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BMR strikes the world's oldest oil

BMR's investigations of potential source rocks in the McArthur Basin generated a lot of excitement this year when BMR Urapunga No. 4 drillhole — drilled to collect samples for analysis and to provide stratigraphic and sedimentological information from the Velkerri Formation and underlying units in the Roper Group — struck live oil.

The McArthur Basin has been known for a long time to contain a thick unmetamorphosed sequence with algal remains and extensive carbonaceous shales. Several years have now elapsed since kerogen from the top of the Roper Group was shown to be *immature* with respect to oil generation (Peat & others, 1978: *BMR Journal of Australian Geology & Geophysics*, 3, 1–17). Soon after, BMR found oily and solid pyrobitumen material in vugs within silicified carbonates of the McArthur Group (Muir & others, 1980: *BMR Journal of Australian Geology & Geophysics*, 5, 301–304) at about the same time that Kennecott Exploration Co. encountered a gas pocket, possibly in the Barney Creek Formation, in a mineral exploration hole.

These petroleum indicators emphasised the need for a systematic evaluation of the basin's petroleum potential. For the past two years, BMR has been carrying out studies in order to locate potential petroleum source rocks in the basin, and assess their capacity to yield petroleum to a reservoir. Analyses of shale systematically sampled from BMR and company stratigraphic and mineral exploration holes showed that potential source rocks exist at three stratigraphic levels: the Velkerri Formation (Maiwok Subgroup of the Roper Group) and the Yalco and Barney Creek Formations (both in the McArthur Group; Fig. 1).

Rock–Eval pyrolysis and organic carbon measurements have been used to screen samples for organic content, maturity, and petroleum potential. Thus, the **Velkerri Formation** in BMR Urapunga No. 3 hole (drilled in 1983) was found to have organic carbon contents of 3.45 to 6.47 per cent with pyrolysis yields ranging from 15 to 30 kg t^{-1} of hydrocarbons. The temperature of maximum pyrolysis yield (Tmax) increases from 439°C at 30 m to 453°C at 90 m; yields in excess of 5 kg t^{-1} indicate oil-prone organic matter, and the range of the oil-generating zone is considered to be 435°C to 460°C (Tmax). Below 90 m, yields of free hydrocarbons were similar to the yields of pyrolysable hydrocarbons. These data indicated the presence of migrated hydrocarbons in the section below 90 m.

The hydrocarbon-generating capability of the Velkerri Formation was confirmed in no uncertain fashion in June 1985. A live oil show was encountered towards the base of the formation in the interval 345.4-346.55 m in BMR Urapunga No. 4 hole, which was drilled 60 km east of Urapunga

