on the origin of diamond. Recent Rb-Sr and Sm-Nd dating of such inclusions (Richardson & others, 1984; Richardson, 1986) has yielded crystallisation ages older than their volcanic host, implying that diamonds are mantle xenocrysts. We report on the nature of syngenetic inclusions and the carbon isotopic composition of the host-diamond from the Proterozoic Argyle lamproite pipe with the aim of determining their origin.

Syngenetic inclusions in the Argyle diamonds are overwhelmingly of eclogitic paragenesis (Hall & Smith, 1984; Harris & Collins, 1985). Orange garnet is the most common with omphacite, coesite, kyanite, rutile, and sulphide less abundant; very rare ilmenite and moissanite (SiC) have also been found. Peridotitic inclusions are mostly olivine with less abundant purple chrome-pyrope and enstatite. Sulphide (chiefly pyrrhotite) occurs both in peridotitic diamonds and with graphite alone without silicate inclusions. Epigenetic inclusions are widespread, the most common being graphite, followed by orthoclase, phlogopite, talc, calcite, quartz, hematite, chlorite, anatase, sphene, rutile, kaolin, and very rare priderite.

The Argyle eclogitic suite exhibits a wide range in Ca-Mg-Fe. Garnets range from relatively Ca-poor, almandine-pyrope (6 wt % CaO, $Mg_{70}$) to more calcic pyrope-almandine as Fe-rich as $Mg_{34}$ to rare grossular-rich garnet (17-18 wt % CaO). Characteristic features of the eclogitic garnets from the Argyle diamonds are their very high Na (commonly 0.45-0.55, up to 0.71 wt % $Na_2O$), P (up to 0.39 wt % $P_2O_5$) and Ti contents (1.45 wt % $TiO_2$). Although unusually sodic and of undoubted high-pressure origin the Argyle garnets differ significantly from the exceptionally Na-rich garnet inclusions with excess Si (pyroxene component) described from diamonds from the Monastery Mine by Moore & Gurney (1985); these may have formed within the asthenosphere. Omphacites from the Argyle diamonds have very high jadeite components (up to 9 wt % $Na_2O$, 20 wt % $Al_2O_3$) and extremely high $K_2O$ contents (up to 1.3 wt %). Such high jadeite contents and the significant solubility of K in pyroxene, like the Na substitution in garnet, indicate formation under very high pressure.

The Argyle peridotitic inclusions, like peridotitic inclusions in diamonds elsewhere, are characterised by refractory compositions, i.e. high Mg/(Mg+Fe) in olivine ($Mg_{92-94}$) and Cr-rich pyrope (up to 15% $Cr_2O_3$).

The Argyle peridotitic-suite diamonds, like the bulk of inclusion-bearing diamonds elsewhere, including both peridotitic and eclogitic stones from Ellendale, are characterised by carbon-isotopic compositions with small negative $\delta^{13}C$ values (Fig. 1). In contrast, the majority of the Argyle stones with eclogitic inclusions have distinctly lighter C-isotopic compositions lying mostly in the range -9 to -12 $\delta^{13}C_{PDB}$‰ (Fig. 1).

Our study of the Argyle diamonds has shown an association of stone morphology and inclusion type. Sharp-edged octahedra with etched and frosted surfaces contained only peridotitic inclusions and have a restricted range of C-isotopic compositions. These diamonds resemble the diamonds recovered from peridotite xenoliths from the Argyle pipe (Hall & Smith, 1984).

Two distinct sources for the Argyle diamonds are suggested. (1) The octahedral (and associated forms) formed during a relaxed (low) geothermal gradient in Archaean (?) refractory, reduced peridotite inferred to comprise much of the lower lithosphere beneath the Kimberley craton. This peridotite may be the residue of Precambrian magma extraction (Richardson & others, 1984) which has subsequently been enriched in incompatible elements (Sun & others, 1986). (2) The bulk of the diamonds - rounded, resorbed dodecahedra - are of eclogitic paragenesis and younger, 1580 Ma (Richardson 1986). It is suggested that these may have crystallised from melts derived from recycled crustal materials. This recycled crustal material may be the same as the ancient (>2 By) enriched lithospheric component identified in the Argyle lamproite since the calculated Sm-Nd trajectory for the source region of the Argyle lamproites overlaps the initial $^{143}Nd/^{144}Nd$ of the Argyle syngenetic inclusions. A dual or multiple origin for the Argyle diamonds is consistent with the very wide range in $^{3}He/^{4}He$ and other noble gas ratios recently reported for the Argyle stones by Honda & others (1985).

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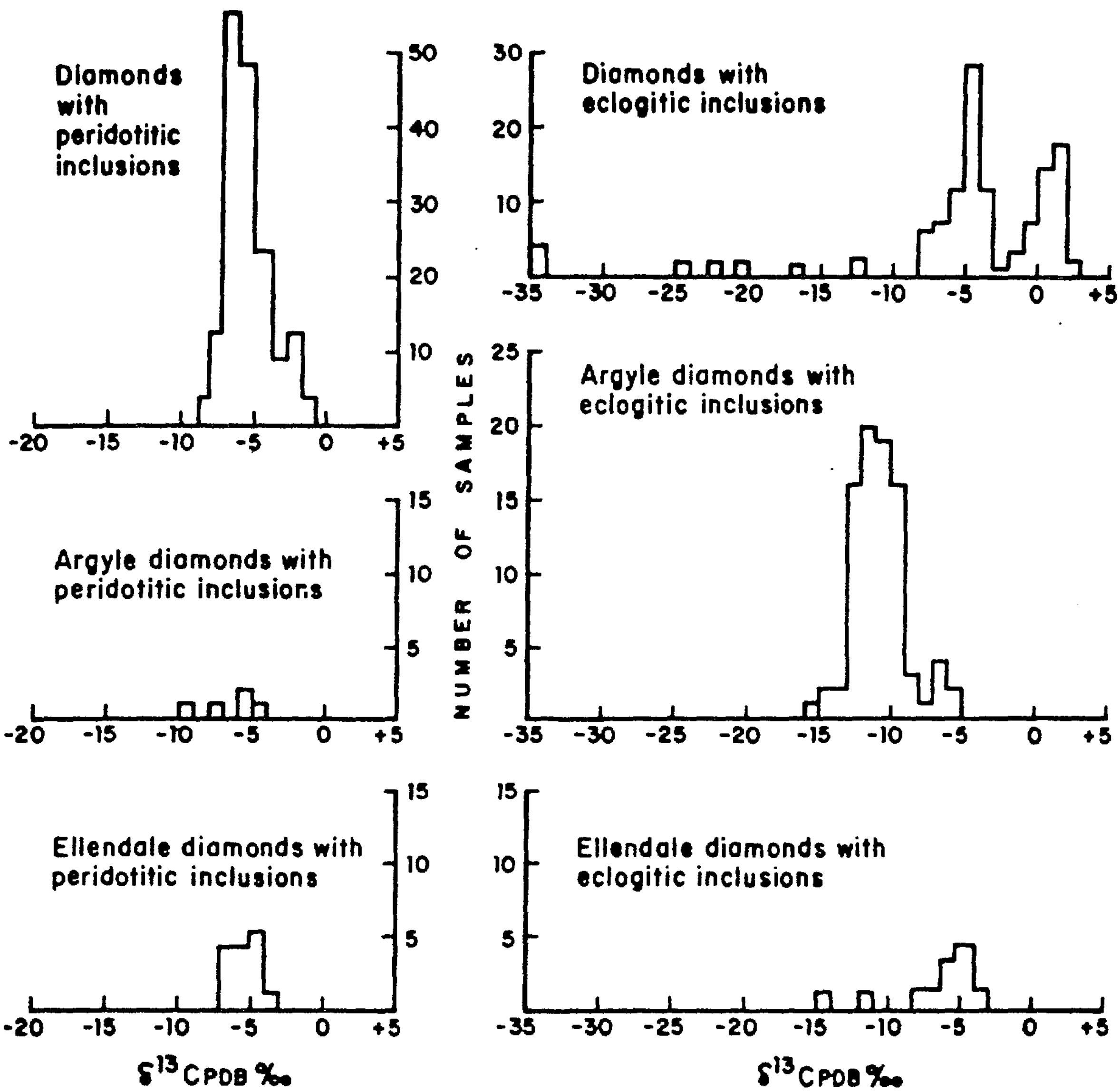


**Figure 1.** Carbon isotopic compositions of inclusion-bearing diamonds from Argyle and Ellendale compared with inclusion-bearing stones elsewhere (modified after Jaques & others, 1986).

Australian Geomagnetic Reference Field : the attractions of an Australian model in the field

C E Barton, P L McFadden, & A J McEwin, BMR

The magnetic field at the surface of the Earth, when averaged over a sufficient interval of time to remove transient variations (nominally one year), consists principally of a contribution originating from the Earth's core, called the "main field", and a lesser contribution arising from permanent and induced magnetisation of the crust. The International Geomagnetic Reference Field (IGRF) is the internationally adopted set of spherical harmonic models which are intended to represent the main (core) field and its secular variation. Regional models of the geomagnetic field represent a combination of the main field and the broad-scale crustal field. They are used as aids for navigation, surveying, certain military applications, geophysical exploration, determination of sea-floor ages and spreading history, and in studies of geomagnetic phenomena.

Due to the paucity of observations in the southern hemisphere, the IGRF for the Australian region is relatively poorly constrained, being dependent on a high proportion of remote observations. As a consequence, the IGRF is not a particularly good representation of the magnetic field over Australia. Ground measurements of total field, smoothed to remove effects of local anomalies, typically show departures from corresponding IGRF values of up to a few hundred nannotesla. Differences between the regional model for 1980 (BMR/80) and the Definitive IGRF (DGRF) for 1980 are illustrated in Figure 1. DGRF 1980 is a particularly accurate model of the field for 1980 because it includes a large amount of MAGSAT data. Fits to regional models would not normally be as good as illustrated in Figure 1. Since by definition the IGRF is the best representation of the Earth's main field in any region it is not intended, and cannot be expected to give a very close match to the actual field observed.

The situation regarding secular variation is somewhat different. Since the regionally observed secular variation is essentially the secular variation of the main field, there should be agreement with the IGRF secular variation model. Figure 2 shows the distribution of differences in annual change in total field for 1985 at repeat stations and observatories in the Australian region (Fig. 3) and corresponding values for IGRF 1985. Clearly IGRF values are systematically lower (more negative) than the regional observations, and the distribution peaks at about 10 nT/yr. Such differences become substantial as they accumulate over many years.

IGRF secular variation models are based essentially on observatory data. Observatories certainly provide the highest quality secular variation information, but in the Australian region their average separation is very large (approximately 2600 km). By combining observatory data with "first-order" observations at repeat stations (i.e. observations designed to eliminate diurnal and transient disturbances) a much better regional secular variation model can be obtained. Charts and models of components of the geomagnetic field and their annual changes in the Australian region have been prepared by BMR at approximately five-yearly intervals since epoch 1942.5, with the exception of 1975.0 (Table 1). Models for 1970 onwards have been developed principally to show the secular variation of the field. The observatory and repeat station data set used for these models is too small to provide a good representation of the regional field itself. The models are appropriate for reducing survey data to a common epoch, but, are not adequate as reference models for detrending aeromagnetic and marine magnetic survey data, or for investigations into long wavelength magnetic anomalies.

By analogy with the IGRF, a suite of reference field models in standard numerical form is being developed for the Australian region - the "Australian Geomagnetic Reference Field" (AGRF). The AGRF for 1985 has been designed to preserving the main field information in IGRF 1985 and take advantage of the versatility of orthogonal functions for modelling the regional component. All data were reduced to epoch 1985.0 by subjective extrapolation of secular variation trends. Corresponding values of IGRF 1985.0 were then subtracted, and the residuals modelled by rectangular harmonic analysis to obtain a set of coefficients representing the potential of the residual field. The regional field at any point is a recombination of the residual and main field synthesised from the two sets of harmonic coefficients. This technique is computionally efficient and permits flexibility in the choice of smoothing required of the model by appropriate truncation of the series of coefficients. The secular variation model for AGRF 1985 is based on the regional secular variation data only. AGRF 1985 is being made available as a FORTRAN software package.

The residual regional field component of AGRF 1985 still suffers from the limited size of the database (observatories and repeat stations only). Hence for removing trend surfaces from airborne and marine magnetic survey data to obtain magnetic anomalies, AGRF 1985 should be truncated to remove the residual regional field entirely. This is equivalent to using IGRF 1985, extended to later epochs using the regional secular variation model.

AGRF 1985 is an intermediate step in the development of retrospective AGRF models which incorporate a comprehensive analysis of all available regional field information - from land, marine, airborne and satellite surveys. These models will define the long wavelength magnetic anomaly structure of the continent, and will provide the basis for levelling adjustments to individual magnetic surveys used to assemble the "Magnetic Map of Australia". AGRF 1990 will incorporate this information.

Table 1. Charts of the geomagnetic field and its secular variation in the Australian region produced by BMR

| | Survey | | | | |
|---|---|---|---|---|---|
| Epoch | Compt. | year(s) | Stns[1] | Charts | Author(s) |
| 1942.5 | D | 1911-1939 | 45 | D[2] | J M Rayner |
| 1950.5 | D | 1944-1945 | 47 | D | W M Holmes |
| 1955.5 | D | 1952 | 51 | D | F W Wood, I B Everingham |
| 1957.5 | DH1 | 1952-1957 | 51 | DHIZF[3] | W D Parkinson, R Curedale |
| 1960.5 | DHZ/1 | 1952-1957 | 51 | D | W D Parkinson |
| 1965.0 | DHZ/F | 1959-1964 | 58 | D | J van der Linden |
| 1970.0 | DHF | 1966-1970 | 81 | All[4] | D M Finlayson |
| 1980.5 | DHF | 1978-1979 | 71 | All[5] | A J McEwin, P M McGregor & G R Small |
| 1985.0 | DHF | 1981-1985 | 82 | All[6] | A J McEwin, C E Barton & P L McFadden |

1: number of observatories plus repeat stations used to determine the secular variation;
2: based on the initial set of 450 field stations, including the 45 repeat stations;
3: incorporates a large amount of additional field survey data;
4: based on combination of cubic spline fitting and hand contouring, incorporates some second-order and third-order survey data and is continuous with the New Zealand model for 1970.0;
5: based on 4th degree polynomial fits to the observatory plus repeat station data only;
6: based on rectangular harmonic analysis of observatory plus repeat station data only.

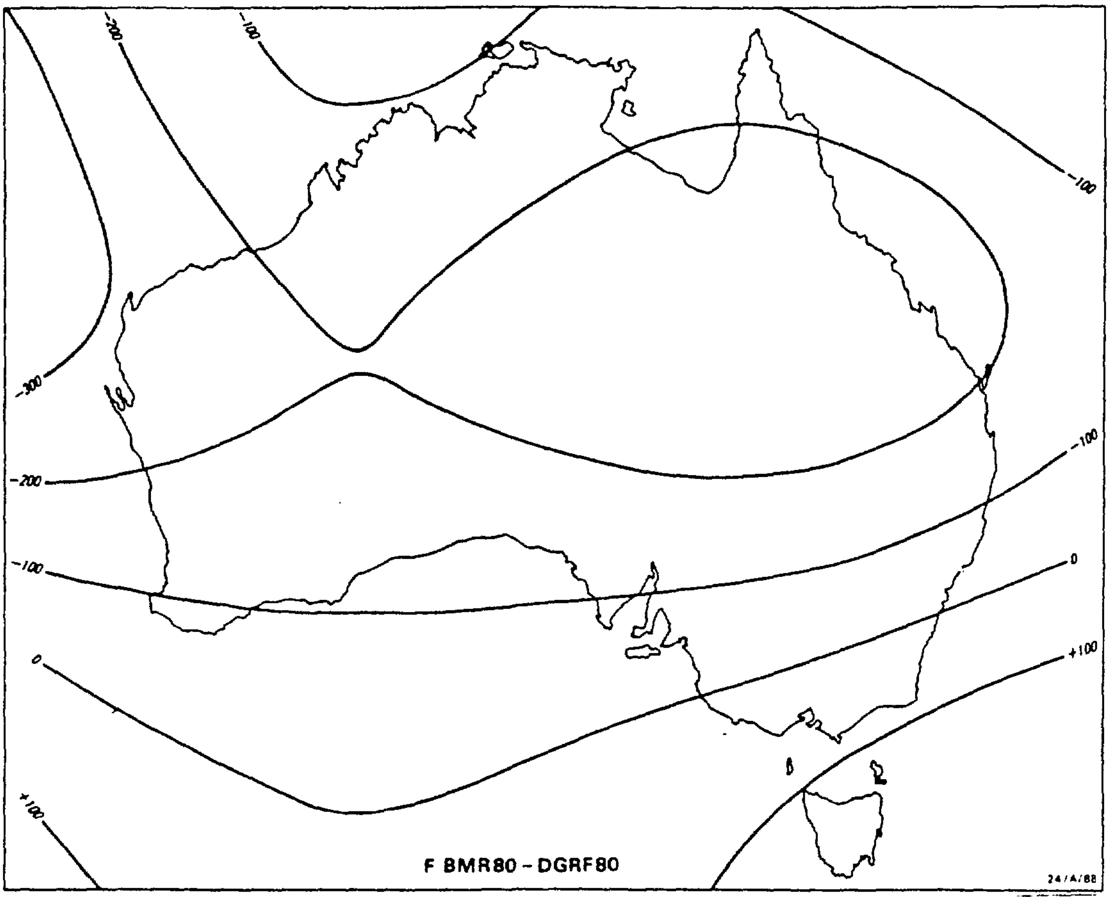


Figure 1. Contoured differences in total field in nT between the BMR regional model for 1980, BMR/80 and DGRF 1980.

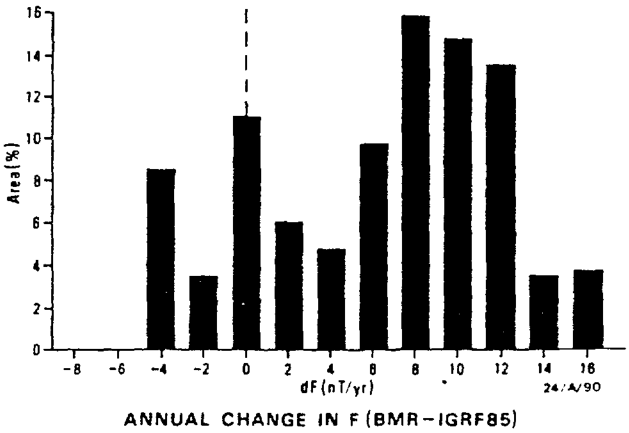


Figure 2 Distribution of differences between the annual change of total field (dF in nT/yr) for epoch 1985.0 at 80 repeat stations and observatories and corresponding DGRF values. The ordinate is the percentage of stations with differences in dF in successive 2 nT/yr intervals centred about the values given on the abscissa.

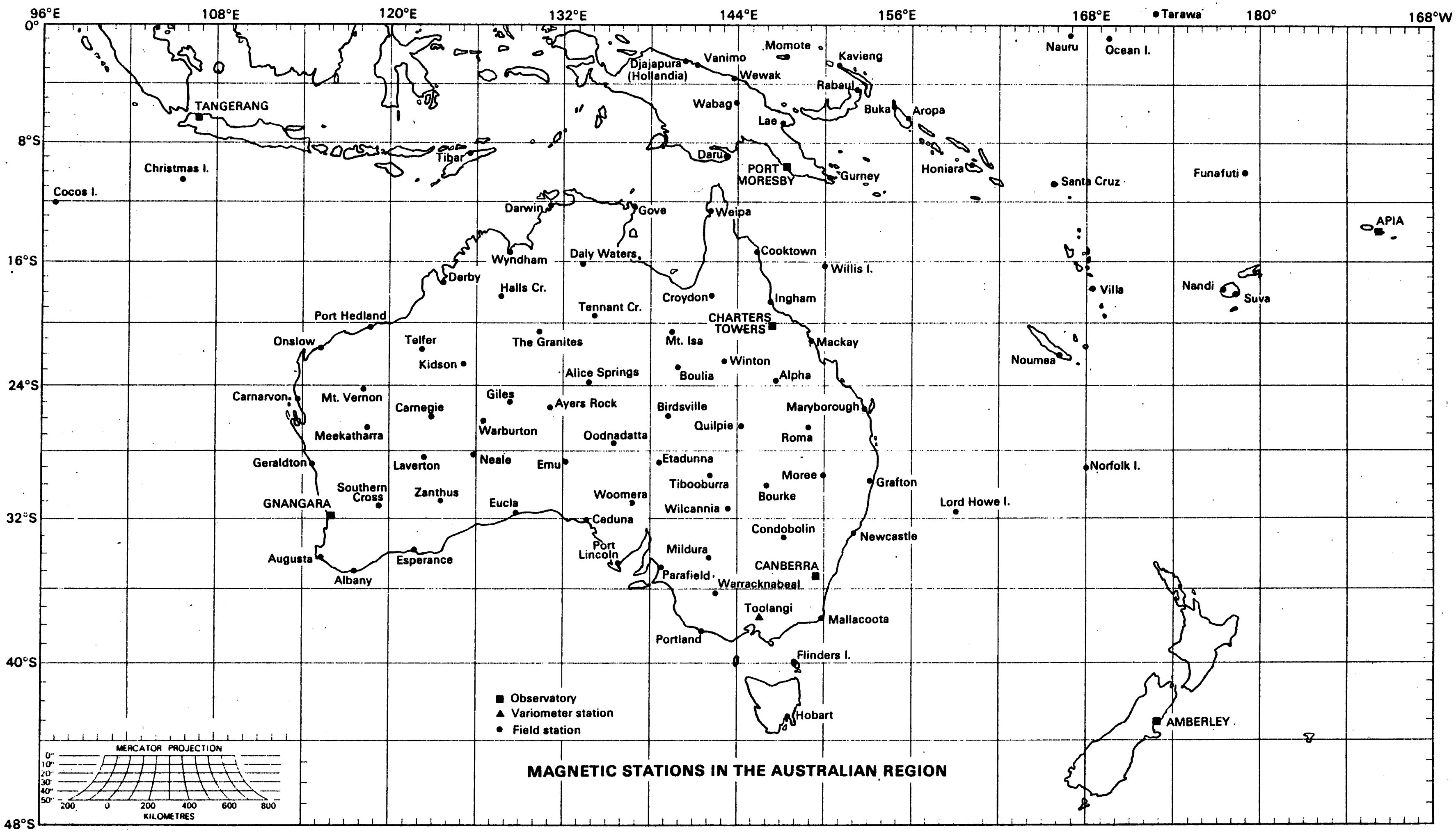


**Figure 3** Magnetic observatories and repeat stations in the Australian region. Toolangi has been replaced by Canberra as the principal Australian observatory. Since 1985 Toolangi has been operated only as a variometer station.