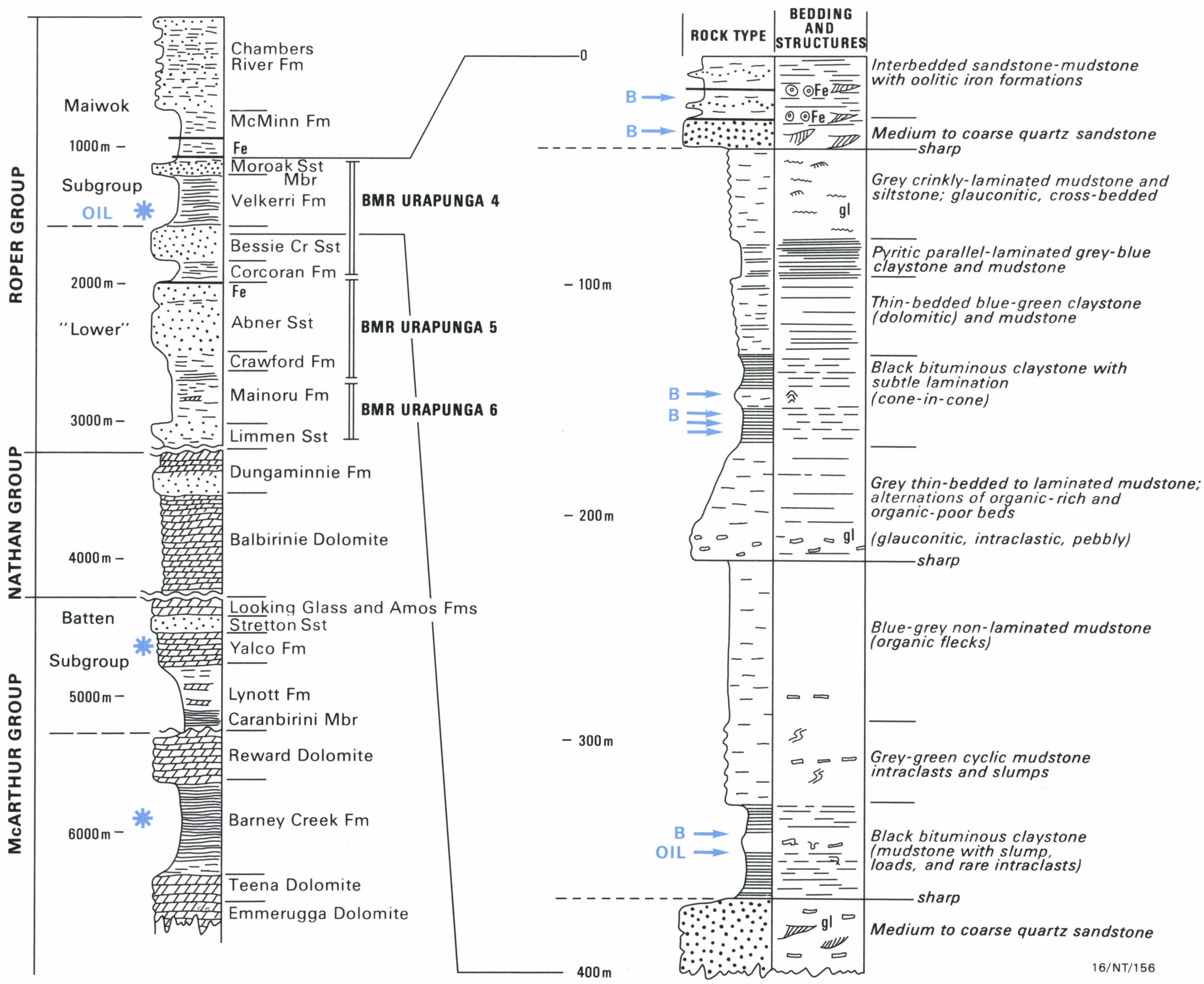

Fig. 1. *(left)* Simplified regional stratigraphy of the McArthur Basin in the Urapunga region showing known potential source horizons (asterisked); *(right)* simplified log of BMR Urapunga No. 4, showing main facies subdivisions and hydrocarbon occurrences (B refers to occurrences of bitumen).

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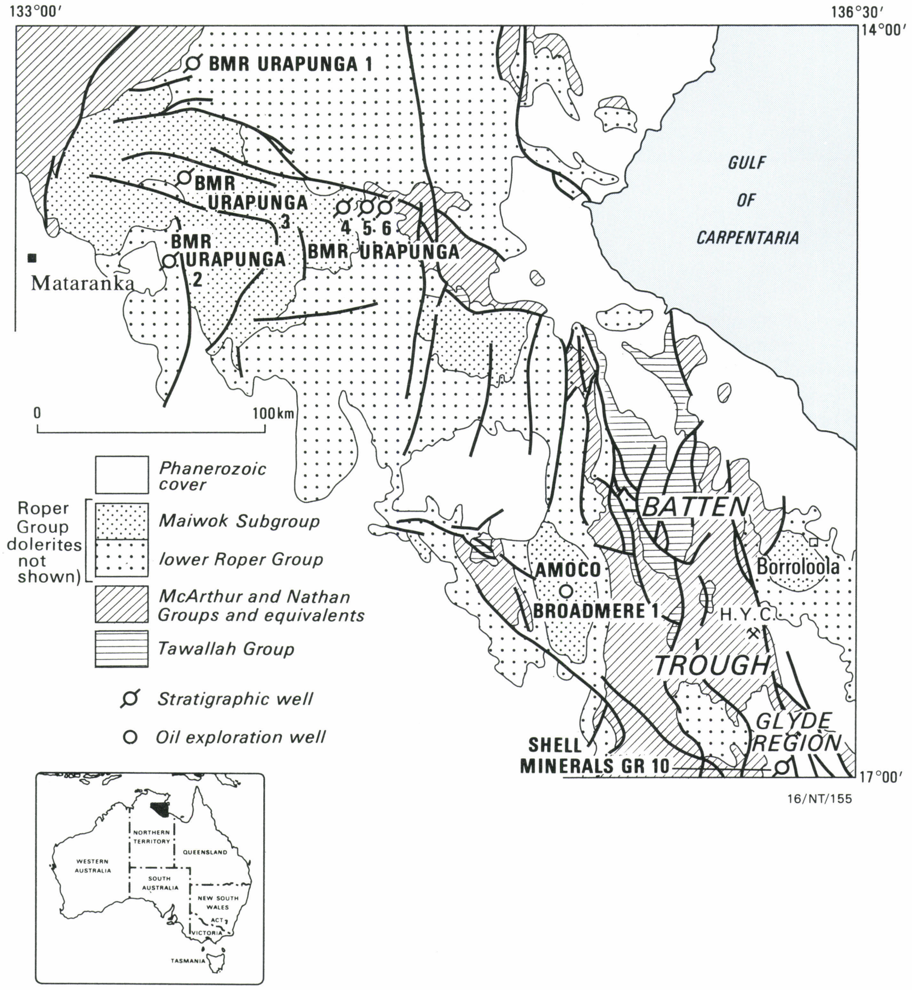


Fig. 2. Simplified geology and some of the stratigraphic and petroleum exploration wells drilled in the Urapunga–Glyde region of the McArthur Basin.

No. 3 (Figs. 1 and 2). This interval is tight: one sample has an average porosity of 10.8 per cent, an oil saturation of 70 per cent, and a permeability of 0.03 md. Bituminous matter also occurred between 150 and 160 m in the Velkerri Formation and in coarse-grained Moroak Sandstone near the top of the drillhole. The underlying Bessie Creek and Abner Sandstones are highly porous and permeable in outcrop, but appear to be cemented with quartz at depth; few porosity and permeability measurements of rocks in these formations are available, but artesian groundwater flows in some areas indicate that porous and permeable zones exist.

The **Batten Subgroup** is generally overmature in the Batten Trough, and samples have low pyrolysis yields. However, these rocks are commonly marginally mature to mature on the margins of the Batten Trough, where the Yalco Formation contains thin (1-4 m) organic-rich intervals (up to 5.5 per cent TOC) that have yielded up to 33 kg t^{-1} — indicating oil-prone organic matter. Samples of the Lynott Formation have organic carbon values ranging up to 1.21 per cent, and shale of the Caranbirini Member has organic carbon values up to 3.5 per cent, but averages around 0.6 per cent.

The **Barney Creek Formation** has been a target for mineral exploration companies in the Batten Trough because of the large stratiform HYC lead–zinc deposit that it hosts. Boreholes have penetrated up to 700 m of Barney Creek Formation in the Glyde region (Fig. 2), where — in Shell Minerals GR10 hole — Tmax values indicate that it is just mature at a depth of 80 m and overmature at 650 m. Samples from shallow depths show pyrolysis yields up to 36 kg t^{-1}, and organic carbon contents up to 7.57 per cent. These data indicate excellent potential source rocks in this formation.

The results of BMR's reconnaissance work have clearly shown the existence of potential petroleum source rocks in this Proterozoic basin. Geochemical work is under way to further investigate the source rock potential by characterising the organic matter through a variety of extract and kerogen analyses. The age of the McArthur Basin sequence (1400–1700 Ma) confirms that the oil from the Velkerri Formation is the oldest known oil in the world and is contemporaneous with the initial development of the eucaryotic organisms. Present evidence suggests that the source organic matter is primarily of bacterial origin with some contribution from cyanobacterial remains. We must now aim to establish a maturation scale which will allow us to map more precisely the zones of maturity, and enable us to assess the timing and rates of maturation.

The recently completed drilling program (Urapunga Nos. 4, 5, and 6) provides a 1600-m-thick continuous section through most of the Roper Group. In addition to geochemical studies, sedimentological work is under way to elucidate reservoir characteristics, environments of deposition, diagenetic changes, and other features critical to an assessment of the petroleum potential of the basin. Detailed field logs of the drillholes, and initial sedimentological interpretations, will be available in a completion report that will be issued as a *BMR Record*.