# Mount Isa Block as a 700 km-long zone of reworking of Proterozoic crust: an interpretation based on gravity and magnetic anomalies

P Wellman, BMR

In the last few years there has been renewed interest in the relationship of the basement of the Mount Isa area to the basement to the east and west, and in models for crustal formation of this and other Proterozoic crustal blocks. Using gravity and magnetic anomalies, I map the extent of the Mount Isa crustal block, infer its relationship to surrounding blocks, and subdivide it into bands of similar history and rock content.

The Mount Isa area is unusual geophysically in that the gravity and magnetic anomalies are of high amplitude, and are very elongate (Fig. 1). The anomalies have a wavelength of about 100 km, a strike-length of about 700 km, and a strike-direction changing from north-northwest in the south to north-northeast in the north. The anomalies have a total width of 300 km in the south, and they thin northward to 150 km wide. The area of these elongate anomalies is called here the Mount Isa (crustal) Block. In the adjacent areas gravity and magnetic anomalies are of lower amplitude, and anomaly direction and continuity is less consistent.

A relatively younger age for the Mount Isa Block structures, relative to those in the crust to the west and east, is suggested by the relative regularity and extent of the gravity and magnetic anomalies, by their trends truncating trends in adjacent crust to the west and east, and by the margins of the Mount Isa Block being relative gravity highs (gravity highs are found on the younger side of the majority of Proterozoic block boundaries). In this interpretation, older crust crops out on the Murphy Tectonic Ridge (Murphy Metamorphics), in the Kamerga Dome area of the Lawn Hill Platform (Yaringa Metamorphics), and west of the Rufus and Mount Isa Faults (Saint Ronans Metamorphics). The oldest rocks of the Mount Isa Block (Kurbayia Migmatite, Plumb Mountain Gneiss, and Double Crossing Metamorphics) are similar in age to these rocks (Black, in press), but they are more metamorphosed and deformed, and they have north-south trends. The only age control is a U-Pb zircon age of about 1.9 Ga for the Yaringa Metamorphics west of Mount Isa. The eastern edge of the Mount Isa Block is concealed, but is only a few kilometres east of Soldiers Cap Group outcrops.

The Mount Isa Block is truncated in the south by Palaeozoic rocks of the East

Australian Orogenic Province. Towards this boundary the block becomes increasingly deformed: (1) 120 km from the boundary the west-northwest trending Mount Isa structures have their first displacement to the southwest on southwest faults, (2) 30-40 km from the boundary most of the upper crustal structures are reworked as indicated by an abrupt loss of magnetisation and loss of most density contrast between crustal bands, (3) 20 km from the boundary the west-northwest-trending gravity anomalies are lost, and (4) at the boundary a major gravity gradient is interpreted to mark the edge of Proterozoic upper and lower crust. Towards the northern end of the Mount Isa Block the north-northeast trends become irregular, they are then truncated, but no marked gravity or magnetic anomaly is present, so there may not be a major change in crustal structure.

In the Mount Isa area the gravity highs generally correlate with mafic volcanics or basement outcrops, and the gravity lows with granite and felsic volcanics. Most magnetic highs correlate with mafic volcanics and magnetic granites. The Mount Isa Block consists of seven bands of high or low gravity. These bands are more continuous than suggested by mapped geology, implying that rocks are more continuous at depth. The western gravity, and also magnetic, high contains metabasalts of the Eastern Creek Volcanics in the north (A of Fig. 2) and Jayah Creek Metabasalt in the south (B). The adjacent gravity and magnetic low to the east contains Kalkadoon and Ewen Granites and Leichhardt Volcanics (C). The next two gravity high bands contain the calc-silicate Corella Formation (D & F). The intervening and eastern gravity lows contain Williams Granite (E & G), and the easternmost gravity and magnetic high band contains Soldiers Cap Group (H). To the west of the Mount Isa Block bands can be identified of Sybella Granite (L of Fig. 2), Oroopo Metabasalt (J), Saint Ronans Metamorphics (K), and mafic volcanics(I).

The gravity and magnetic anomalies are consistent with the Mount Isa Block being an elongate band of reworking and addition of crustal material, within a pre-existing mosaic of Proterozoic crustal blocks. The Mount Isa Block was later truncated and reworked at its northern and southern ends.

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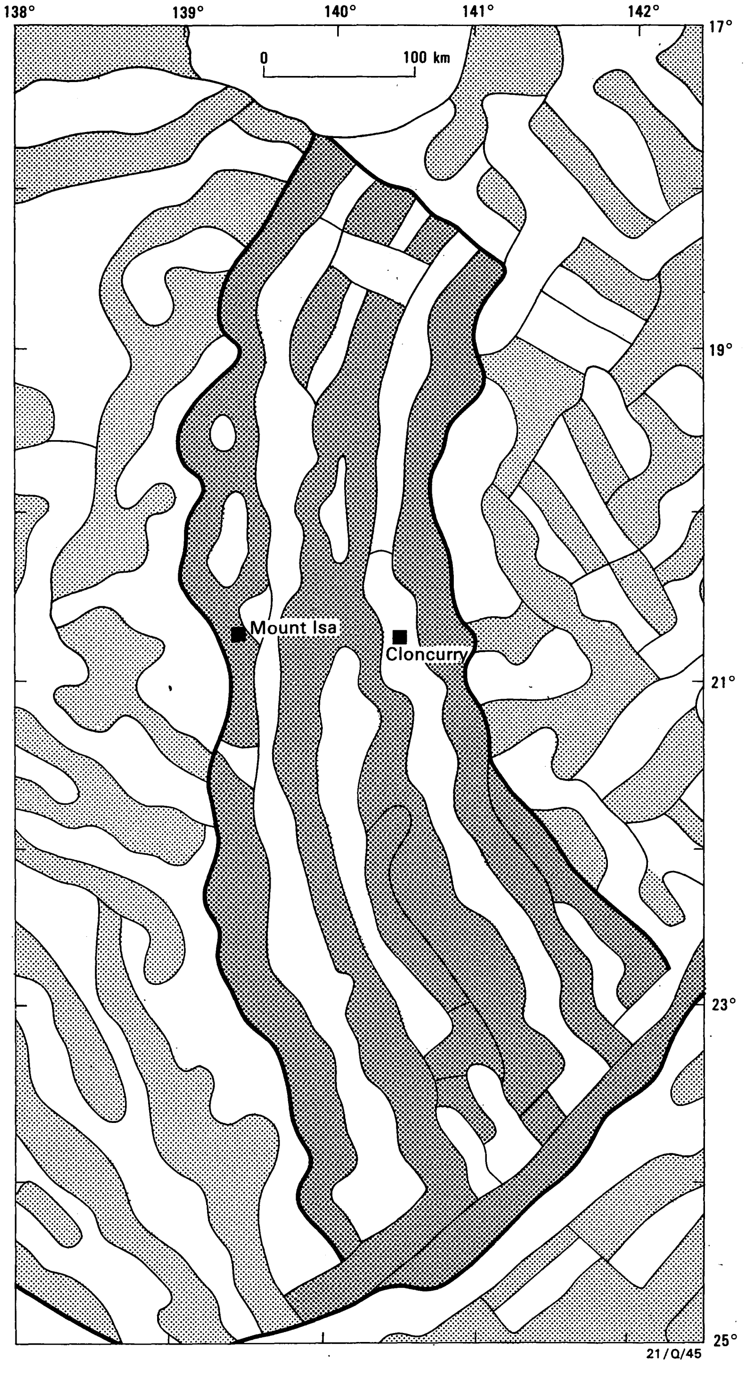


Figure 1. Residual gravity anomalies in the Mount Isa Region. Stippled areas are gravity anomaly highs. Thick lines give the sub-surface extent of the Mount Isa Block and the East Australian Orogenic Province.

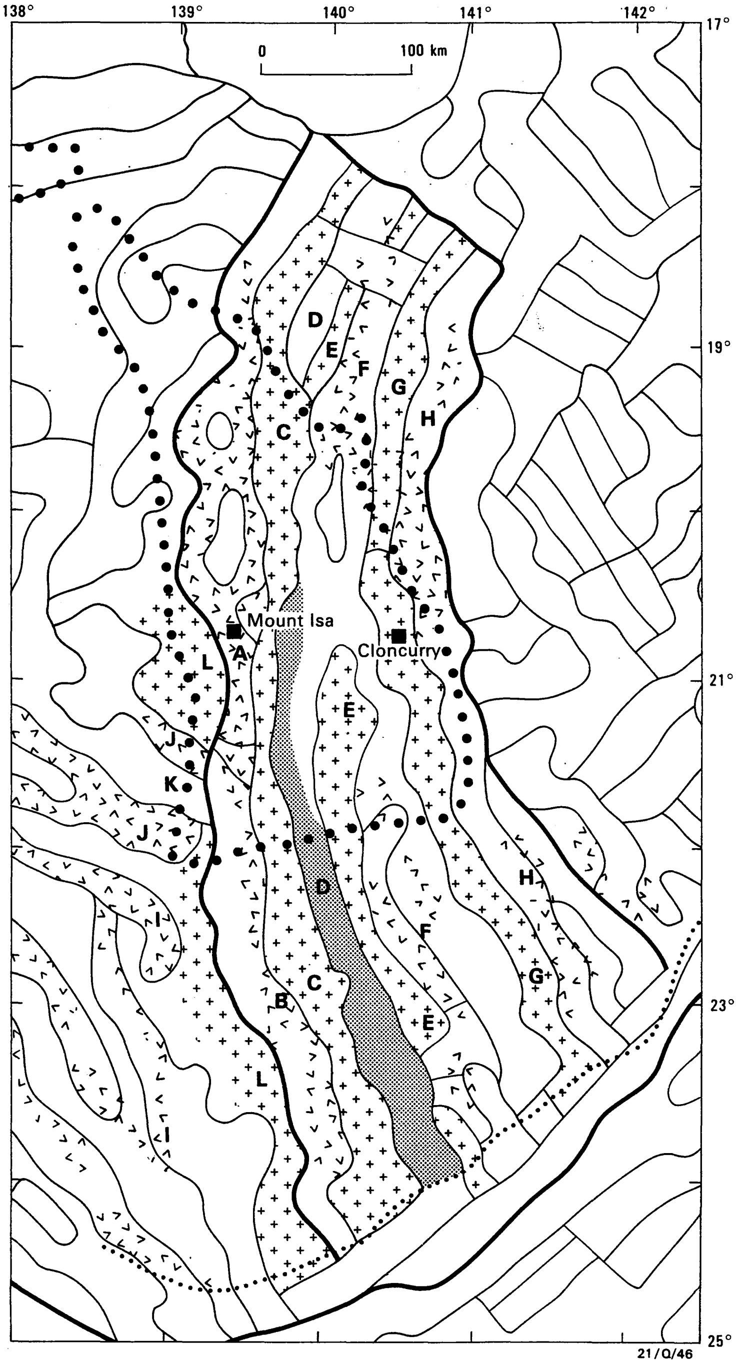


Figure 2. Mount Isa Region, showing extent of Mount Isa Inlier and Murphy Tectonic Ridge (line of big dots), and southern extent of Mount Isa Block upper-crustal structures (line of small dots). The letters mark bands of rock referred to in the text.

# Basement faults in the southern Adavale Basin and the structuring of the overlying Eromanga sequence

J Leven, BMR

Recent oil discoveries within the Eromanga Basin have been made in structural traps which were either formed or enhanced by reactivation of pre-existing basement faults. Examples of such oil discoveries are the Jackson, Tintaburra, and Kenmore Fields. Since the nature of the pre-existing basement faults underlying these features controlled their geometry, by studying the nature of this reactivation we can infer the fault geometry within the basement of the Thomson Fold Belt.

## The basement faults

Figure 1 is a map of the basement structure of the central Eromanga Basin region which shows the distribution of major faults, and provides an indication of the style of basement faulting involved. The Canaway Ridge which is also shown in this figure; represents a major north-south trending structural boundary. To the west of this ridge, near vertical north-northwest - south-southeast striking faults predominate and have an anastomosing character with relatively small throws, while in contrast, to the east of this ridge, major thrust faults predominate.

Table 1 lists the major tectonic events which have influenced the development of the central Eromanga Basin region. The major structural episodes of the Devonian are best resolved within the southern Adavale Basin region to the east of the Canaway Ridge, as here large-scale deformation of the Devonian sequence has been preserved. The basement structure of this region shows the intersection of two nearly-orthogonal faults sets. Evidence from the stratigraphic thickness of the Devonian Adavale sediments shows that movement on these faults first affected the overlying Adavale sequence during the Lower Devonian. The variation of thickness of the Adavale stratigraphic units over these structures has been used to date the initiation of movement, and shows that the predominantly east-west trending faults formed first in the Lower Devonian. These faults are interpreted to indicate a Lower Devonian period of north-south compression. The second phase, interpreted as an east-west compression, commenced in the Middle Devonian, producing the predominantly north-south trending thrust faults. This compression continued to form the troughs characteristic of the southern Adavale Basin.

The Tertiary Winton compressional episode extensively reactivated faults within the region, and these reactivations are well recorded in the structural deformation of the Eromanga sequence. This Tertiary compressional episode reactivated faults on either side of the Canaway Ridge, producing significantly different structures within the Eromanga sequence.

Basement fault construction method

Davidson (1986) discusses a construction method for deriving the geometry of the underlying listric fault from the form of the roll-over produced during extensional listric faulting. Davidson's method, however, assumes flexural slip-folding which is inappropriate for modelling compressive reactivation of basement faults. A more appropriate model in this case would be simple shear deformation of the block above the fault with no deformation of the underthrust block. To reconstruct the geometry of the basement fault, we require a baseline from which the structural reactivation can be measured and a knowledge of the heave of the fault during the reactivation. The Eromanga sequence provides a convenient reference for this purpose. Using these assumptions, the form of the underlying basement faults responsible for these reactivations can be constructed.

Examples of basement faults

The calculated basement fault geometry of a number of structures within the central Eromanga Basin suggests that there are two styles of faults which have been reactivated. The Paradise Fault reactivation profile (Fig. 2) displays a form which is characteristic for the reactivation of a listric-form fault. The geometry of the constructed basement fault displays the fault soling out to an approximately horizontal attitude at a depth of approximately 17 km.

Figure 3 shows a cross-section of the Jackson-Naccowlah structure (Nelson, 1985), and the form of the underlying basement fault which produced this ramp-anticlinal reactivation. The basement fault has a listric form, becoming almost horizontal at a depth of approximately 15 km. In this respect it is similar to the structures seen to the east of the Canaway Ridge.

The Tintaburra structure, in contrast, has resulted from the reactivation of a near-vertical fault within the basement, producing a structure which is more closely localised around the fault. The Harkaway Fault (Fig. 1) also displays a block uplift and rotation with little deformation within the block.

Two basement fault geometries have been identified in the central Eromanga Basin, and they produce different reactivation structures. The geometry of these underlying basement faults and the timing of the compressive tectonic episode relative to the hydrocarbon migration are important factors in considering the prospectivity of the Eromanga sequence.

TABLE 1

| TIME & TECTONIC PHASE | TECTONIC ACTIVITY | INTERPRETED ORIENTATION |
|---|---|---|
| LATE ORDIVICIAN TO EARLY SILURIAN | REGIONAL META-MORPHISM | NW-SE COMPRESSION |
| LATE SILURIAN | IGNEOUS EMPLACEMENT | |
| SILURIAN? | EROSION | |
| DEVONIAN ADAVALE | FORELAND BASIN DEVELOPMENT | N-S STRIKE |
| LOWER DEVONIAN | BASEMENT THRUSTING | N-S COMPRESSION |
| LATE DEVONIAN TO CARBONIFEROUS | THRUSTING & BASIN FOLDING | E-W COMPRESSION |
| CARBONIFEROUS | EROSION (ICE SHEET?) | |
| PERMIAN DARALINGIE | COMPRESSIVE REACTIVATION | NE-SW |
| TRIASSIC NAPPAMERRI | COMPRESSIVE REACTIVATION | NW-SE |
| JURASSIC-CRETACEOUS EROMANGA | REGIONAL DOWNWARP | |
| TERTIARY WINTON | COMPRESSIVE REACTIVATION | NNE-SSW |

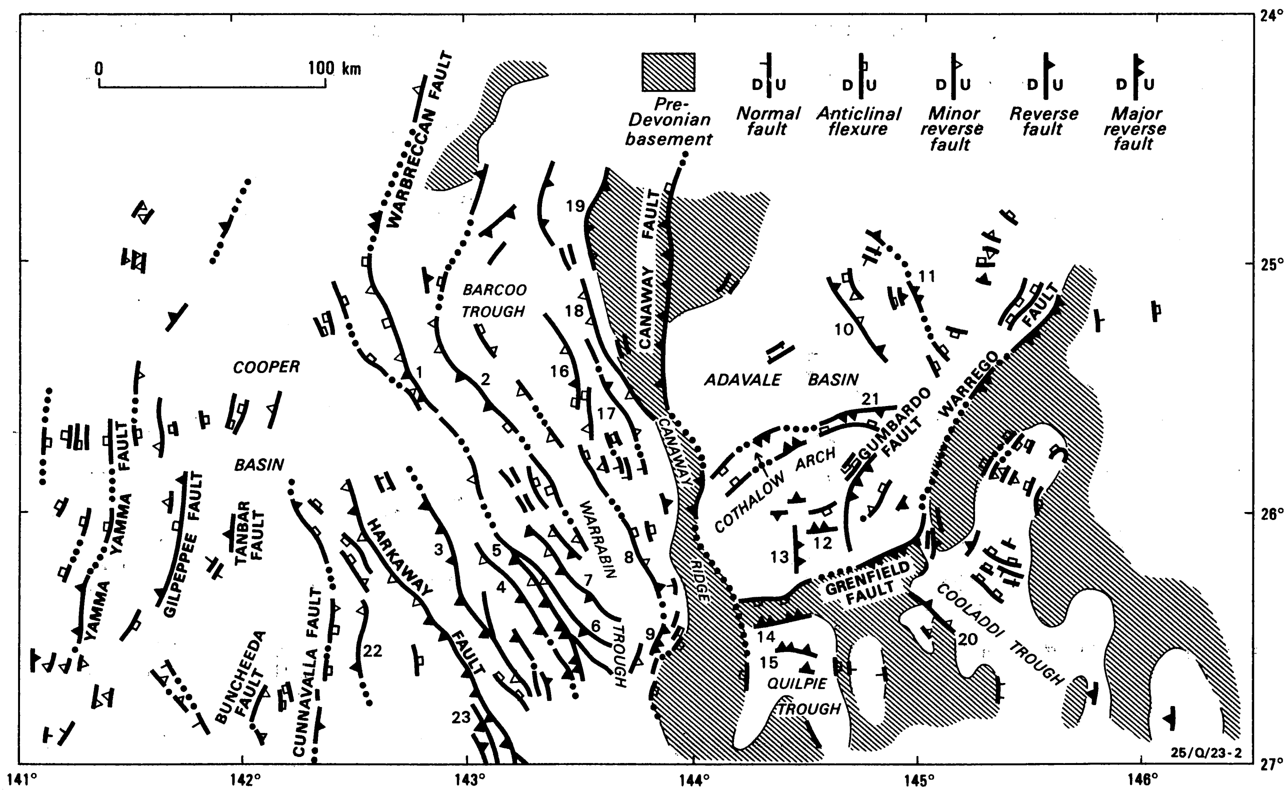


Figure 1 Major faulting within the central Eromanga Basin region (after Finlayson and others, 1986), showing the marked change in character of the faulting on either side of the Canaway Ridge.