For further information, contact Dr Trevor Powell (geochemistry), Mr Ian Crick (organic petrology), or Messrs Jim Jackson or Ian Sweet (geology) at BMR.

Murray Basin

Mid-Tertiary palynological biostratigraphy and climate

In a paper published in the latest issue of the *BMR Journal of Australian Geology & Geophysics* (Vol. 9.4, pp. 267–295), E.M. Truswell, I.R. Sluiter, & W.K. Harris describe palynomorph suites from a section in the western Murray Basin in which foraminifera provide independent time control; the section is that in the South Australian Department of Mines & Energy's Oakvale No. 1 well.

The study was undertaken to provide a frame of reference for other palynological studies in less well dated sequences in the Murray Basin, and for anticipated work in the eastern Lake Eyre Basin. Its main purpose was to provide detailed biostratigraphic data on the ranges in time of as many as possible of the palynomorph taxa recovered from the Oligocene–Miocene Geera Clay and Renmark Group in the Oakvale section. The need for such data arises because of the difficulty of identifying in inland localities those palynological zones which have been defined in coastal basins — such as the Gippsland and Otway Basins. For this reason the identification of the base of one of the Gippsland Basin zones — the Early Miocene *Triporopollenites bellus* zone — in the Oakvale section is of interest, although the identification is only tentative because of the scarcity of marker species. However, Late Oligocene–Early Miocene foraminifera recovered by Murray Lindsay (SADME) from intervals of greater marine influence in the Geera Clay in this section — probably reflecting sea-level rises spanning the TP2.2 to TM1.1 transgression of the Vail curve — provide an independent means of dating the palynomorph-bearing sediments.

A bonus that the study provided is the climatic information that it revealed. The palynomorphs in the section include pollen, spores, and dinoflagellates which were deposited apparently in a shallow-marine environment, perhaps in the interdistributary bays of a delta system draining broad marshlands. The pollen and spore component was analysed statistically, by methods which allow the recognition of two major zones; the younger of these was further divided into four subzones. Although the pollen spectra reflect the presence of rainforest in the region throughout the interval studied, evidence for a major climate change can be detected within the Late Oligocene. At that time, it appears that complex rainforest dominated by the southern beech, *Nothofagus*, and by trees of the family Myrtaceae — a rainforest which must have flourished under a high year-round rainfall regime — was replaced by rainforest of a drier type, in which *Araucaria* was a major element. As well as representing a distinct drop in rainfall, this climatic change in the Late Oligocene probably also reflects an increase in the seasonality of rainfall, in which a dry phase followed the summer wet. The same climatic boundary can be detected later, in the Early Miocene, in the eastern Murray Basin, suggesting that it migrated coastwards through time.

Further details from Dr Liz Truswell, BMR.

Gas storage

BMR and the Society of Petroleum Engineers (NSW/ACT Branch) will host the First Australian Symposium on Gas Storage at the Australian Academy of Science, Canberra, from 11–12 February 1986.

The objective of the Symposium is to provide a forum for persons in industry, educational institutions, and government departments to exchange ideas on a wide variety of gas storage topics.

Enquiries to Dr Stanley Ozimic at BMR.

Heard on the Kerguelen Plateau

Marine Division's new research vessel *Rig Seismic* recently completed a cruise over the Australian sector of the Kerguelen Plateau in the south–central Indian Ocean. This offshore area under Australian jurisdiction is defined around the Territory of Heard and McDonald Islands. About 5500 km of 48-channel seismic, gradiometer magnetic, gravity, and bathymetric data were collected (Fig.3). This has greatly enhanced the data set on