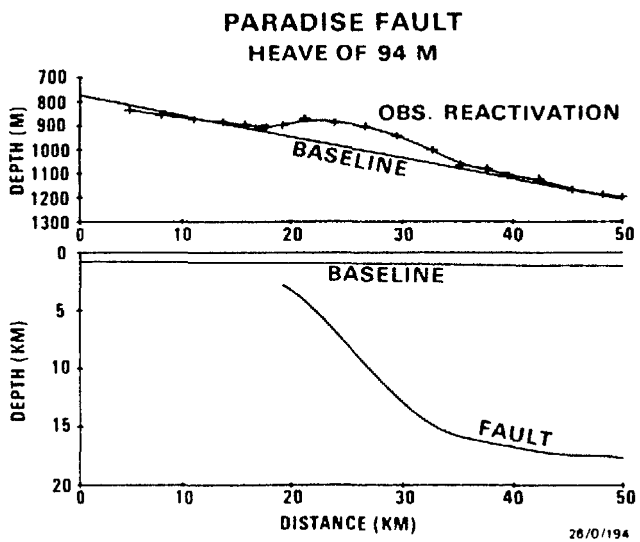


Figure 2 The profile of the Cadna-Owie reflection event within the Eromanga sequence over the Paradise Fault, and the calculated geometry of the basement fault responsible for this structure.

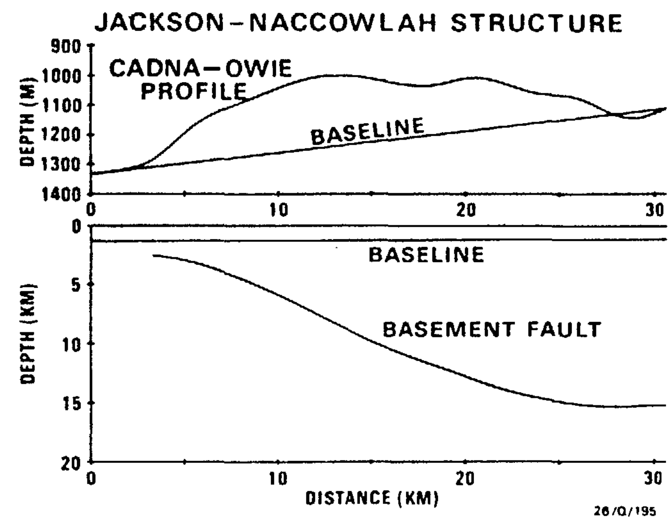


Figure 3 The profile of the Cadna-Owie reflection event over the Jackson-Naccowlah structure (after Nelson, 1985), and the calculated basement fault geometry.

# The NASA/Australia remote sensing experiment

C J Simpson, BMR

In late 1984 the CSIRO received an offer from the US National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory (JPL) to bring their advanced remote sensing research aircraft to Australia for a joint research project in this environment. The offer arose because of the high standing of Australian geological remote sensing research.

Primary costs for the project were to be carried by Australian participating organisations. The CSIRO Division of Mineral Physics and the BMR jointly provided seed-funding of about one-third of the estimated total costs. Invitations were sent to all organisations throughout Australia known to have an interest in remote sensing. This resulted in the establishment of the US/Australia Joint Scanning Project, jointly managed by CSIRO and BMR, involving NASA, JPL and supported by an additional 22 organisations.

Under this project the NASA C-130 (Hercules) research aircraft and a crew of 19 were brought to Australia for 28 days of mission-flying during October 1985. During that period advanced sensor data were acquired over 54 target areas for various research requirements including mineral and petroleum exploration, rock-type discrimination, hydrogeology, soil salinity, wetlands and rangelands mapping, irrigation, and soil degradation research. All original data acquired for this project are restricted to participants for a two-year period (until November 1987) when it will become publicly available via the Australian Centre for Remote Sensing.

Three advanced sensing instruments were simultaneously operated on the aircraft; recorded wavelengths are shown in Figure 1. The NS001 Thematic Mapper Simulator is an eight-band multispectral scanner, the forerunner of the seven-channel Thematic Mapper (TM) currently operating on the Landsat 5 satellite. The Thermal Infrared Multispectral Scanner (TIMS) instrument is the only prototype in existence which records six channels across the thermal infrared region (8-14 micrometres). It is of particular interest to geology because of its ability to discriminate rocks and soil on the basis of silicate content.

The Airborne Imaging Spectrometer (AIS) is the most advanced airborne imaging sensor in existence. Over a swathe width of 32 pixels it records 128 bands per pixel in the wavelength interval 1.2-2.4 micrometres, a region of particular interest for differentiation of minerals in rock and soil. Because it records a continuous spectrum, the absorption features recorded are diagnostic of the mineralogy. This instrument is the forerunner of similar, more advanced sensors that NASA will place in orbit in 1994.

The BMR Divisions of Continental Geology, Petrology & Geochemistry, and Geophysics established a project to analyse the data acquired for BMR at the following sites:

Mount Isa Region, Qld. - (Eastern Creek Volcanics, Sybella Granite, Mary Kathleen) - to research expressions of mineralogical changes associated with rock types, structure, and metamorphism.

Duchess, Qld - to research differentiation and delineation of phosphatic and non-phosphatic sediments of the Georgina Basin.

Munni Munni, WA - to research the spectral and thermal signatures of basic and ultrabasic rock types.

Palm Valley, NT - in conjunction with detailed airborne geophysics, to attempt to determine whether there are any subtle surface mineralogical changes indicative of gas seepage in the vicinity of the Palm Valley Gas Field.

Leonora, WA - to research expressions of mineralogical changes associated with rock types and structures.

St Ives, WA - to investigate the spectral and thermal expression of surficial weathering phenomena and regolith materials.

Preliminary results of the data analyses indicate considerable success with the airborne instruments for differentiation of flows and sediments within volcanics, detection of phosphatic material, differentiation of gabbroic and ultramafic rocks and subdivision within such complexes.

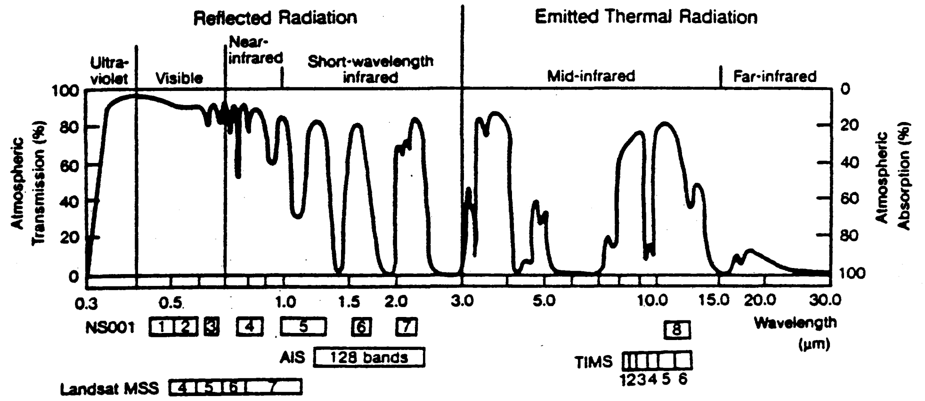


Figure 1. Bands recorded by NS001, AIS, TIMS, and Landsat.

# Applications of regolith studies

C D Ollier, University of New England

Regolith is widespread in Australia, but it is also widely ignored. Geologists tend to be interested in the fresh rock largely concealed by regolith, and soil scientists only in the top metre. Regolith consists of surficial materials and weathering profiles, often tens or even hundreds of metres thick. The bulk of a regolith profile is no-man's-land. To improve our knowledge of regolith we need to answer two main questions. "What is it?" and "Where is it?" The first involves study of regolith material and trying to understand its genesis; the second involves mapping its distribution.

At BMR we experimented with regolith mapping. Using the basic principle of surveying that you should work from the whole to the part, we made a map of all Australia at 1:5 000 000 scale. This is based on existing soil maps, reports, papers and imagery. For much of the country basic data is lacking, so geomorphic features were mapped as a surrogate for regolith, and the units are Regolith-Landscape units. We also produced maps at 1:1 000 000 scale which is more appropriate for practical use. Areas chosen were Hamilton, which has wide variety, and Kalgoorlie, where there is a lot of interest and which was originally thought to be geomorphically simple. Neither area turned out to be especially simple, and the Regolith-Landscape maps are considerably different from pre-existing maps.

Remote sensing is sometimes thought to be a magic aid for mapping. We made use of several kinds, but also made systematic ground-truth tests of some imagery. The degree of reliability was often disappointing, and at present there is no substitute for field work.

Several techniques are available for dating the regolith, and in Australia it is often of an antiquity that startles visitors from the northern hemisphere who equate surficial features with the Quaternary. In the Kalgoorlie area there is stratigraphic evidence for deep weathering long before the Eocene. Elsewhere in Australia weathering profiles have been dated by palaeomagnetism, with ages of 110 Ma in some instances. These old ages are important for several reasons. One is that regolith formation is seen to be on the same time-scale as biological evolution and global tectonics, with all sorts of consequences for its interpretation. Another is that much of the regolith was formed before the onset of aridity in Australia. This has a big impact on groundwater geochemistry and the nature of chemical reactions that made weathering profiles, and may have moved economic elements around the landscape.

Studies of the genesis of regolith materials have made important advances in recent years. The idea that there are unconformities in regolith profiles has been in the literature for a quarter of a century, but the widespread nature of unconformities and the significance in ferricrete-bearing profiles has only recently been appreciated. Similarly the significance of relief inversion seems to be gaining in understanding and acceptance. There is still an unfortunate tendency to think of weathering profiles as vertical columns like test-tubes in which materials move only up or down. Lateral movement is now seen as enormously important, and geochemical landscapes must be considered in three dimensions. Another concept shift of recent years has been the increased realisation that chemical diffusion can do some of the work that was once thought to be done by solutions moving through the regolith. With the vast time-scale now seen to be available this can have important geochemical consequences.

Regolith is made, preserved, or eroded. The distribution of regolith depends on preservation, and on the pattern of erosion. This in turn is controlled by morphotectonics. Some land surfaces in Australia are of great antiquity, but others are stripped of any old regolith. The distribution of regolith depends on tectonic patterns, some of which are of widepread development. Geochemical processes, techniques of geochemical exploration, and indeed economic prospects as a whole vary with these different sorts of geochemical landscapes. The study of regolith should therefore be closely tied to a study of geomorphic history. The BMR team attempted a few studies of geomorphic history, but this is only a dabble into the nature of future work, for this requires more detail than the preliminary work of broad regolith mapping.

Another aspect of regolith work is to try to quantify rates of weathering, diffusion, erosion, sedimentation and all other related processes. We now have some approximate figures for the rate of most processes, but there are still surprises. A knowledge of rates is also important for dealing with environmental aspects of the mining industry.

The regolith is concerned with the existence of some economic deposits, with techniques of mineral exploration, and is a filter through which remote sensing information must pass. It should be a routine component in economic geology. How long can it be routinely ignored?

# Facies model for Australian exploration: passive margin/reef association

P J Davies, P A Symonds, C Pigram & D A Falvey, BMR

Large carbonate platforms are intimately associated with passive continental margins. Off northeast Australia mega-carbonate platforms occur in three separate but related environments; the Great Barrier Reef, the Queensland Plateau and the Marion Plateau, which are separated by the Queensland and Townsville Trough rift basins - major depocentres in their own rights.

The controls on platform development include:

1. Cretaceous rifting which produced the marginal plateau, rift troughs, major boundary faults, and structural highs which form the underlying controls on the location and form of the carbonate platforms.
2. Northward drift of the Australian continent as a consequence of break-up with Antarctica; this underlies the diachronic nature of the onset of reef growth. Temperate carbonates and clastics should therefore underlie the tropical carbonate and clastic facies.
3. Rapid subsidence pulses may have punctuated the normal rift-initiated margin subsidence. Such a pulse in the Pliocene may have triggered reef growth throughout the Great Barrier Reef and contributed to the complete cessation of reef growth on the Marion Plateau.
4. The humid tropical climate of northeast Australia has ensured the formation of fluvio-deltaics with high organic contents proximal to the reefs. Sabkha environments have not evolved.
5. Sea-level oscillations are a major determinant of the style of both reef and clastic sediments, particularly in the Quaternary. The reefs are typical of the transgressive/stillstand scenarios seen in many ancient reef systems. However, the extremely rapid transgressions typical of the Quaternary are matched by the vertical accretion potentials of the reefs. Drowning, as a consequence of rapid transgression alone, is therefore an unacceptable explanation for the demise of the reefs.
6. The physical energy of the system is a fundamental control on growth style and the biological and sedimentological facies produced. The platform-margin reefs of all three platform areas are high-energy systems and the growth style and facies clearly reflect energy gradients in the biological, sedimentary and diagenetic facies on individual reefs as well as across the shelf from reef to reef.

7. Aspects of ocean chemistry may have controlled the sudden and rapid spread of coral reefs at a particular time within any transgressive sea level oscillation. This is clear for the Holocene.

The facies developed in the platforms of northeast Australia should reflect the interplay of the above factors. Temperate and tropical, high and low sea-level facies may be defined on all three platforms (Table 1). The temperate facies include high sea-level shelf-margin carbonates and terrigenous clastics, while the tropical facies include high sea-level reefs, periplatform and slope-onlap facies and low sea-level fluvio-deltaics.

The northeast Australian carbonate platform facies models predict sedimentary and diagenetic facies, and should be applied usefully to the interpretation of platform development elsewhere, for example the Jurassic and Cretaceous of the eastern USA and the Devonian of Western Australia.

Table 1. Summary of development of carbonate platforms in northeast Australia

| AGE | CONTINENTAL SHELF | DEEP SHELF TERRACE | OCEANIC PLATEAU |
|---|---|---|---|
| EOCENE to E.OLIGOCENE | HSL Temp. carbs. LSL Temp. fluv. clastics | Temp. shelf-edge carbs. Shelf onlap. | Temp. shore clastics and shelf carbs. |
| L.OLIGOCENE | DROP IN SEA LEVEL | | |
| E.MIOCENE | Reefs in north. Fluv. clasts. in central GBR. | Reefs widespread. | Reefs on highs. |
| LATE EARLY MIOCENE | DROP IN SEA LEVEL | | |
| M.MIOCENE | Reefs in north. Fl. clasts. in central GBR. | Reefs widespread. | Reefs extensive. |
| L.MIOCENE | DROP IN SEA LEVEL | | |
| PLIO/PLEIST | Reefs spread from north and QP. | Foram. oozes. | Reefs contract. |

# Oil prospectivity of the Middle Proterozoic of northern Australia

M J Jackson, BMR

The McArthur Basin contains an unmetamorphosed, structurally-simple mid-Proterozoic sedimentary sequence. The upper half of the sequence contains formations of stromatolitic dolostone and carbonaceous shale (Fig. 1). Field research, drilling and laboratory studies between 1983-1986 have indicated the presence of potential petroleum source beds within several of the formations; one hole drilled in 1985 intersected a 1 m-thick interval of live oil. These results have significantly upgraded the petroleum potential of the Proterozoic sequence in a large area of the Northern Territory (Fig. 2) - an area previously regarded as non-prospective basement. They also have important implications for adjacent parts of northern Australia which always have been considered as non-prospective for oil also.

The potential source beds are contained within two distinctly different sequences - one with an age of around 1700 Ma (McArthur Group), the other around 1400 Ma (Roper Group). The older sequence consists largely of interbedded stromatolitic, evaporitic carbonate and dolomitic siltstone and shale (Fig. 1). Sedimentary cycles are thin and variable. The sediments were deposited within a complex series of interfingering environments including shallow marine, lagoonal, sabkha, lacustrine, playa and fluvial settings. Rapid fluctuations in the energy of the depositional environment and numerous breaks in sedimentation, from small-scale diastems to local disconformities, are evident. The rocks were intermittently deposited in small rifted basins only a few kilometres across; at other times they were laid down in more extensive broad sags. The potential source beds occur as thin shales within stromatolitic carbonates or as thicker distal lacustrine black shale facies (Table 1).

In contrast, the younger sequence comprises thicker and more uniform facies, lacking obvious stratigraphic breaks. It was deposited in a variety of shallow to deep marine environments. Uniform grainsize, regular mm-scale lamination, and minor wave and current-induced structures characterise the source beds in the Roper Group. These shaley formations are commonly hundreds of metres thick and are separated by formations of shallow-marine, fine to coarse-grained, clean quartz arenite.

Organic matter reflectivity, Rock-Eval pyrolysis, and gas chromatography/mass spectrometry studies have been used to assess the petrographic and geochemical characteristics and petroleum-generating capacity of these potential source beds. The level of maturation of the organic matter of largely bacterial origin, and the potential yields, vary markedly from place to place, especially for source beds in the McArthur Group in the Batten Trough. In some drillholes the organic matter ranges from under-mature near the surface to over-mature at depth (650-700 m). The most impressive source beds found to date are in the Barney Creek and Velkerri Formations - they are comparable in quality to the Jurassic source beds in the North Sea oil fields.

Bitumen globules and oil stains in vuggy porous zones in the Moroak Sandstone, Stretton Sandstone and Looking Glass Formation, and a gas blowout from the Teena Dolomite indicate that migration and entrapment of hydrocarbons has occurred within both the Roper and McArthur Groups. Even with our limited information we envisage two prime reservoir targets: vuggy carbonates underlying stratigraphic breaks (McArthur Group) and porous intervals within thick quartz-arenite formations (Roper Group). The Looking Glass occurrence is an example of the former, the Moroak Sandstone staining an example of the latter. The second type of reservoir appears to be more attractive for very large oil fields, especially as the Roper Group contains large gentle folds. An anticlinal structure near Broadmere with an area of closure of some 100 sq km was drilled in 1984 by Amoco, but all of the sandstones intersected were tight.

Although some of the Roper Group sandstone units are highly porous in outcrop and at shallow depth, initial results from routine permeability/porosity (P/P) measurements on core from the holes drilled so far has been disappointing. There are rare thin zones of coarser grained sandstone with high P/P values, but in general the sandstones are relatively tight (Table 2). Early siliceous and hematitic cements have occluded primary pore spaces in most specimens examined in thin-sections. However, inhibition of pore-filling cements by early migration of hydrocarbons has been recognised in vuggy carbonates in the Yalco and Looking Glass Formations and also in clastics of the Stretton Sandstone and Moroak Sandstone.

In summary, this study has indicated that there is some petroleum potential in the mid-Proterozoic of this area - an area that had previously been largely ignored by petroleum explorers. There are excellent source rocks with impressive generating capacity, and migration and trapping has occurred. In addition, the presence of live oil indicates that, despite the antiquity of the sequence hydrocarbon, accumulations could have survived.

A similar stratigraphic sequence to that of the McArthur Basin is present in the Victoria River region. A limited reconnaissance in 1985 identified a sequence of thick sandstone formations and interbedded shale that is probably the lateral equivalent of the Roper Group. Given the almost complete lack of subsurface information, it is conceivable that some of the thick non-outcropping intervals could also contain potential source beds. This region, and the equally large area between there and the Roper River (Fig. 3) are also worthy of assessment for oil prospectivity. The arrows on Figure 3 point in the direction of inferred increasing prospectivity, that is, to the west of the Lawn Hill and Roper areas.

Table 1 : Potential source beds

| FORMATION | ROCKS | TOTAL ORGANIC CARBON (%) | POTENTIAL (kg/tonne) Rock-Eval |
|---|---|---|---|
| McMinn | thin shales | 0.7-2.9 | 2-15 |
| Velkerri | thick shales | 1.7-7.2 | 8-33 |
| Mainoru | thick shales | 0.8-1.2 | |
| Yalco | thin shales | 0.8-5.4 | 4-33 |
| Lynott | thick shales | 0.2-3.4 | <0.3 |
| Barney Creek | thick shales | 0.2-10.0 | 1-71 |

Table 2 : Selected porosity/permeability measurements

| FORMATION | ROCKS | POROSITY (% bulk volume) | PERMEABILITY (Md) |
|---|---|---|---|
| McMinn | Thin coarse sst | 4-21 | 0.01-44 |
| Bessie Creek | Thin fine quartz sst | 3-15 | 0.10-10 |
| Abner | Thick fine quartz sst | 6-14 | 0.10-100 |
| Limmen | Thick coarse sst | 2-4 | <0.1 |
| Stretton | Conglomeratic sst | 5-16 | ~27 |
| Yalco | Vuggy siliceous dolostone | 1-18 | ~10 |

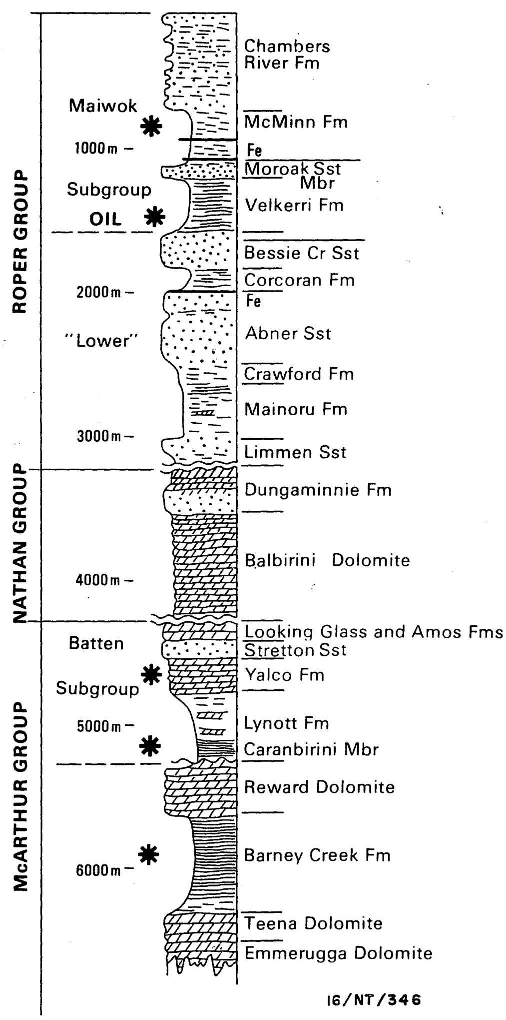


Figure 1. Simplified stratigraphic column of the upper part of the McArthur Basin sequence showing main potential source beds –✱

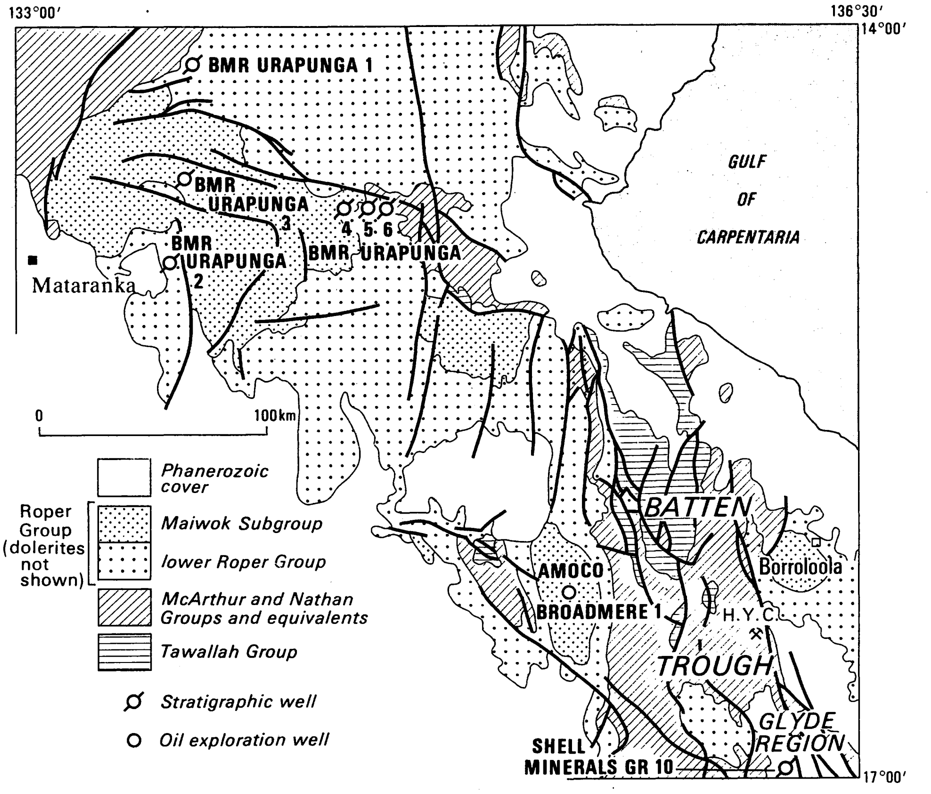


Figure 2. Simplified geology and selected drillholes in Roper-McArthur area

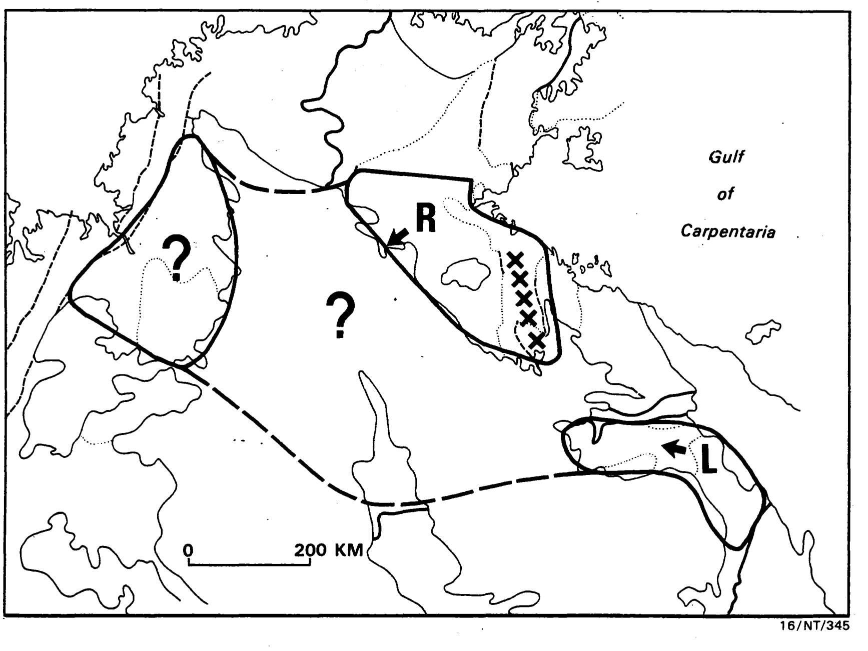


Figure 3. Northern Australia with main geological provinces outlined and areas so far assessed (R Roper-McArthur; L Lawn Hill-South Nicholson; xx is complex Batten Trough). Areas underlain by similar-aged sequences, but not yet assessed, shown as?

Petroleum source rocks: Proterozoic to Tertiary, non-marine to marine

T G Powell, BMR

The formation of anoxic or micro-oxic conditions is necessary for the preservation of oil-prone organic matter and has been related to a variety of climatic, topographic and circulation conditions in marine and non-marine environments. However, within both marine and non-marine environments, there is much variability in the composition of oil-prone organic matter. This can be related firstly to the nature of the primary source material (algal, bacterial or higher plant) and secondly to the depositional conditions and host lithofacies which control the extent and nature of bacterial reworking prior to burial.

The Toolebuc Formation (Cretaceous) of eastern Australia is typical of many marine petroleum source rocks containing Type II organic matter. Biological marker compounds indicate that the organic matter is derived mainly from planktonic sources. The organic matter has been modified by aerobic decay during deposition. This is particularly the case in the carbonate-poor lithofacies where lower organic carbon contents are associated with oxygen-enriched kerogens. In contrast, the kerogens from the carbonate-rich facies are depleted in oxygen and are enriched in sulphur. In the absence of reactive iron, hydrogen sulphide produced by sulphate-reducing bacteria has been incorporated into the organic matter. The geochemical evidence suggests that the organic matter accumulated as an organic ooze which was generally coincident with the redox boundary. Degradation of organic matter was controlled in part by the availability of reactive iron which affected the concentration of dissolved sulphide in the interstitial waters.

The Barney Creek Formation is a potential Proterozoic (1690 Myr) source rock in the McArthur Basin. It was deposited in a lacustrine or lagoonal environment. As is typical of many lacustrine source rocks, the organic matter is of Type I. The primary photosynthetic biomass appears to have been a mat-forming organism of presumed cyanobacterial affinities and the host lithology is dolomitic. There is evidence of incorporation of sulphur into the organic matter during diagenesis. Apart from the ubiquitous hopanes, the main bacterial biomarkers in most samples can be assigned to archaebacteria (possibly methanogens). High abundances of these latter biomarkers are typical of alkaline lake environments. A few samples contain abundant eubacterial biomarkers (iso- and anteiso-alkanes) and lower amounts of pristane and phytane which represent the primary photosynthetic biomass. This indicates more extensive bacterial decay of the primary organic matter prior to preservation. This effect is seen to a greater degree in the source rocks of the Velkerri Formation (ca 1400 Myr) in the McArthur Basin. Both the source rock and its derived oil are dominated by iso- and anteiso-alkanes; pristane is in very low abundance and phytane is absent. The source rock is predominantly clastic, the organic matter is Type II and is depleted in organic sulphur.

In non-marine environments, such as the Permian Jurassic and Tertiary sequences of southeastern Australia, the oil potential of terrestrial organic matter can be related to the nature of the land flora and the enrichment of oil-prone components of terrestrial organic debris during bacterial degradation. The hydrocarbon potential of terrestrial organic matter is explicable in terms of a mix of hydrogen-rich and hydrogen-poor components. Permian coals are generally depleted in hydrogen compared with their Jurassic and Tertiary counterparts. In the Permian of the Cooper Basin, dispersed organic matter and coals are of similar composition, whereas in the Jurassic of the Eromanga Basin dispersed organic matter is enriched in hydrogen compared with adjacent coals. These differences reflect variations in the degree of bacterial degradation of wood and cellulose during preservation and the extent of the contribution of bacterial remains to the preserved organic matter. Thus, all Australian non-marine oils contain abundant bacterial biomarkers. This indicates that bacterial modification of the source plant material is a significant process in the formation of oil source rocks in the non-marine environment.

The association between the composition of sedimentary organic matter and the conditions of preservation transcends the classification of organic matter as oil-prone or gas-prone and of oils as marine or non-marine. It enables the prediction as to whether the primary oil product is paraffinic, paraffinic-naphthenic or aromatic-asphaltic and the likely distribution of hydrocarbon markers. This has implications for thermal modelling of hydrocarbon generation and the use of the chemistry of oil shows for determining potential source beds and migration paths.

# Improving seismic signal-to-noise ratios by non-linear stacking

P.L. McFadden, B.J.Drummond and S. Kravis, BMR

Geophysical data are often noisy, so multichannel observations are usually made and the data stacked to extract the signal. The simple linear stack is most commonly used; it is the arithmetic mean of the observations. If the noise is Gaussian the linear stack is optimal: it is both linear and unbiased and has the smallest variance of any linear, unbiased estimator. However, stacks do not always need to be linear and unbiased. For example, in many seismic applications it is necessary only to identify genuine arrivals and measure their onset times. Under such circumstances linearity and lack of bias are unimportant. In addition, seismic data are often not well-behaved, and the noise distribution is frequently non-Gaussian. For example, one problem is noise spikes which highly perturb the linear stack. In order to overcome this problem, other stacking procedures such as the α-trimmed stack, the median stack, and the weighted stack are often used. Each of these stacks is relatively expensive in computing time but they are very resistant to noise spikes. Although they overcome the problem of noise spikes, they do not address the fundamental question of what is the best stacking process for the particular application.

The Nth-root stack was originally introduced by Muirhead (1968) to deal with teleseismic data polluted by noise spikes. Although it is not as resistant to spikes as, for example, the median stack, it is better than the simple linear stack and requires less computation than the median stack. It is a nonlinear process, but it has some other very powerful characteristics which make it useful in other applications. If we have m observations $t_i$ then the result R of an Nth-root stack of these observations is defined by

$$R = \left( \frac{1}{m} \sum_{i=1}^{m} \{t_i\}^{1/N} \right)^N$$

with the sign of the signal preserved throughout the process. Because the Nth-root stack is nonlinear, one cannot write a general transfer function for it. Consequently its behaviour has not previously been understood and most applications to date have been restricted to reducing the effects of incoherent noise spikes. The behaviour has now been strictly determined for several cases including the asymptotic (large m) case (McFadden & others, 1986). From these its general behaviour may be determined, and is demonstrated in Figures 1 and 2 for synthetic and real data respectively.

An Nth-root stack gives a biased estimate at each point in the record, the bias being such that the expected result is less than the signal. Because it is nonlinear the amount of bias depends in a complicated way on the signal-to-noise ratio (SNR), the number of channels, and the noise distribution, with the bias increasing as the SNR decreases. This dependence on the SNR at each point on the waveform produces distortion, seen in Figure 1l d-f. Where the signal is very small signal destruction can occur, as exemplified by the destruction of the subsidiary side peaks, especially on the right-hand wavelet, in Figures le and 1f. However, the distortion has the effect of sharpening signal wavelets without any time shift.

Dynamic noise reduction is another property of the Nth-root stack. When the SNR is large an Nth-root stack is less effective in reducing the noise than a simple linear stack: if the variance of the noise is $s^2$ then the variance of a linear stack is $(s^2/m)$ and that for an Nth-root stack is slightly greater than this. However, this is relatively unimportant with a large SNR. When there is no signal the variance of an Nth-root stack decreases dramatically to $(s^2/m^N)$, while the variance of a linear stack remains unchanged. Thus an Nth-root stack provides very powerful suppression of background noise with reasonable noise suppression in the presence of a signal. This enhances the contrast between times when there is a signal and times when there is not; eg. in Figure 1f, the background noise in regions away from the wavelets is almost completely removed.

Figure 2 demonstrates the application of the Nth-root stack to real, 12-fold seismic data contaminated by bursts of noise on single channels. Noise such as this behaves in the same way as spikes and in the linear stack is still evident despite its 12-fold reduction, requiring extensive trace editing before further processing. In the 2nd-root stack the noise is greatly reduced; in the 4th- and 8th-root stacks it is effectively removed. Note also the sharpening of the reflection events. The distortion for the 2nd- and 4th-root stacks is not great, indicating that even though the Nth-root process is nonlinear this does not necessarily restrict further processing.

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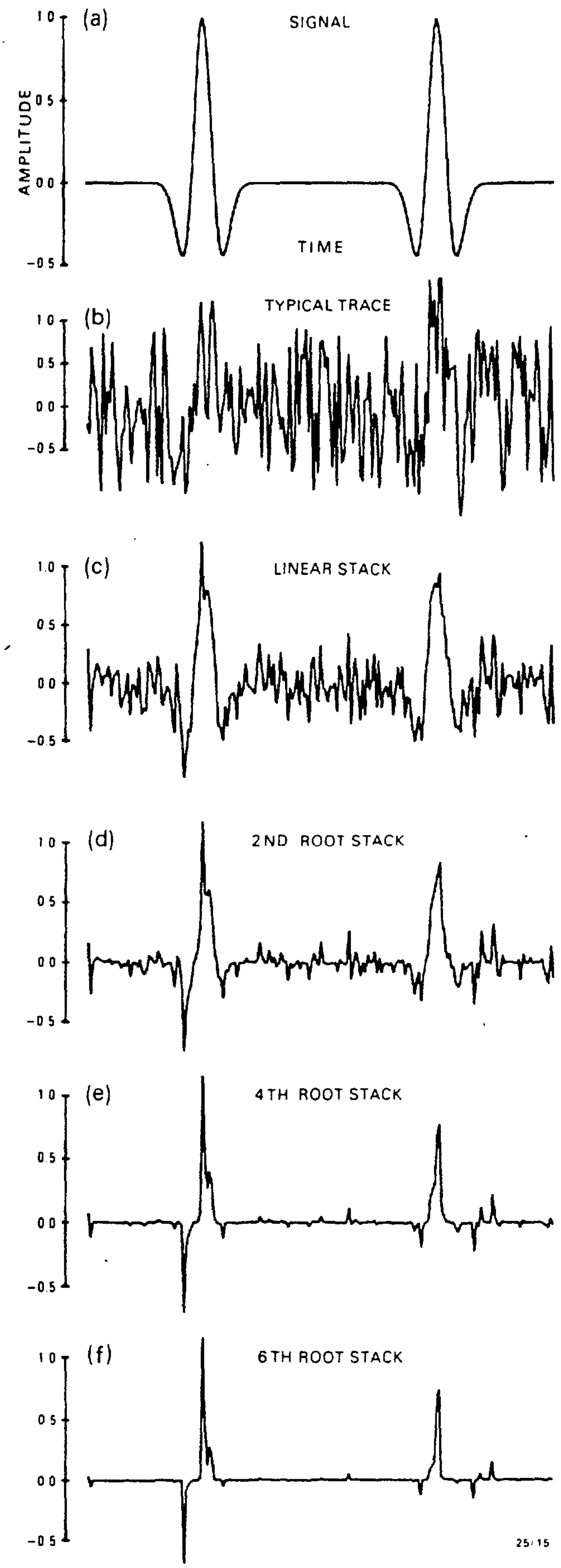


**Figure 1:** 1a shows a trace in which the signal is represented by two identical wavelets. Twelve such traces were generated and random noise added to each; an example of a noisy trace is shown in 1b. The traces were then stacked using linear, 2nd-, 4th-, and 6th-root stacks (1c, 1d, 1e and 1f resp.)

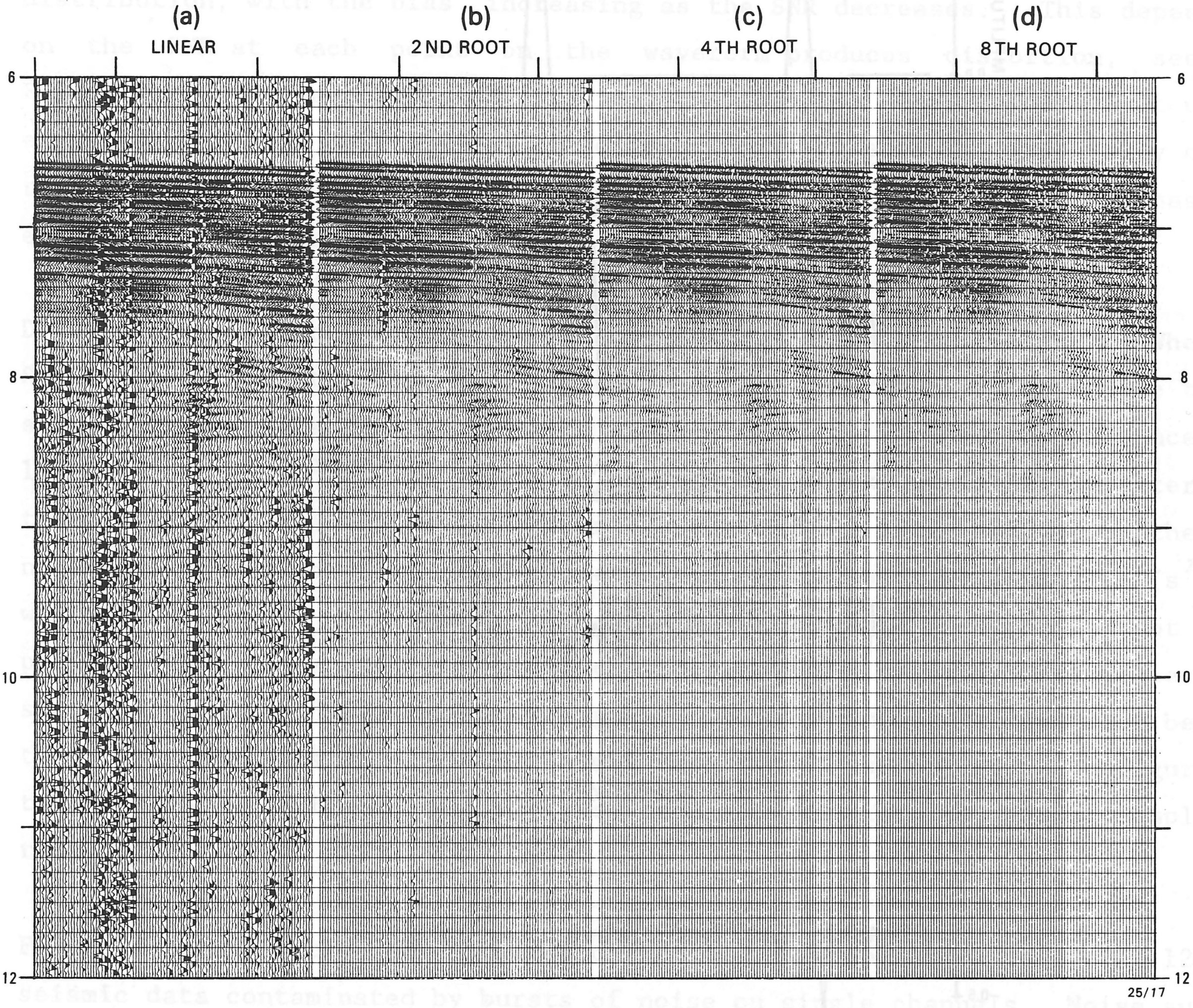


**Figure 2**: 12-fold stacks of reflection data from the Solomon Sea. (a) Linear stack, (b) 2nd-, (c) 4th-, and (d) 8th-root stacks. The data contain random bursts of noise on single channels. In all displays the amplitudes have been normalised for display purposes.

# New seismic results from the central Australian region and their implications for basin evolution

C Wright, B R Goleby & C D N Collins, BMR

In 1985, the Bureau of Mineral Resources undertook a program of seismic reflection and refraction profiling across the Arunta Block and the Ngalia and Amadeus Basins in central Australia (Fig. 1). The primary objective of this seismic work is to enable constraints to be placed on the deep structure and tectonic evolution of the central Australian region. It is now recognised that the understanding of the development of intracratonic sedimentary basins requires the mapping of geological structures below the sedimentary section into deep basement, The near-vertical-incidence profiling was therefore recorded to times of 24s to enable reflections from the lowermost crust to be identified. This paper summarises the tectonic problems associated with the evolution of the central Australian region that have been emphasised by earlier geological and geophysical studies (Lambeck, 1984; Shaw & others, 1984). A few of the more significant results of the seismic profiling will be presented; these preliminary results have stressed some difficulties in interpretation that require new avenues of seismological research. Finally, consideration will be given to how seismic imaging of the entire crust may assist in understanding the deformational history of the central Australian region and possibly in providing information on petroleum migration.