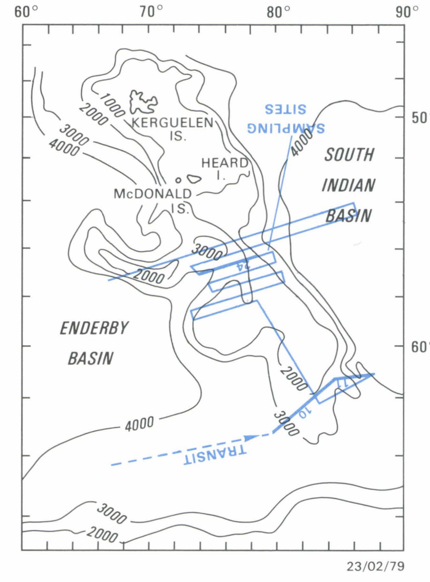


Fig. 3. Kerguelen Plateau bathymetry (metres), ship's tracks, and sampling sites.

this poorly understood feature. Major accomplishments of the study include the delineation of a large sedimentary basin in the southeastern part of the plateau; confirmation of the existence of a block of deep, presumably old oceanic, crust on the eastern flank of the plateau; and the recovery of rock samples, some of which are of continental affinity. Despite this, we have so far failed to answer the fundamental question as to the origin of the plateau: continental or oceanic?

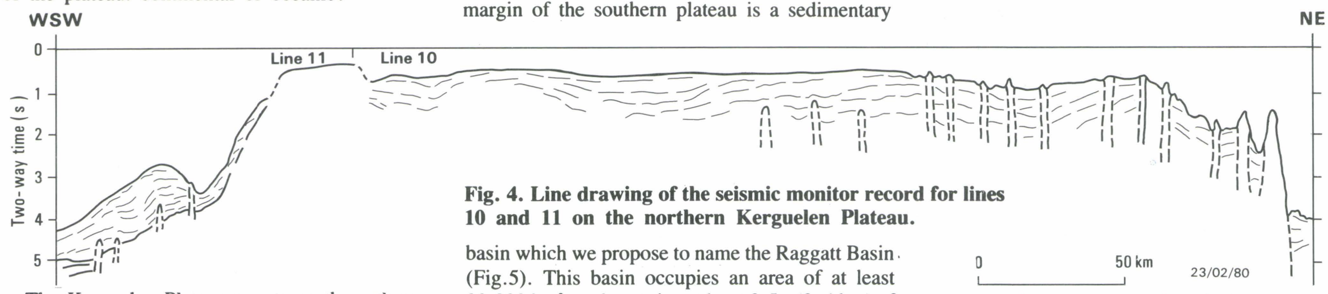


Fig. 4. Line drawing of the seismic monitor record for lines 10 and 11 on the northern Kerguelen Plateau.

The Kerguelen Plateau trends north-northwesterly, is about 2500 km long by up to 600 km across, and has a relief of 2 to 4 km above the adjacent sea-floor. It lies on the Antarctic Plate, in a position roughly corresponding to that of the Broken Ridge/Naturaliste Plateau on the Australian Plate. The only subaerial expressions of the plateau are the Kerguelen Islands (French jurisdiction) and the Australian Territory of Heard and McDonald Islands, which are all mainly volcanic in character. The Kerguelen Islands are an Eocene–Quaternary volcanic complex consisting mainly of alkali basalt. Heard Island was constructed by alkaline volcanic activity on a basement of uplifted pelagic limestone of mid-Eocene to mid-Oligocene age. Eruptions on Heard Island have been recorded historically, most recently in January 1985 (*Scientific Event Alert Network Bulletin*, 10, 2-3). Virtually the only geophysical study of the southern (Australian) sector of the plateau is by Houtz & others (1977: *Marine Geology*, 25, 95-130), based on single-channel seismic data recorded onboard the USNS *Eltanin* and Lamont–Doherty ships in the 1960s and early 1970s.

Initial interpretation of our data indicates that the plateau is structurally complex. On the basis of one and a half transects of the northern sector, north of Heard Island, we observe that the main part of the plateau is underlain by adjoining sedimentary basins containing up to about 1.5 s of sediment; subvolcanic intrusions cutting the sedimentary pile decrease in frequency to the west (Fig.4). The sediments display structures characteristic of an active physical oceanographic regime, but there is little evidence of significant faulting. The eastern margin is a largely sediment-free steep slope buttressed by igneous intrusions. The western margin of the plateau is formed by what appear to be uplifted basement blocks displaying large-amplitude magnetic and gravity anomalies. To the west, the plateau descends gradually to abyssal depths.