The main features observed along the main north-south profile (Fig. 1) have been inferred by examination of both the single-shot records and the brute stacks (Fig. 2). Statics problems are particularly severe in central Australia due to very deep weathering. The single-shot records were therefore used to determine if the stacking was removing important reflection information. The stacking does preserve the most significant reflection features but degrades some of the bands of high-frequency energy. Strong reflectors within deep basement occur below the Northern Arunta Province and the Ngalia Basin and suggest that the thrusting of the Arunta rocks over the northern margin of the Ngalia Basin involved the entire crust (Wright & others, 1986; Goleby & others, 1986). The significance of the strong bands of reflectors at times between 6 and 10s beneath the Redbank Zone remains to be determined. There is a superficial resemblance to the reflections in the sedimentary section below the Missionary Plain to the south and that suggests a possible sedimentary origin of these rocks at depths below 18 km. Shaw & others, (1984), have emphasised the importance of the tectonic movements in the Arunta rocks in controlling the deformation of the Ngalia and Amadeus Basins; the preliminary seismic results provide abundant evidence of this.

The seismic refraction survey on the Arunta Block (Fig. 1) shows that the seismic velocities are about 6.2 km/s on average to depths 31 km, where they increase rapidly to 7.2 km/s. This boundary may correspond to the base of the reflecting zone that ends at times of about 10s below parts of the Arunta Block (Fig. 2). No arrivals with velocities greater than 8 km/s are observed. However, late arrivals at offsets between 200 and 240 km may be wide-angle reflections from the crust-mantle boundary at about 55 km depth. This result is not easy to reconcile with a physical model of the evolution of the central Australian region (Lambeck, 1984) or with other geophysical data (Lambeck & Penney, 1984) that suggest a thin crust under the Arunta Block near the western end of the refraction profile (Fig. 1); rather complex crustal models involving some subducted crust may have to be invoked.

Experimental seismic profiles in the form of expanding reflection spread, large offset shots and refraction tomography have been undertaken in the Arunta Block and across the Missionary Plain in the northern part of the Amadeus Basin. This additional work is providing information supplementary to the results of near-vertical-incidence profiling on faulting, fracture content, seismic velocity variations and the lithology of rocks throughout the crust.

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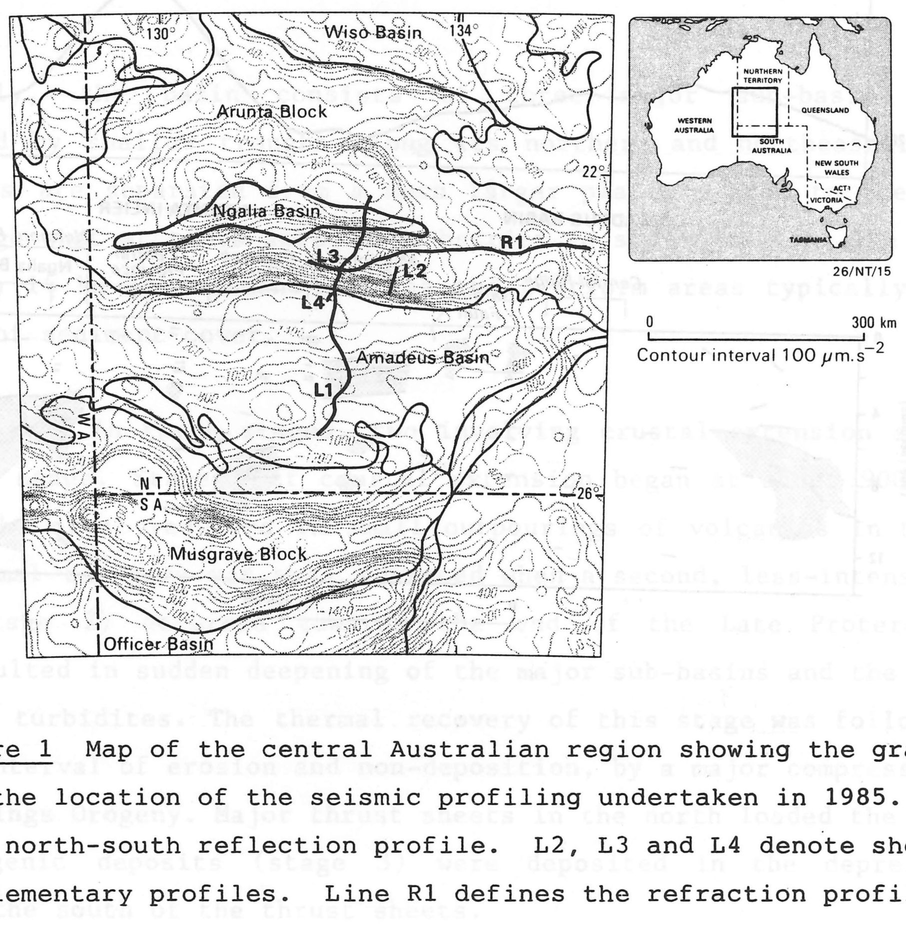


Figure 1 Map of the central Australian region showing the gravity anomalie and the location of the seismic profiling undertaken in 1985. L1 denotes t main north-south reflection profile. L2, L3 and L4 denote shorter supplementary profiles. Line R1 defines the refraction profile within the Arunta Block.

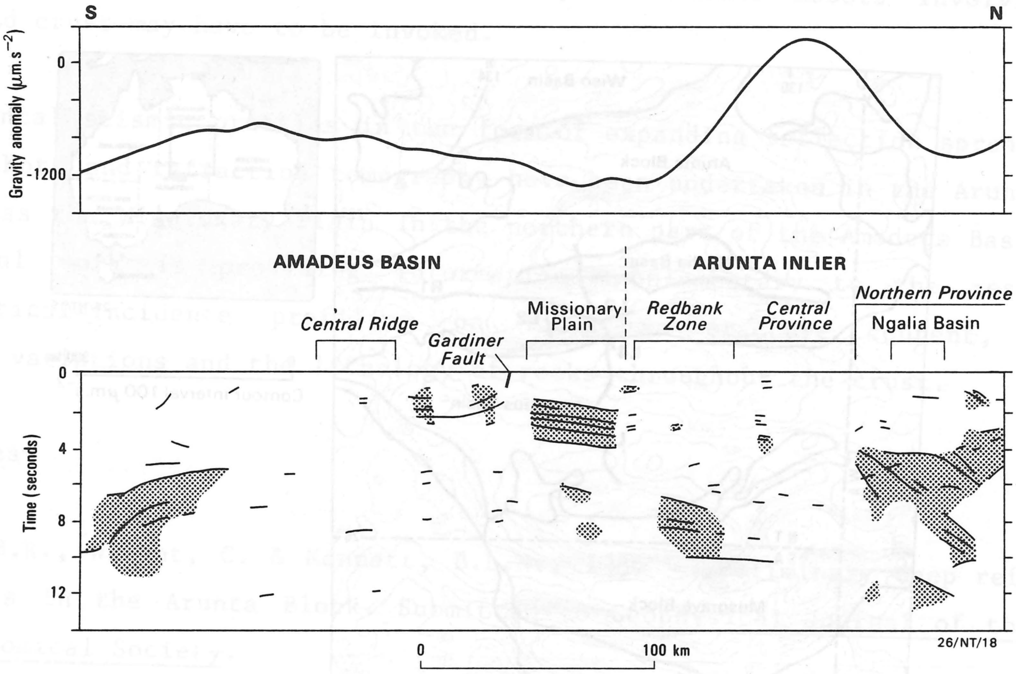


Figure 2 Line diagram showing the main deep crustal features observed along reflection line 1 of the central Australian seismic experiment (Fig. 1) with the observed gravity profile. In the line diagram only the most prominent features have been shown, and the shading denotes regions of strong bands of reflected energy. Vertical exaggeration is 2.8:1.

# The Amadeus Basin : a new perspective

J F Lindsay, R J Korsch & the Amadeus Basin Group, BMR

The Amadeus Basin is a broad, relatively shallow, crustal depression lying at the centre of the Australian continental block. The basin, which contains a Late Proterozoic to mid-Palaeozoic succession has been the focus of an integrated three-year BMR program. The program has involved an interdisciplinary group which has carried out detailed sedimentological studies of key depositional sequences throughout the succession and developed a refined biostratigraphy to provide a basis for the development of a larger-scale three-dimensional perspective of the basin.

Morphologically, the basin consists of three major sub-basins that are interconnected by shallow troughs along its northern and northeastern margins. The sub-basins are separated from a much larger platform area to the south and west by a ridge that at times acted as a barrier to sedimentation. The sub-basins contain up to 14 km of sediment whereas the platform areas typically have less than five km of sediment cover.

The basin evolved in three stages, two involving crustal extension and a final compressional stage. Stage 1 of crustal extension began at about 900 Ma. Rapid thinning of the crust resulted in small outpourings of volcanics in the initial grabens. Thermal recovery was well advanced when a second, less-intense, crustal extension (stage 2) occurred towards the end of the Late Proterozoic. The extension resulted in sudden deepening of the major sub-basins and the subsequent deposition of turbidites. The thermal recovery of this stage was followed, after a prolonged interval of erosion and non-deposition, by a major compressive event, the Alice Springs Orogeny. Major thrust sheets in the north loaded the crust, and thick synorogenic deposits (stage 3) were deposited in the depression that developed to the south of the thrust sheets.

The style of sedimentation and major sequence boundaries within the basinal succession was controlled to a large degree by basin dynamics. Apparent sea level rose with the initiation of each extensional stage and then gradually declined as sedimentation began and the peripheral bulge appeared, peaked and declined. Following the demise of the peripheral bulge, relative sea level again appeared to rise as thermal subsidence became the dominant controlling mechanism. As a consequence, a predictable depositional pattern occurred. During the major sea-level cycle following initial crustal extension, shallow marine clastics were followed by evaporites as the peripheral bulge developed and the supply of clastic sediments was gradually restricted. The evaporites were then replaced by carbonates which shallowed upward to an erosional surface as the peripheral bulge peaked and began to decline. As thermal recovery began to dominate, mature shallow-marine clastics were deposited over the major sequence boundary.

Sedimentation throughout both stages of crustal extension and subsequent thermal recovery occurred in large part at or near sea level. In general sediment supply equalled or exceeded the depositional space created. During stage 1, sedimentation occurred basin-wide. However, during extension and early recovery of stage 2, sedimentation was restricted to the major sub-basins while platform areas became areas of erosion or sediment bypass.

The two stages of crustal extension and thermal recovery produced large-scale apparent sea-level effects. Eustatic sea-level cycles appear to be superimposed on these curves. Thus overall sedimentation patterns were determined by basin dynamics whereas most of the small anomalies in sedimentation and many of the less obvious sequence boundaries relate to eustatic sea-level change.

Australia's potential for further petroleum discoveries
(from May 1986)

D J Forman, BMR

A new method, called the "Trap-by-Trap Creaming Method", has been developed in BMR for the assessment of undiscovered petroleum resources. The statistical basis for the method has been described by Forman and Hinde (1986) and this paper summarises the geological basis for the method and the results of an assessment of Australia's petroleum potential.

In the new method, the size of each undiscovered field is estimated using the equation V=A.V/A; where V is the field size and A is the closure area of the trap. The ratio V/A is referred to as the "retention factor". Because the values of these parameters are not known with any certainty before drilling, they are input as probability distributions that change in a systematic fashion from one prospect to the next. This systematic change is estimated by modelling the creaming phenomenon which is the diminishing effectiveness of exploration with exploration effort.

The "retention factor" is proportional to the quantity of hydrocarbons, expressed as a vertical height, that were generated in the sedimentary source rocks and have migrated upwards to be caught and retained in individual trap-types (Fig. 1). In areas where discoveries have been made, the "retention factor" of each field can be calculated by dividing the field size (V) by the closure area (A) of the structure. A plot of the log of the "retention factor" (log V/A) versus discovery sequence number for fields within a particular trap-type (for example, anticlines: Fig. 2) generally indicates either a horizontal or a weakly-declining trend; and extrapolations of this trend may be used to determine the "retention factor" for undiscovered fields. Alternatively, the "retention factor" (vertical height of hydrocarbons) may be estimated by geochemical and geological modelling. Where both historical and geochemical data are lacking, analogue data may be used to provide estimates of the "retention factor".

A plot of the log of the area of closure of a trap (log A) versus sequence number for prospects of a particular trap-type (Fig. 3) generally forms a strong declining trend that can be extrapolated to indicate the likely closure areas of the undrilled prospects. Where seismic maps are available, the closure area of each undrilled prospect can be measured directly.

BMR, in collaboration with State Mines Departments and private companies, has recently completed an assessment of the petroleum potential of the Phanerozoic sedimentary rocks of the Australian continent. The assessment includes both onshore and offshore areas, but excludes Australia's remote offshore territories. The first step in the assessment was to subdivide these rocks into a number of independent petroleum systems (Ulmishek & Harrison, 1984) within which, because of barriers to migration, the processes of generation and migration are essentially independent of each other.

The assessment was carried out using new computer programs (Hinde, 1986) that simulate drilling each trap-type in each independent petroleum system and add together the undiscovered resources to obtain totals by region (Figs. 4, 5), by basin (Figs. 6, 7), by age (Figs. 8, 9), or by trap-type (Figs. 10, 11). Data input for each independent petroleum system include: the parameters of the straight-line models fitted to the log V/A versus discovery number and the log A versus sequence number plots; existence risks; success rate; the proportion of oil to gas; and minimum and maximum field-size cut-offs.

The results illustrated in Figure 4 indicate that there is potential in Australia to find somewhere between an additional 1000 and 5000 million barrels of crude oil, with an average value of 2400. As indicated in Figure 5, sales gas potential is considered to lie between 10 and 45 trillion cubic feet, with an average value of 23 TCF. These figures refer only to conventional petroleum contained in structures or stratigraphic traps that have not previously yielded oil or gas. A proportion of this oil and gas will occur in fields that would be sub-economic to produce at today's prices.

The average estimates of undiscovered crude oil and sales gas in what we consider to be our key sedimentary basins are shown in Figures 6 and 7. Figure 8 shows that the Jurassic to Recent sequence is believed to have the greatest potential for further oil discoveries whereas Figure 9 shows that the Permian and Triassic sequence is believed to have the greatest potential for further gas discoveries. Figures 10 and 11 show that BMR considers that fault traps, faulted-anticline traps, and stratigraphic traps will be of increasing importance in future exploration for petroleum in Australia.

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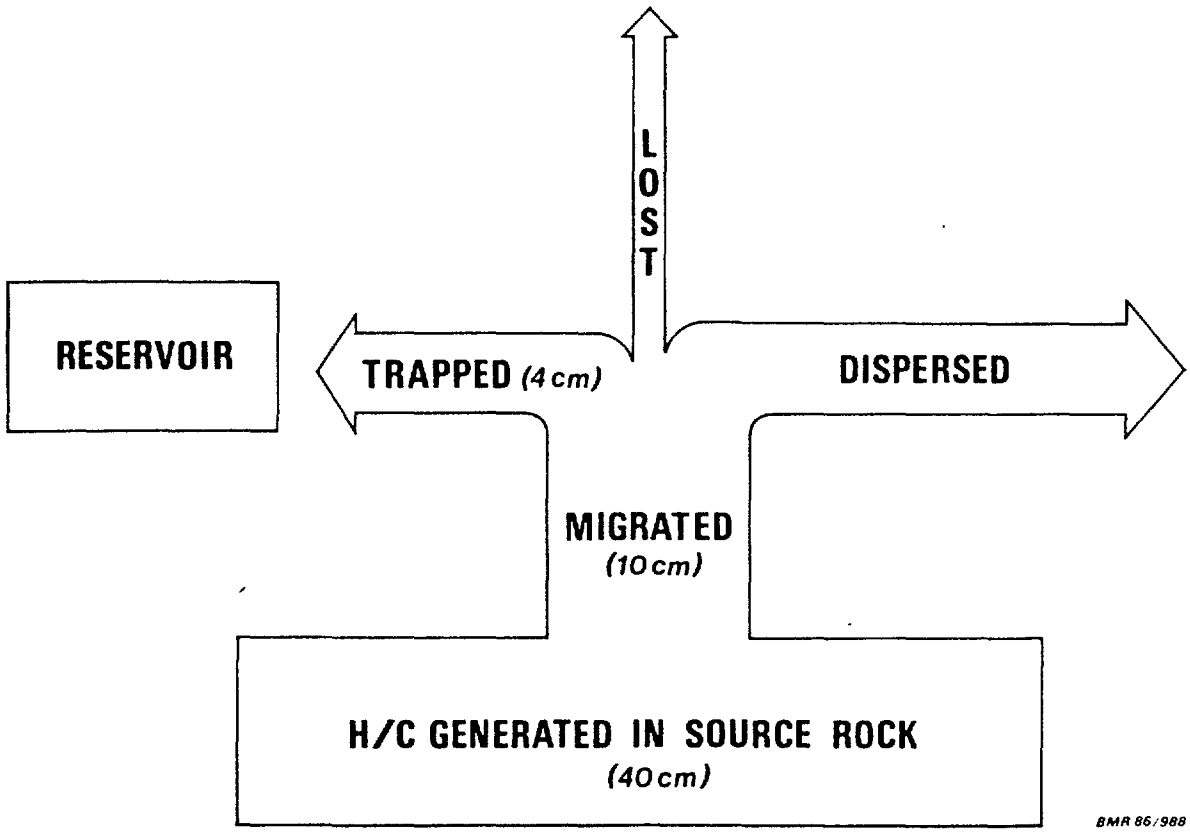


Fig.1 Diagram illustrating how the height of hydrocarbons retained in a trap is dependent on generation in the source rocks, drainage efficiency, and the quality of the seal (Modified after McDowell, 1975, fig.1).

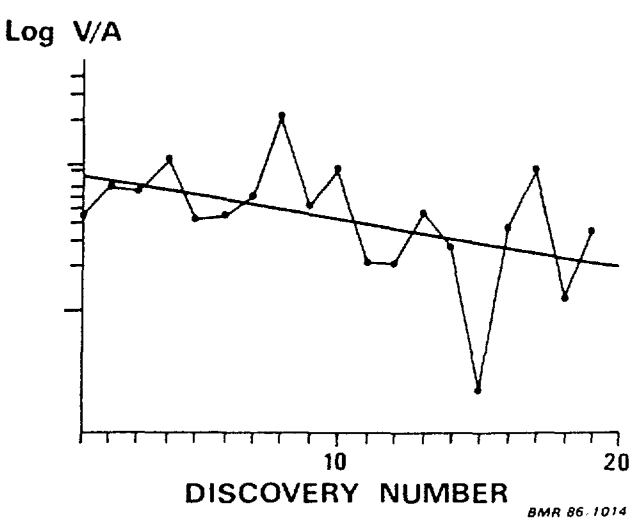


Fig.2 Logarithm of V/A for oil and gas fields contained in anticlinal traps in an onshore area plotted in sequence of discovery.

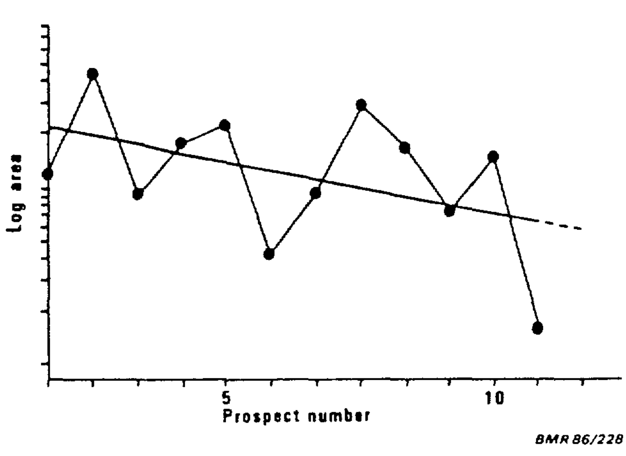


Fig.3 Logarithm of closure area of fault traps in an offshore area plotted in sequence of drilling.

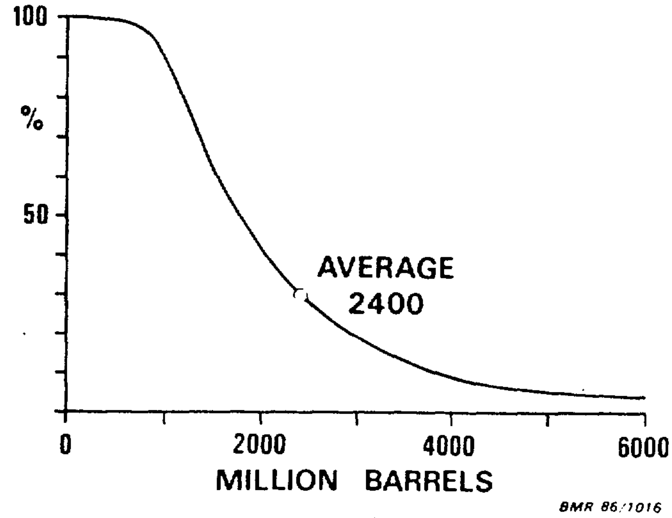


Fig.4 Australia's undiscovered oil resources, as at 5/86.

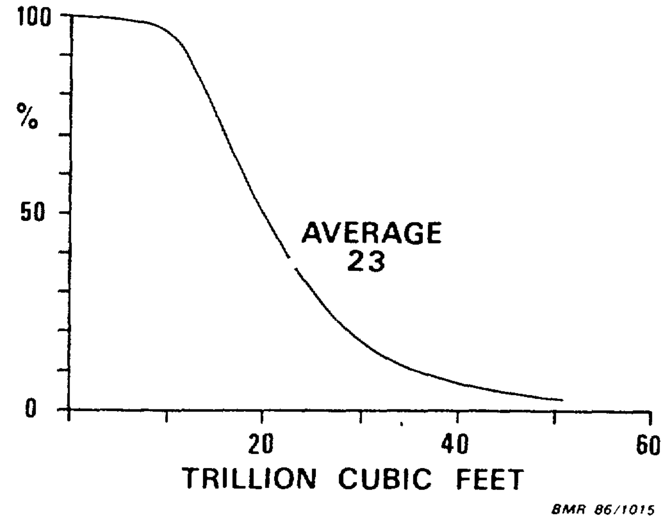


Fig.5 Australia's undiscovered sales gas resources, as at 5/86.

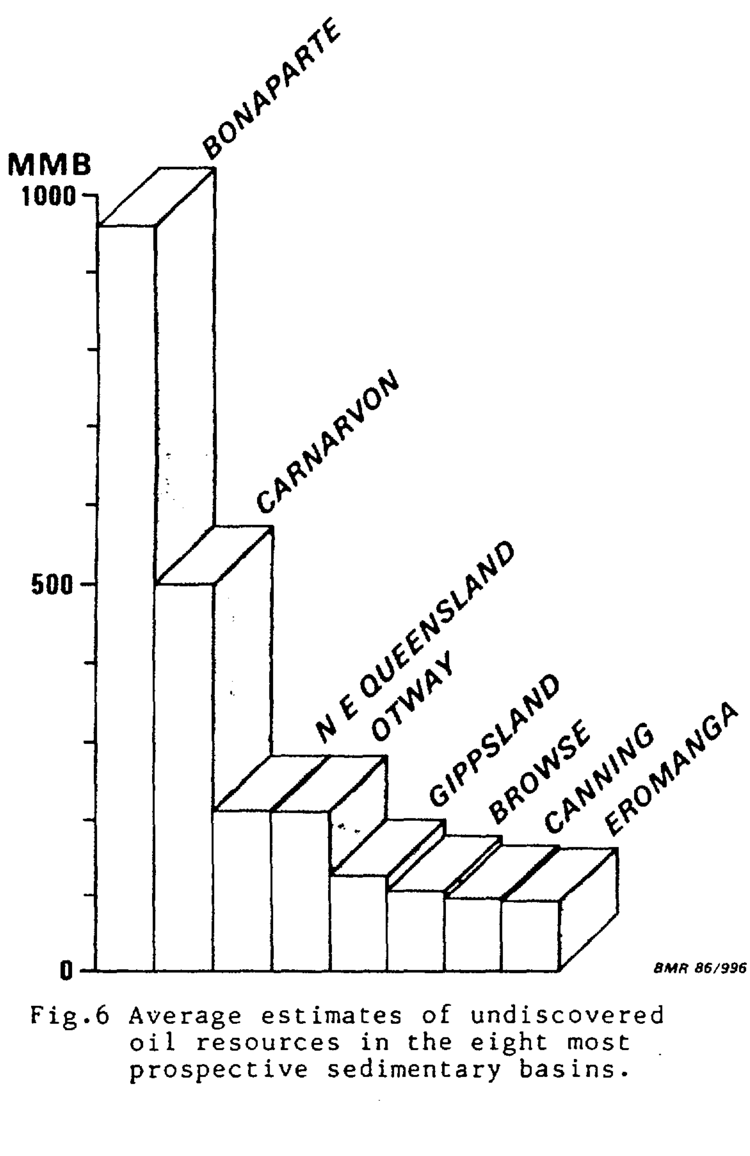


Fig.6 Average estimates of undiscovered oil resources in the eight most prospective sedimentary basins.

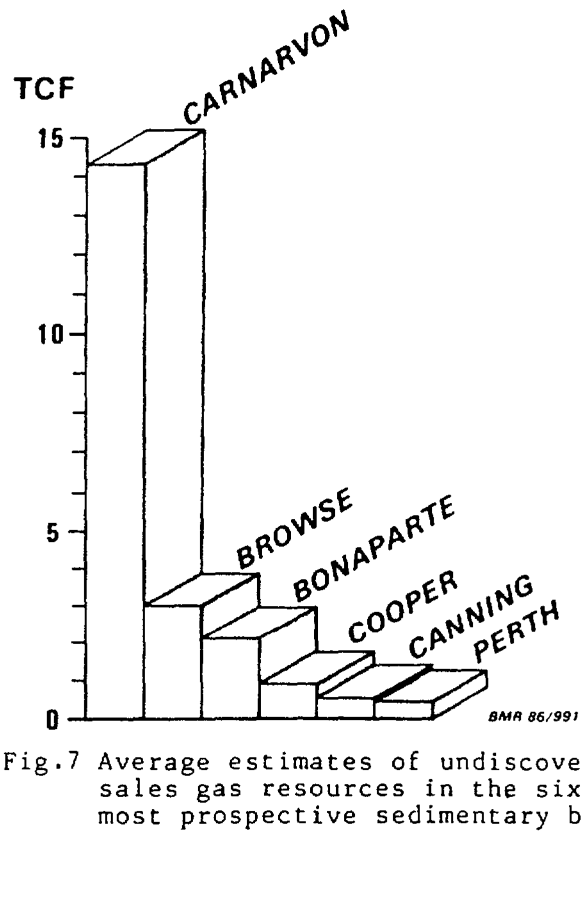


Fig.7 Average estimates of undiscovered sales gas resources in the six most prospective sedimentary basins.

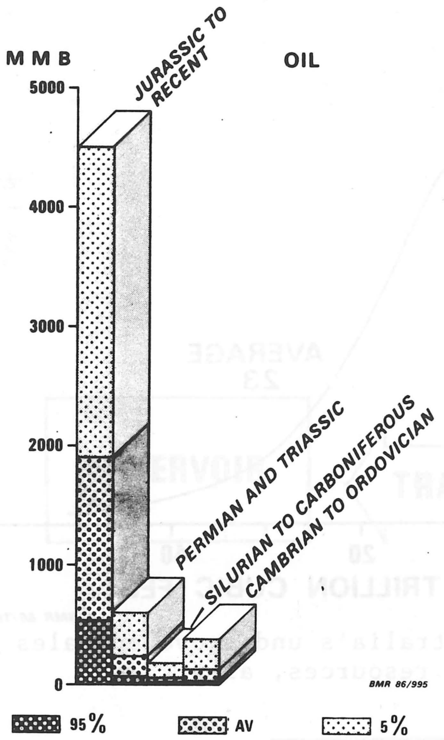


Fig.8 Estimates of undiscovered oil resources in four, continent-wide sedimentary sequences. Estimates shown are the average value and the 95 and 5 percent probability values.

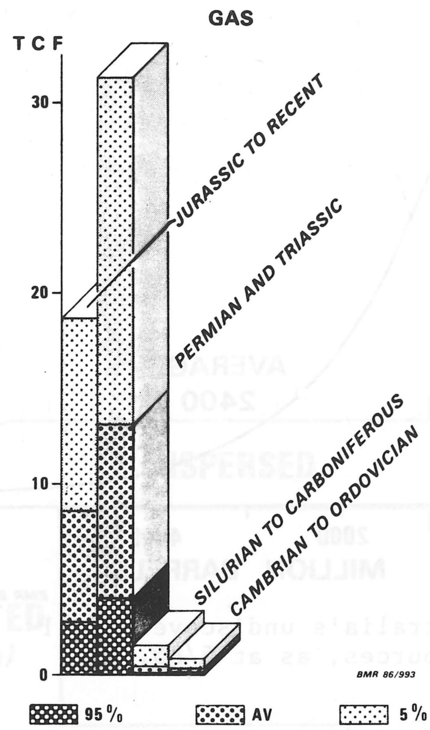


Fig.9 Estimates of undiscovered sales gas resources in four continent-wide sedimentary sequences. Estimates shown are the average value and the 95 and 5 percent probability values.

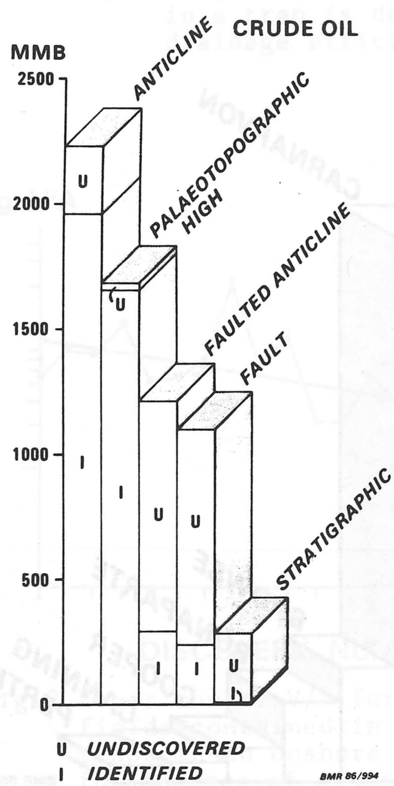


Fig.10 Identified resources of crude oil (I) and average estimates of undiscovered resources (U) by trap type.

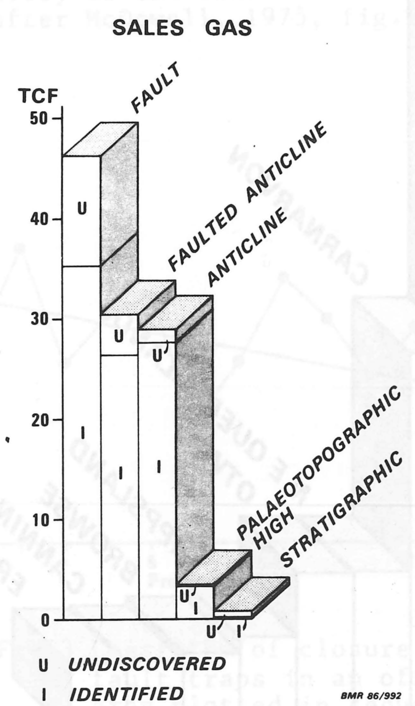


Fig.11 Identified resources of sales gas (I) and average estimates of undiscovered resources (U) by trap type.

# Exmouth Plateau thermal geohistory: implications for further exploration

M G Swift, D A Falvey, T Graham, & H M J Stagg, BMR

The Exmouth Plateau is a subsided continental fragment, lying off the Northwest Shelf at water depths of 900 to 2000 metres. It formed as part of the continental margin in the Late Jurassic and Early Cretaceous by continental breakup and seafloor spreading in the Argo, Gascoyne and Cuvier Oceanic Basins. The plateau contains a thick sedimentary section with many large structures. These were actively explored during the late 1970's and early 1980's. No significant discoveries (except for the Scarborough gas field) were made and exploration activity is dormant (Fig. 1).

The large number of available reports on petroleum exploration wells on and adjacent to the Exmouth Plateau has facilitated a comprehensive thermal geohistory analysis with a view to understanding the relative timing of maturation and structure. This analysis was combined with seabed heatflow data recently acquired aboard R/V Rig Seismic over the Exmouth Plateau and has led to a reappraisal of the region's petroleum potential. The lack of significant liquid hydrocarbons is attributed to insufficient burial and under-maturity of post-Triassic sediments; and a high pre-breakup heatflow regime causing over-maturity of Early Triassic and older sediments at the time of rift-faulting, with consequent escape of any liquid hydrocarbons originating in these older sediments.

Present day heatflow, derived from the corrected bottom-hole temperature of most wells on the plateau, showed a good agreement with the seabed heatflow values determined by measurements made from R/V Rig Seismic. This has allowed construction of a sketch contour map of heatflow over the southern portion of the plateau and part of the adjacent shelf (Fig. 1).

Heatflow data indicate a relative heatflow high of 80 $mW/m^2$ (1.9 heatflow units) over the Barrow Sub-basin with a gradual decrease to the centre of the plateau, where the heatflow almost reaches a low of 20 $mW/m^2$ (0.5 h.f.u.). This anomalously-low value is probably not representative of crustal heatflow. The Barrow Sub-basin was a major depocentre from Early Triassic to Late Jurassic, when active graben development ceased. Unlike the plateau margins to the southwest, northwest, and northeast where the anomalous transient thermal effect associated with a spreading centre has long been removed by seafloor spreading, the effect of heating beneath the Barrow Sub-basin may well have persisted, leaving a residual anomaly to the present day. At the site of thick late Palaeozoic and early Mesozoic sedimentation there may also be a contribution from radiogenic sources in these sediments. Thermal geohistory analysis suggested that the regional heatflow distribution has probably not changed appreciably, apart from a monotonic post-breakup thermal cool-down from 160 Ma b.p.

General geotectonic theories suggest that in the rift phase of continental margin evolution, leading up to the time of continental breakup, heatflow would rise. The magnitude of this rise is model-dependent and was not the subject of any detailed analysis in this area. Suffice it to say that anomalous heatflow was projected to be up to 40 $mW/m^2$ (1 h.f.u.)

A sample geohistory analysis for a typical plateau well (Jupiter-1; Barber, 1982) is shown in Figures 2 and 3. Subsidence and maturation is analysed for the Middle Triassic to Recent section. Initially rapid deposition is indicated, declining through to the Middle Jurassic, at which time breakup occurs and differential subsidence gives rise to erosion of Lower Jurassic sediment. Rapid post-breakup subsidence takes the plateau surface to bathyal water depths by the end of the Jurassic. Cretaceous to Recent deposition is all in deeper water and relatively thin. Taken together with declining heatflow, Triassic bed temperatures actually fall after breakup. Maturation levels become essentially set, leading to an over-mature setting below the Middle Triassic and an under-mature setting above the breakup (Callovian) unconformity. The aim of the present study is to identify those areas of the plateau where Middle Triassic through Early Jurassic sediments are thinner and thus not over-mature before breakup and/or where a post-breakup heating through anomalous heatflow and burial causes a later stage of maturation.

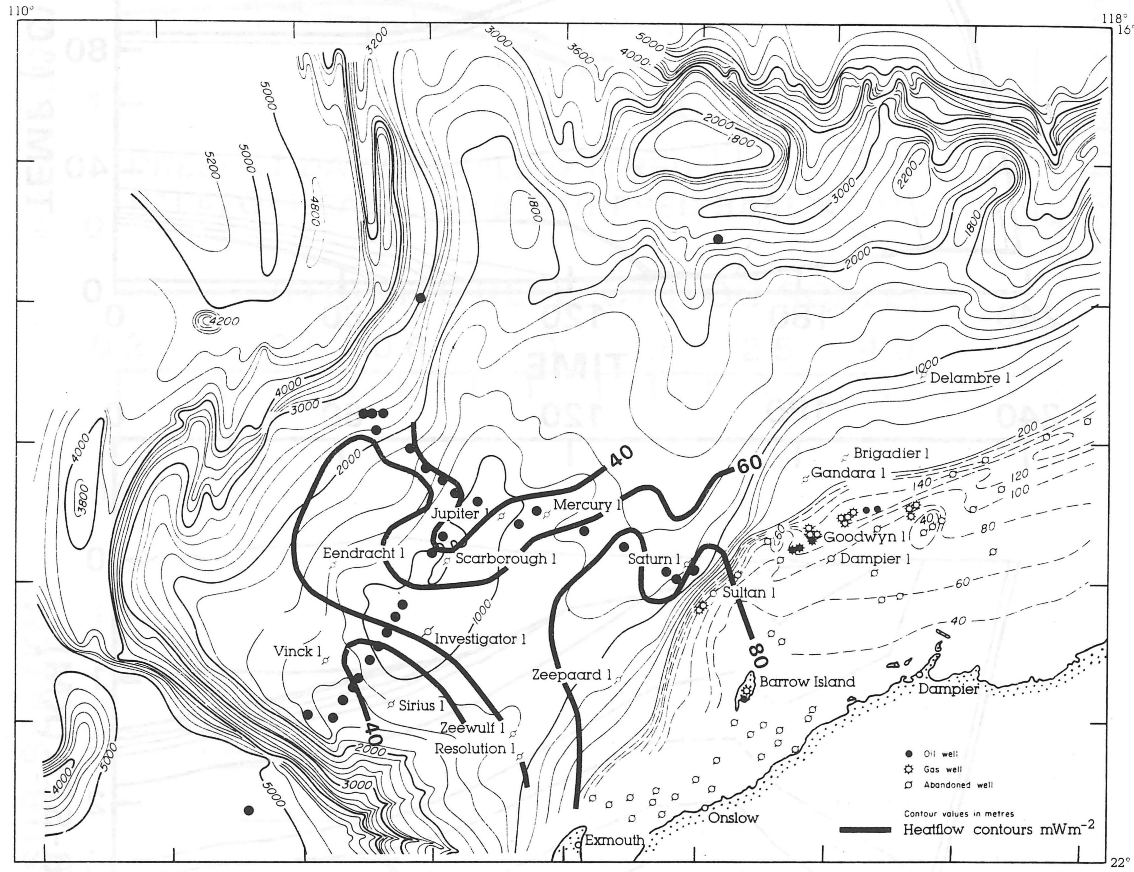


Figure 1 Exmouth Plateau region showing present day heatflow pattern derived from marine heatflow data (location shown by black dots) and well data.

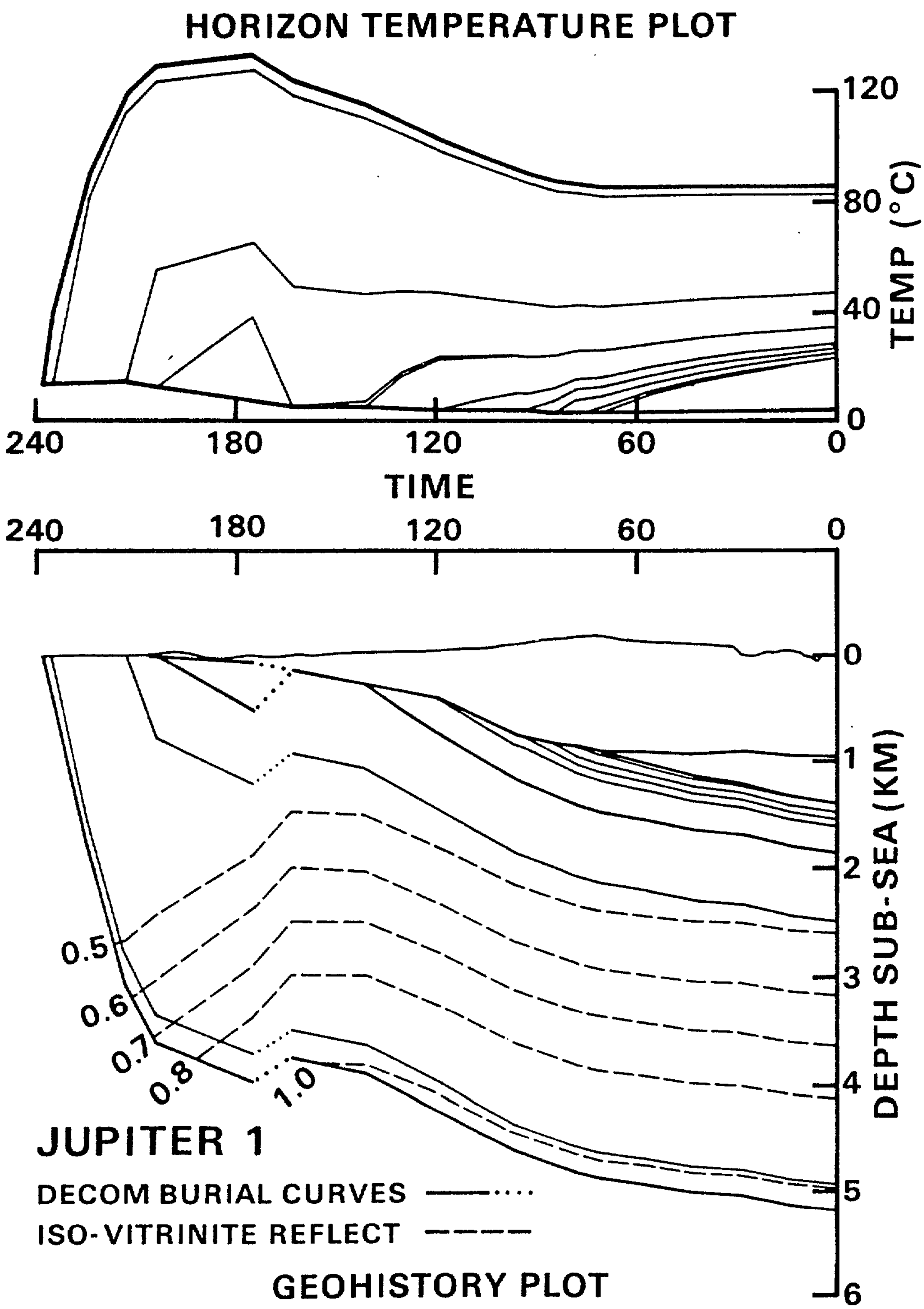


Figure 2 Geohistory plot for Jupiter 1.

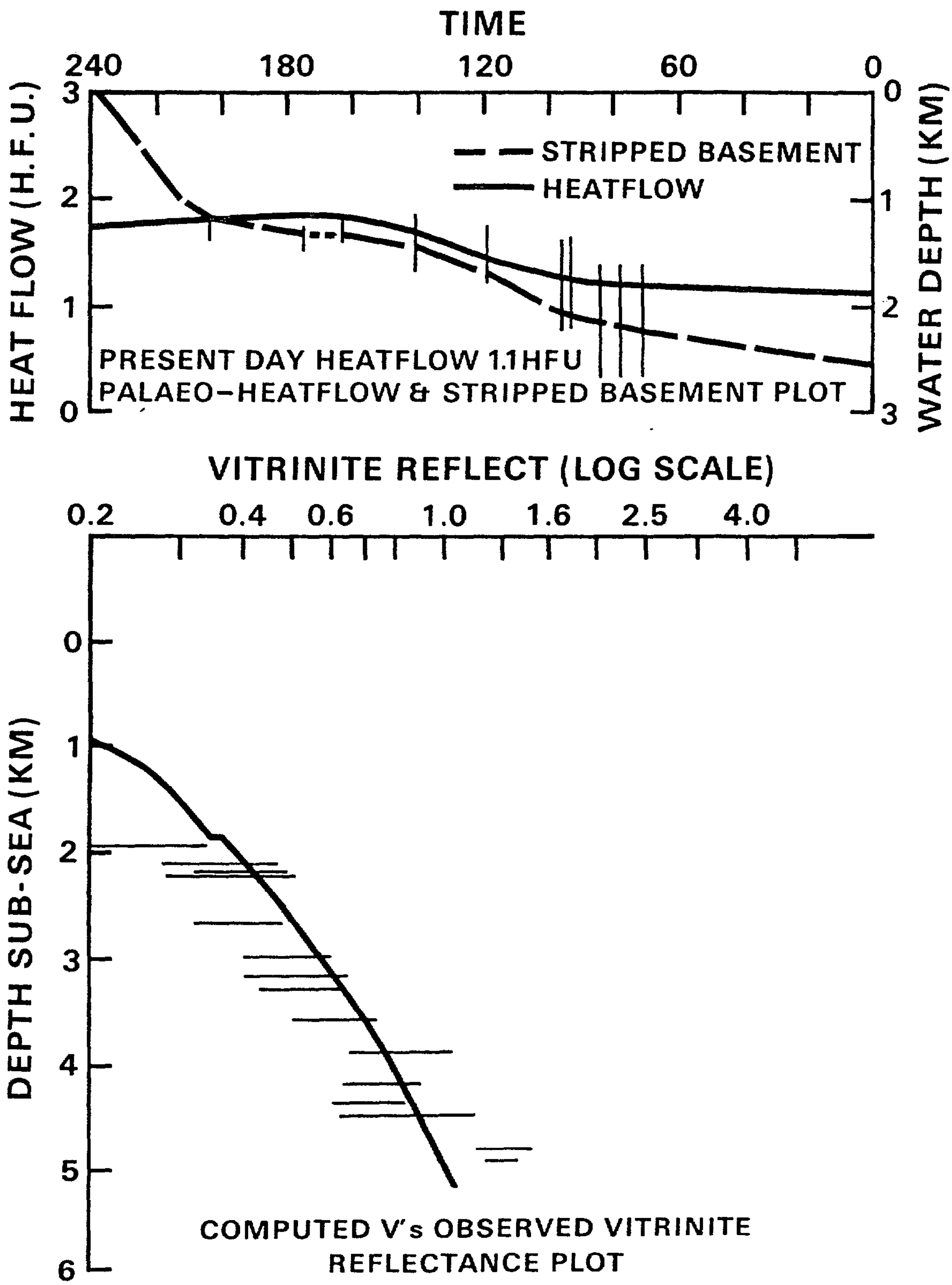


Figure 3 Geohistory plot for Jupiter 1.

# New clues to petroleum habitats of the offshore Otway Basin

P E Williamson, G W O'Brien, M G Swift, A S Scherl, & J Lock, BMR

The Otway Basin is one of three sedimentary basins in the Bass Strait region and occurs west of the Bass and Gippsland Basins. It trends northwest-southeast, straddling the southern Australian coastline for 500 km between the Mornington Peninsula in Victoria and Cape Jaffa in South Australia. It has an average width of 200 km and an average offshore width, in water depths less than 200 m, of 50 km.

The offshore basin consists of three main tectonic units: the Mussel Platform in the east, the Voluta Trough, which occurs in the centre of the basin, and the Crayfish Platform in the west. Structures are formed predominantly by Cretaceous normal faults, downthrown to the continent-ocean boundary, and bounding landward-dipping fault-blocks in the Cretaceous section. Sediment thickness is up to 10 km and consists of terrestrial Early Cretaceous sediments of the Otway Group; Late Cretaceous transgressive-regressive terrigenous sediments of the Sherbrook Group; Paleocene-Eocene transgressive-regressive, terrigenous and carbonate sediments of the Wangerrip and Nirranda Groups; and Oligocene-Miocene shelf carbonates of the Heytesbury Group.

Since the early 1960s, about 50 exploration wells have been drilled onshore and 17 offshore. Shows of oil, gas and condensate have been widespread in both onshore and offshore wells, though only two small economic fields have so far been discovered, both onshore. Exploration, particularly during the 1960s and 1970s, was hampered by poor seismic data quality, due predominantly to the presence of shallow carbonates.

The present BMR study concentrates on the offshore basin, and involved the collection, during 1985, of 3700 km of regional multi-channel seismic reflection data (Fig. 1) by BMR research vessel, Rig Seismic. Approximately 2000 km of this 48-channel BMR seismic data were collected over the continental shelf. For this study, BMR and selected existing industry data were used to produce an approximate 10 km square grid over the continental shelf. These data, and existing well data, have been analysed to study the likely habitats of petroleum in this part of the basin.

Structural definition for the Mussel Platform suggests the presence of suitable Waarre Sandstone traps overlying fault-bounded highs at the mapped Top Otway level for the southern and western platform. Thermal geohistory analysis indicates these have been sourced, in essentially their present configuration, by Eumerella Formation source rocks within the last 10-15 Ma. The relative lack of Upper Cretaceous reactivation of faulting in the region implies that the ability to charge shallower, thermally immature reservoirs via fault zones accessing deeper mature source rocks in the region may be poor, except in isolated areas where suitable late reactivation of faulting has occurred.

In the east of the Mussel Platform, strong intra Lower Cretaceous seismic events are observed and it is possible that an untested play, analogous to the Pretty Hill Formation play on the Crayfish Platform, may exist.

In the eastern Voluta Trough, significant structural closures are present at Top Otway levels, and the Waarre Sandstone (or equivalent) play is again present. In this region, geohistory analysis indicates the onset of liquid hydrocarbon generation (Ro = 0.7) at Top Eumerella level occurred approximately 80 MaBP. Reactivation of faulting occurred in the lower Late Cretaceous after that time, and may have allowed some secondary hydrocarbon migration into shallower Late Cretaceous reservoirs. However, the predominantly shaley nature of the Upper Cretaceous Belfast Mudstone in the eastern Voluta Trough suggests that vertical migration may have been difficult. Vertical migration is more likely to occur where late fault reactivation has been more significant and/or where sandier Upper Cretaceous facies exist around the basin margin. This may have been the case where oil shows were encountered in the base Tertiary at Lindon No. 1, on the flank of the Portland Trough.

The western Voluta Trough shows the most intense Upper Cretaceous and Eocene/Oligocene fault reactivation in the basin. The Waarre Sandstone (or equivalent) play is basically similar to that seen in the eastern Voluta Trough. In addition, significant fault-bounded structural leads have been defined at Top Cretaceous levels and the more intense Upper Cretaceous and Eocene/Oligocene fault reactivation increases the probability of vertical migration into shallower Upper Cretaceous, and possibly Tertiary, reservoirs. On the western margin of the western Voluta Trough (abutting the Crayfish Platform), and on the southern margin of the Crayfish Platform, the combination of sandier Upper

Cretaceous and Tertiary facies, and Upper Cretaceous and Tertiary fault reactivation, may have significantly enhanced vertical migration.

Crayfish Platform structure shows significant fault-bounded closures at intra Lower Cretaceous Top Pretty Hill, Top Early Cretaceous Otway Group, and at Top Late Cretaceous levels. On the Crayfish Platform "proper", the Pretty Hill play is present. On the Platform margins, the Waarre play exists, and Upper Cretaceous fault reactivation is similar to that seen in the western Voluta Trough. This suggests that shallower Upper Cretaceous, and possibly Tertiary, plays also exist. The critical factor in assessing the relative attractiveness of the uppermost Upper Cretaceous and Tertiary plays of the Crayfish Platform margins and the western Voluta Trough is the effectiveness of vertical migration in the Upper Cretaceous. Vertical migration would be enhanced by both the late fault reactivtion, and also the tendency for facies to become sandier, in those intervals, towards the Platform margins. Presumably, an optimum situation exists between the central western Voluta Trough and the Crayfish Platform, for post-Waarre Formation hydrocarbon entrapment.

Deeper water areas, while not presently economically attractive, have the potential for both hydrocarbon generation and entrapment. A higher palaeo-heatflow regime towards the continent-ocean boundary results in the present-day oil window moving progressively shallower in the section in a down-slope direction. Structural configuration and facies in the Cretaceous appear broadly similar on both the continental slope and shelf, although a progressively more marine Upper Cretaceous on the continental slope could present an optimum window for petroleum source rock deposition and preservation.

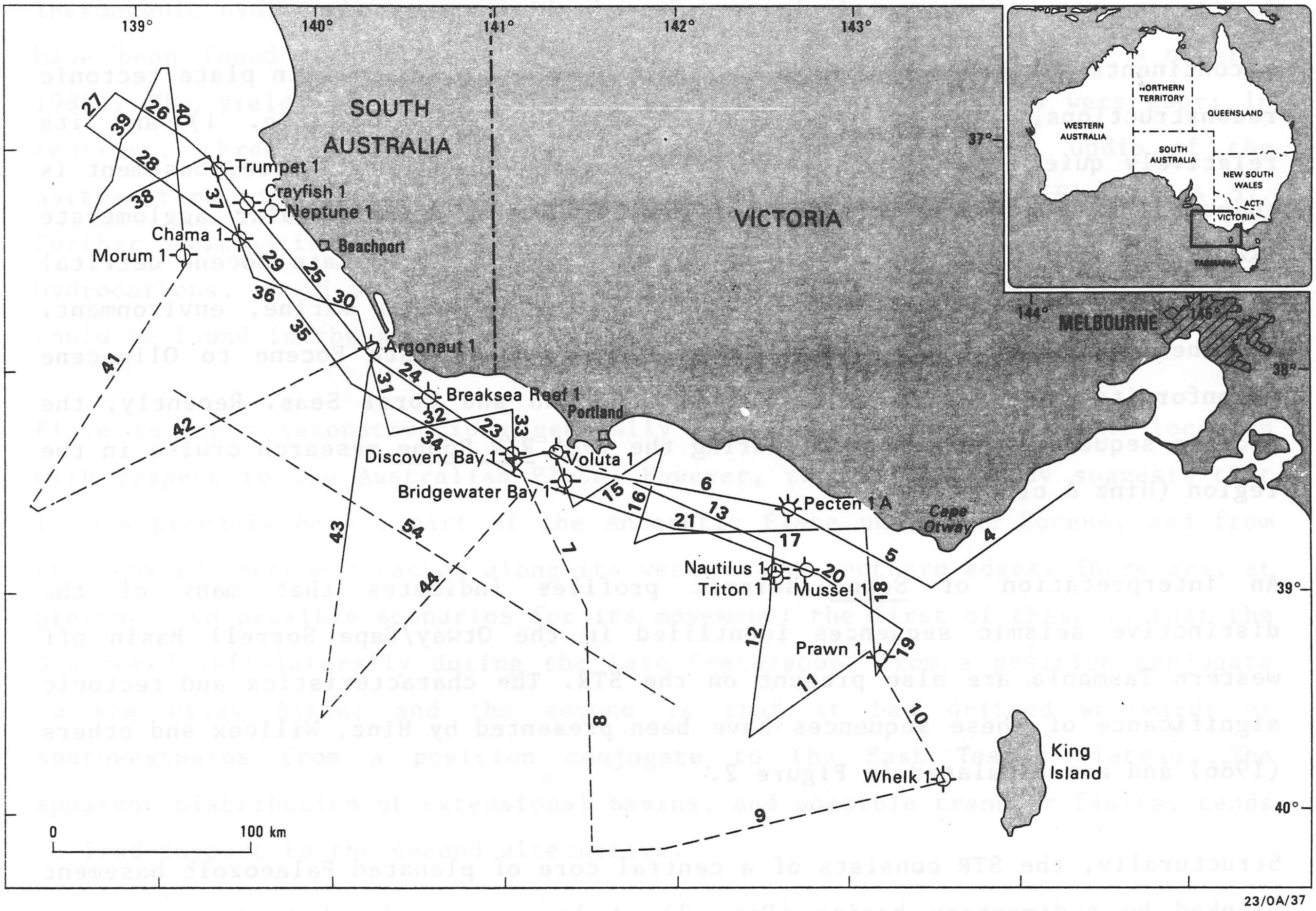


Figure 1. Data collected from BMR vessel Rig Seismic in the Otway Basin showing shelf lines (solid) and continental slope lines (dashed).

## South Tasman Rise : structure, tectonic development and implications for petroleum exploration

J B Willcox, BMR

The South Tasman Rise (STR) covers an area of 140 000 $km^2$ and lies in water depths ranging from about 800 m to 3000 m or more (Fig. 1). It is encompassed by Australia's Legal Continental Shelf, with approximately 70% of the Rise extending beyond an Exclusive Economic Zone (EEZ or 200 nautical miles), (Symonds & Willcox, in press).

A continental origin for the STR is deduced from its location in plate tectonic reconstructions, the drilling results at DSDP Site 281 (Fig. 1) and its relatively quiet gravity and magnetic signature. At the drill site, basement is composed of Palaeozoic mica-schist overlain by a basal angular agglomerate (Kennett & others, 1973). This agglomerate is overlain by Late Eocene detrital sediments deposited in a shallow marine, deepening to a marine, environment. Miocene to Holocene ooze was penetrated above the Late Eocene to Oligocene unconformity which is widespread in the Tasman and Coral Seas. Recently, the Neogene sequences were sampled during the 1985 R/V Sonne research cruise in the region (Hinz & others, 1985).

An interpretation of Sonne seismic profiles indicates that many of the distinctive seismic sequences identified in the Otway/Cape Sorrell Basin off western Tasmania are also present on the STR. The characteristics and tectonic significance of these sequences have been presented by Hinz, Willcox and others (1986) and are tabulated in Figure 2.

Structurally, the STR consists of a central core of planated Palaeozoic basement blanked by sedimentary basins (Fig. 3). A large extensional basin appears to occupy the southwest, and although it contains widespread volcanics within the syn-rift sequence, the sedimentary fill is up to 6000 metres thick in some places. Another extensional basin is developed in the northeast, along the margin opposite the East Tasman Plateau. Both extensional basins are probably related to the Cretaceous rifting episode which created the Otway, Cape Sorell, Bass and Gippsland Basins. North-northeasterly trending structural discontinuities appear to cut across the STR and may reflect the presence of transfer faults which accommodate areas with different degrees of extension.

The western half of the Rise is characterised by northerly-trending 'slivers' of basement, and intervening 'V-shaped' basins, which appear to have been created by trans-tensional movement in the Eocene and earliest Oligocene. Wrench faults extend through the sedimentary section up to the prominent Early Oligocene unconformity, and the western margin of the Rise is a transform fault of similar age. The western part of the Rise is thus structurally similar to the western margin of Tasmania, as discussed by Hinz, Willcox & others (1986).

Thermogenic hydrocarbons in relatively substantial, but variable, concentrations have been found in surface sediment samples from the STR (Whiticar & others, 1985). The yields over the western basins and planated regions were poor: in contrast, three stations on the eastern flank of the Rise, updip of the northeastern extensional basin, gave relatively higher yields (Figs. 4 & 5). Further examination of this area, with a view to long-term exploration for hydrocarbons, would seem to be warranted, particularly if large potential traps could be found in the shallower water (that is, less than 1000 m).

Plate tectonic reconstructions generally show the STR in its present location with respect to the Australian Plate. However, the current study suggests that it has probably been a part of the Antarctic Plate until the Eocene, and from then onwards became detached along its western and southern edges. There are, at present, two possible scenarios for its movement: the first of these is that the STR moved left-laterally during the Late Cretaceous, from a position conjugate to the Otway Basin; and the second is that it has drifted westwards or southwestwards from a position conjugate to the East Tasman Plateau. The apparent distribution of extensional basins, and possible transfer faults, tends to lend support to the second alternative.

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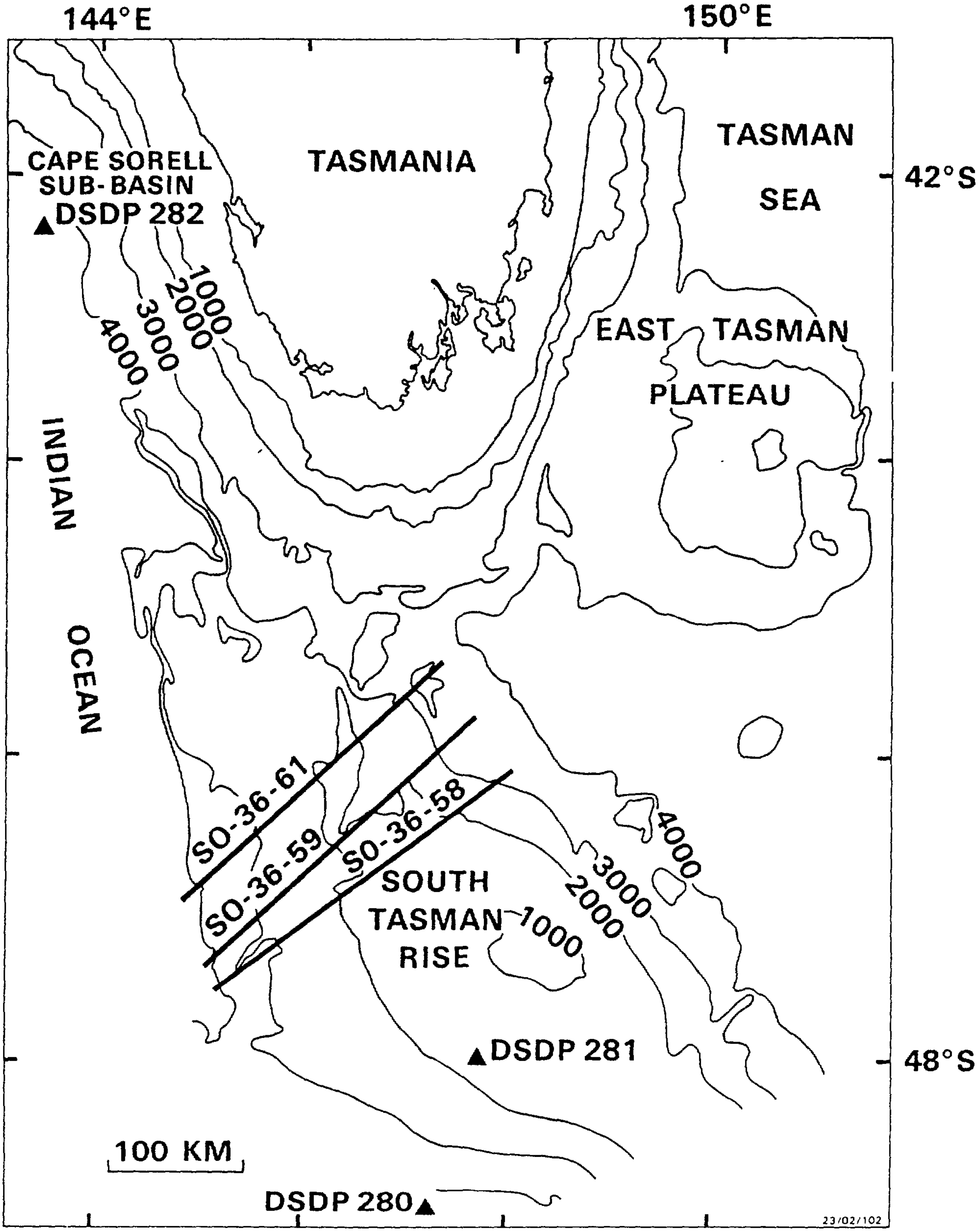


**Figure 1**
Bathymetry of the Tasmania-South Tasman Rise region (1000 m contours) showing Deep Sea Drilling Project (DSDP) sites 280, 281 and 282, and 'R/V Sonne' Lines SO-36-58, SO-36-59 and SO-36-61 (Figure 3).

| Unconform (Sequence) | Characteristics | Tectonic Significance | Facies Interpretation | Approx Thickness (m) | Proposed Age Identification: Stratigraphic | m.y. | Equivalent Mag Anom | Otway Basin Shelf Equivalent and Unconformities | Comment |
|---|---|---|---|---|---|---|---|---|---|
| | Low frequency, stratified and folded Floors Jurassic or Early Cretaceous rift beneath the lower continental slope | Pre–rift Tasman Geosyncline Crustal extension and first stage rifting at about U14 time | Varied metasediments and volcanics | Unknown | Palaeozoic and ? Precambrian | | | | "Basement" |
| U14 | | | | | | ? 140 | | | |
| S(13–14) | Low frequency, stratified on rift shoulder<br>Contorted fill in first stage rift | <br>Lower rift–fill | Continental–? fluvial, lacustrine<br>Alluvial fan and/or volcanics | 1000<br>3000 + | Jurassic and Early Cretaceous | | M Series | Casterton Beds and Otway Group Non–marine clastics and volcanogenic sediments | |
| U13 | | | | | | 105 | | | |
| S(12–13) | Bedded fill in first stage rift Now incorporated into tilted blocks beneath lower continental slope | Upper rift–fill, probably preceding marine transgression ? Development of shelf edge on U12 | Fluvial–lacustrine possibly grading to marginal marine | 0–?1000 | "late" Early Cretaceous (? Albian) | | | Probably time equivalent to Eumeralla Formation (Otway Gp) Continental environments with volcanism | This sequence appears confined to the first stage rift |
| U12 | | | | | | 95 | 34 | | |
| S(11–12) | Well stratified with onlap onto U12 U12/13 block–faulted beneath continental shelf | U12 (possibly U13) is main rift–onset unconformity in Otway Basin S(11–12) marine transgression | Marginal marine–marine (foram evidence from Ribis and Apthorpe, 1969) | 0–?1000 | Late Cretaceous (approx Cenomanian) | | Slow spreading episode (Cande and Mutter, 1982) | Approximate Waarre Formation (Sherbrook Group) equivalent Shoreline facies | Wrenching and uplift of the tilted blocks beneath lower slope commenced (Willcox and Symonds, in preparation) |
| U11 | | | | | | | | | |
| S(10–11) | Stratified sediment wedge with onlap onto U11 Basal channelling landward of old shelf edge | U11 eustatic lowstand in ? Coniacian (Vail et al., 1977) S(10–11) basin transgr restricted by blocks below lower continental slope | Shallow marine (restricted basin) | 0–1000 + | Late Cretaceous | | | Belfast Mudstone and Flaxman Formation (Sherbrook Group) Marginal marine–marine | 1570 m Belfast Mudstone in Voluta 1 |
| U10 | | | | | | | | | |
| S(9–10) | Stratified sediment wedging out below lower slope Downlap onto U10 | U9 and U10 relative falls in sea level U9–slowing or termination of movement of tilted blocks beneath lower slope | Shallow marine (regressive) | 0–500 + | Late Cretaceous (approx Maastrichtian) | | | Curdies/Paaratte Formations (Sherbrook Group) Shoreline–continental | Slow spreading episode in southeast Indian Ocean has less influence on outer Otway Basin |
| U9 | | | | | | 65 | 29 | | |
| S(8–9)<br>U8<br>S(7–8)<br>U7<br>S(6–7)<br>U6<br>S(5–6) | S(5–6) to S(8–9) are distinctive, high frequency, downlapping sequences beneath lower continental slope Lower frequency, continuous, high amplitude beneath upper continental slope | A period of minimal subsidence in the outer Otway Basin due to contact between Australian and Antarctic plates in Tasmanian region Sedimentation influenced by elevated blocks beneath lower continental slope Outbuilding of fine clastics with minimal aggradation Unconformities largely reflect eustatic changes in sea level | Shelf clastics, grading into fine grained progradational wedges at palaeoshelf–edge (largely terrigenous) | 200–1500 | Paleocene—Middle Eocene | | ? | Age equivalent of the Wangerrip Group Shallow marine→shoreface→continental (regressive) | Sequences S(5–6) to S(8–9) are believed equivalent to depositional cycles TP1, TP2, TE1 and ?TE2 of Vail et al., (1977) |
| U5 | | | | | | 42 | 18 | ? ? | |
| S(4–5)<br>U4<br>S(3–4) | Stratified, onlapping S(3–4) extends across outer tilted blocks | Accelerated movement along Australian–Antarctic plate boundary Major wrenching and development of flower structures in southeast Otway Basin and western margin of Tasmania | Shallow marine (largely terrigenous) | 0–800 | Late Eocene—earliest Oligocene | | | Nirranda Group (transgressive) — shallow marine | ? Minor volcanism at U5 time |
| U3 | | | | | | 35 | 13 | | |
| S(2–3)<br>U2<br>S(1–2)<br>U1 | Stratified, channelled, shelf–edge progradation | U3 is widespread Early Oligocene unconformity marking clearance of Australian and Antarctic plates and establishment of open marine conditions | Shelf – open marine (largely carbonate) | 0–600 | Late Oligocene and Neogene | | Southeast Indian Ocean spreading | Heytesbury Group (transgressive) marine carbonates | Main episode of seafloor spreading |

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**For stratigraphy refer to BMR line 22/23 (Figure )*
*Tectonic events after Willcox and Symonds (in preparation)*

**Figure 2**

The ages, characteristics and tectonic significance of seismic sequences in the southeast Otway Basin (Hinz, Willcox and others 1986) which probably have correlatives on the South Tasman Rise.

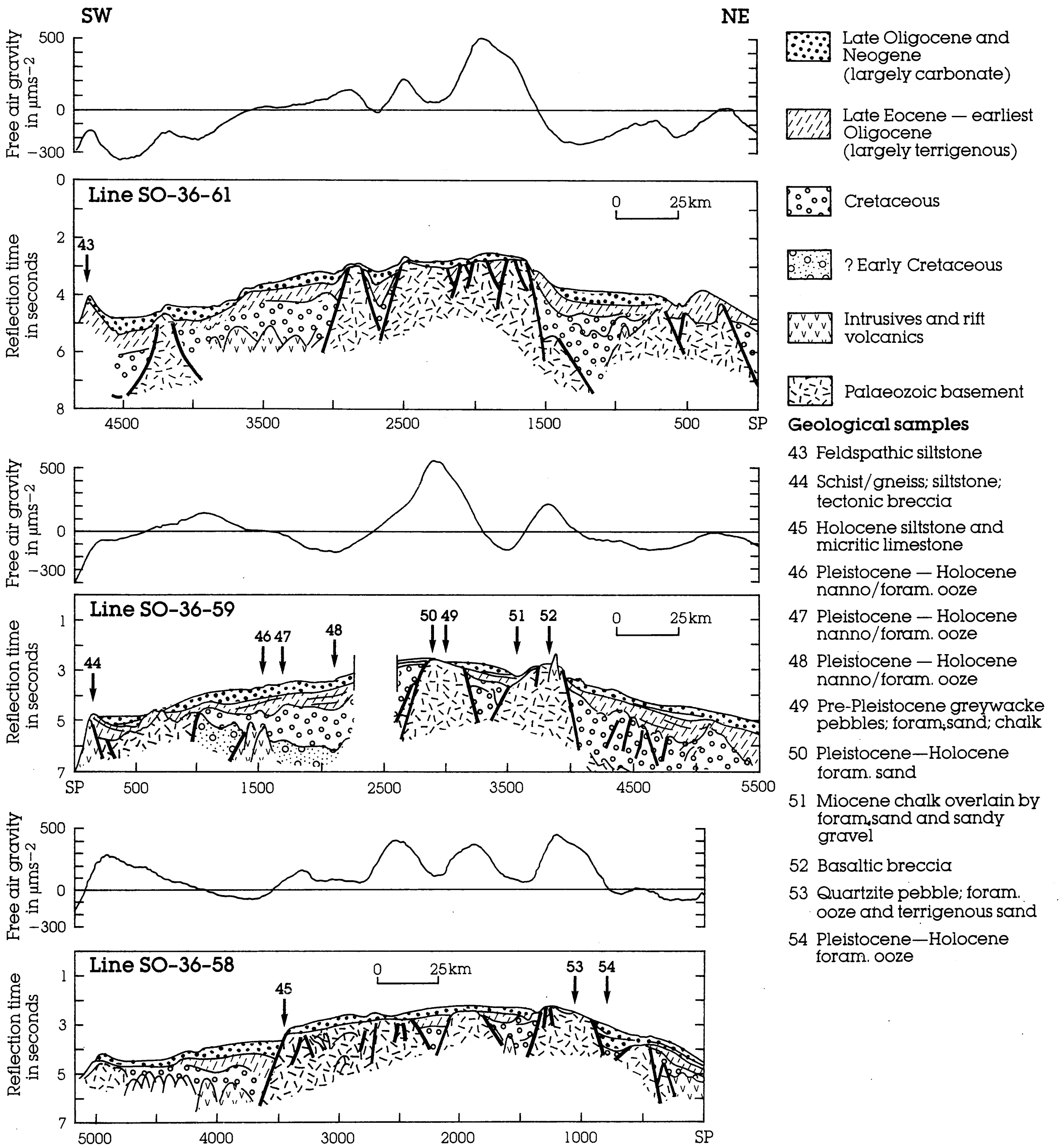


**Figure 3**

An interpretation of 'R/V Sonne' seismic profiles SO-36-61, SO-36-59 and SO-36-58, spaced approximately 50 km apart (Locations in Figure 1). Shows free-air gravity anomaly and sampling sites. 23/02/104

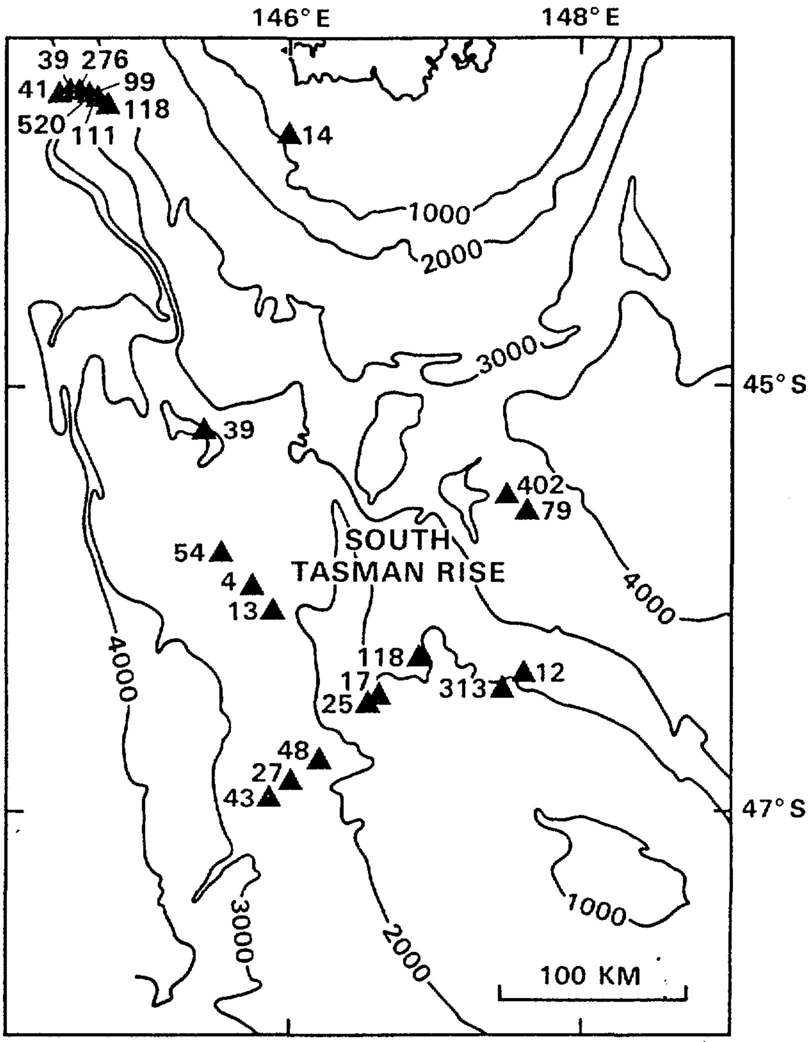


**Figure 4**
Total yield of thermogenically derived hydrocarbons (ppb) from surface sediments in the South Tasman Rise region (Whiticar and others, 1985)

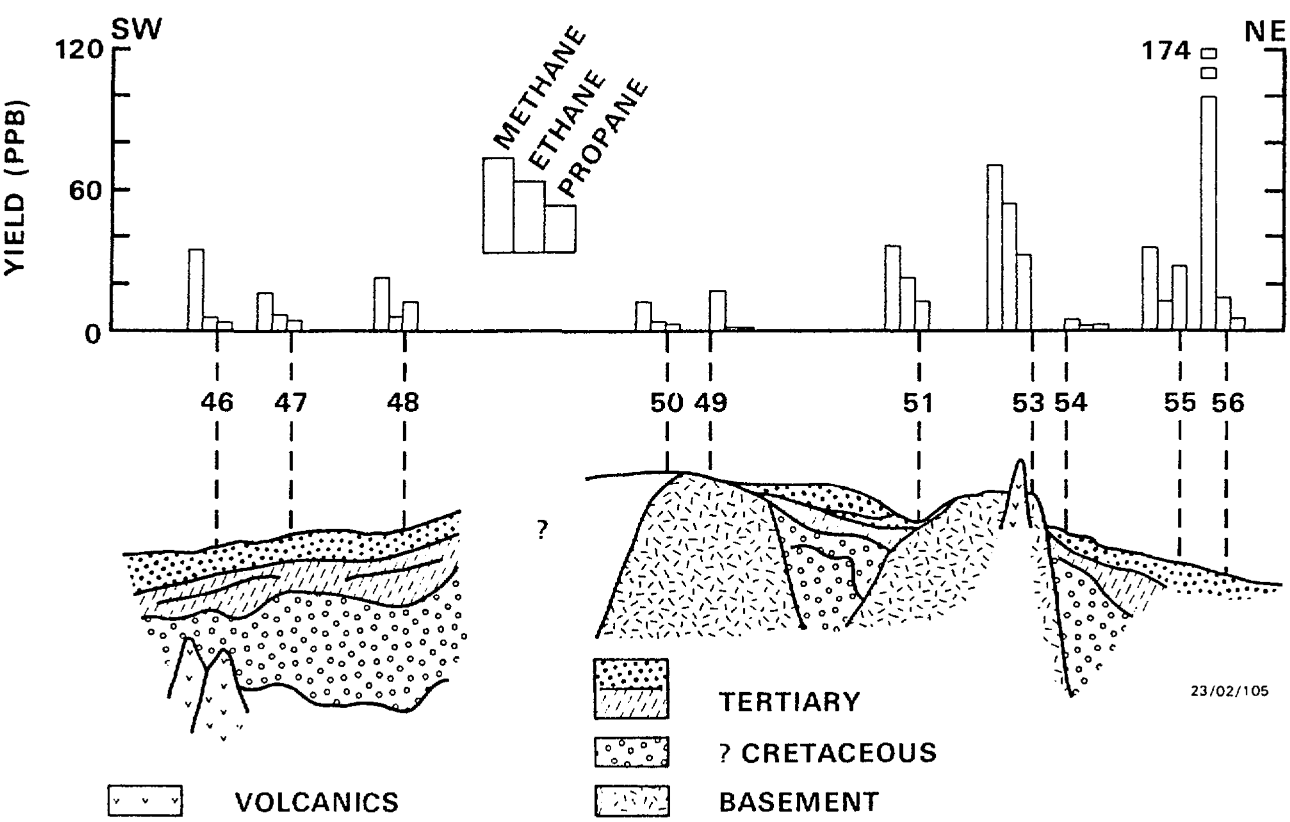


**Figure 5**
Yields of thermogenically derived methane, ethane and propane (ppb) in relation to structure (Whiticar and others, 1985)

# N O T E S

BMR Record 1986/31

OPENING OF 15TH BMR RESEARCH SYMPOSIUM
BY SENATOR THE HON. GARETH EVANS, Q.C.,
MINISTER FOR RESOURCES AND ENERGY

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Some 18 months ago, in March 1985, I gave my first major address as Minister for Resources and Energy at BMR's Petroleum and Minerals Review Conference, a conference which reflects the activities of the Resource Assessment Division in BMR. I am pleased today to be able to open BMR's other major annual public conference - the Research Symposium - which reflects the activities and results of BMR's research Divisions.

The Petroleum and Minerals Review Conferences bring together government and a wide range of commercial and technical groups interested in the past performance and future opportunities for the Australian petroleum and mineral industry. BMR's research symposia, in their turn, provide an important avenue of interaction between BMR's research scientists and other geoscientists involved in research and exploration related to petroleum and mineral resources.

At the Petroleum and Minerals Review Conference in 1985 I described the resources sector as the cornerstone of the Australian economy. Since that time the deterioration in the terms of trade and the collapse in oil prices have created major difficulties for the Australian economy, in general, and the resources sector in particular. Nevertheless, the sector continues to underpin our economy and in 1985 was responsible for about 50% of Australia's export earnings.

There is little doubt that we must depend upon the resources sector tc provide the economic bridge to the future during this difficult period of economic adjustment. Our resource industries must enhance their capacity to respond to opportunities which will arise in future in an increasingly competitive international environment.

The greater our geoscientific understanding of our continent and its mineral resources, the more efficient and effective will be the industry's exploration efforts. The task of finding new mineral and petroleum deposits will become increasingly difficult and will require more sophisticated concepts and techniques based on fuller geoscientific understanding.

Research designed to increase that understanding is, of course, BMR's primary function. It's strategic objective is to provide the fullest understanding of the genesis, abundance, age and location of Australia's petroleum and mineral resources through knowledge of the three-dimensional structure, composition and evolution of the earth's crust.

Earlier this year, BMR celebrated its 40th anniversary. During its life BMR has had widely acknowledged success in providing the basis for development of the nation's petroleum and mineral resources.

In recent years, the nature of BMR's activities has changed substantially in response to the ASTEC Review and changing national requirements: but the overall purpose to provide a basis for mineral and petroleum exploration remains the same.

Until its restructuring in 1980, one of BMR's major contributions was the systematic geological and geophysical mapping of Australia and its territories at a scale of 1:250 000. Much of this work was carried out in co-operation with the geological surveys of the Australian states and the Northern Territory, and it has provided a framework for the current phase of more detailed geoscientific research, as well as for explorations.

BMR's research activity is, of course, designed to complement the efforts of industry itself and of other geoscientific organisations in Australia such as state geological surveys, CSIRO and universities. Broadly speaking, it is similar to that of national geological surveys elsewhere, such as the US Geological Survey and the Geological Survey of Canada. Indeed the US and Canadian organisations are responsible for comparable land areas and operate within broadly similar federal systems.

While it may be difficult for Australia to match the efforts of those countries in terms of quantity of research there is no reason why we should not match them in the quality and relevance of our research effort.

BMR has made substantial progress in recent years in strategic research planning and is now being assisted by an Advisory Council with representation from both industry and basic research areas and from the State Geological Surveys. I would like to take this opportunity publicly to thank Mr Webb and the members of the Advisory Council for the valuable contribution they are making to the determination of BMR's research priorities. It is important to note that the Council is now having a significant influence on the organisation and presentation of BMR's programs.

At the end of this symposium there will be an opportunity for participants to have direct input into a discussion of BMR's future research directions. I hope you will take advantage of that opportunity to give BMR's management and the Advisory Council representatives who will be present the benefit of your suggestions and views.

At the recent Energy 2000 Conference, a basic theme which emerged was the need to maximise the level of petroleum self-sufficiency consistent with the efficient and equitable allocation of resources, and there can be no doubt that a very high priority for BMR must be research directed at assisting the petroleum exploration effort.

One of the most important initiatives in recent times has been the establishment of the Continental Margins program in BMR using the advanced research capabilities of the research vessel Rig Seismic. It is pleasing to note that several of tomorrow's contributions in this symposium arise from that program.

There is, however, also a continuing need to undertake strategic research in the mineral industry, particularly in relation to commodities that can be identified as likely to be of continuing or increasing importance in the longer term. Today's sessions largely reflect that activity, while they also give some attention to BMR's other research responsibilities, for example, in relation to geophysical observatories.

Another area of growing importance to all BMR's activities is the establishment, maintenance and expansion of national databases, many of which are likely to have wider application and use by industry and researchers throughout Australia. The integration of various data sets using the latest technology will play an important part in the future of the mineral industry and BMR hopes to equip itself to be at the forefront of this activity.

The partnership between government and industry in Australia has been highly successful in promoting the development of a key sector of our national economy. BMR's research, resource assessment, and database activities are clearly an important component in the Government's strategy in support of the exploration and development of Australia's economically significant petroleum and mineral resources.

I hope that this conference will facilitate the exchange of research results and will lead to even more effective collaboration and interaction between those in government and industry who are dedicated to the understanding of, and exploration for, our nation's mineral resources.

I have much pleasure in opening the 15th BMR Research Symposium.