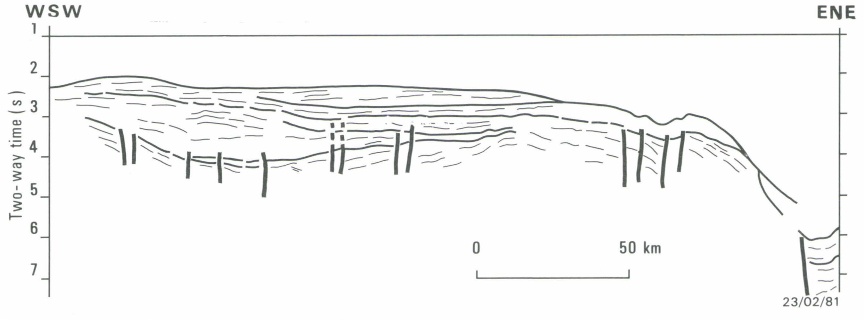


Fig. 5. Line drawing of the seismic monitor record for line 24 on the southern Kerguelen Plateau.

The southern sector of the plateau, the main focus of our study, contrasts markedly with the northern sector. Here the plateau is morphologically more symmetrical, the topography is more subdued, and the water depth is generally greater. Igneous intrusions, common in the northern sector, are rarely apparent here, but there is compelling evidence for repeated deformation throughout much of the history of the southern sector. A major feature delineated on the eastern margin of the southern plateau is a sedimentary basin which we propose to name the Raggatt Basin (Fig.5). This basin occupies an area of at least 30 000 km^2, and contains at least 2.5 s (3–4 km) of sediment in places. It appears to have been formed by deposition on a steadily subsiding surface, which we correlate with a prominent reflector reported by Houtz & others *(op. cit.)*. This reflector elsewhere has been provisionally dated as the top of the Cenomanian, so — if the correlation is correct — this helps to constrain the age of the Raggatt Basin. The eastern margin of the basin is defined by a basement block, which also forms the edge of the plateau. The western margin is more complex, but is generally fault-bounded. Although faulting of different ages is common throughout the basin, it does not appear to have been a major controlling factor in its evolution.

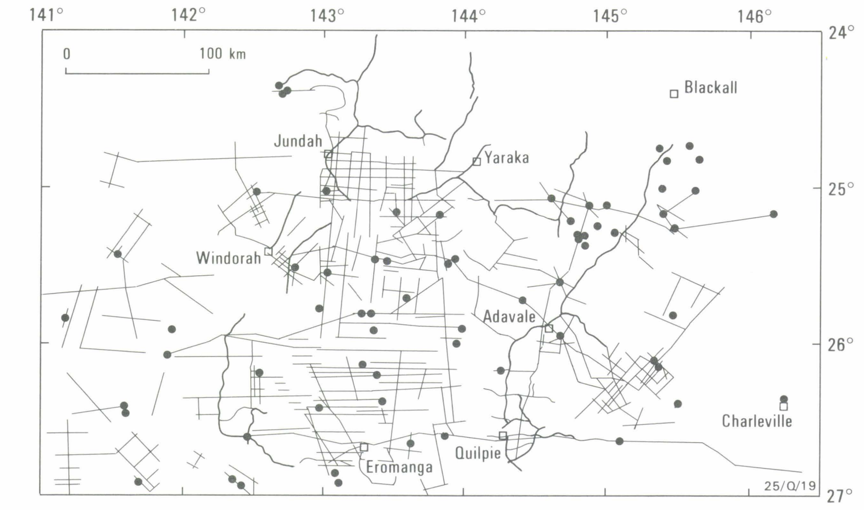
The oldest dated oceanic crust — identified by magnetic anomaly patterns — to the east of the Kerguelen Plateau in the South Indian Basin is about 40–45 Ma. Houtz & others *(op. cit.)* hypothesised that a sudden change in basement depth — apparent on a seismic line off the eastern flank of the northern plateau — represents a structural boundary. They ascribed the anomalously deep crust adjacent to the plateau to a mantle hotspot, presumably locally weakening the lithosphere and producing a moat effect. We have tentatively confirmed the existence of this zone of deep basement on the basis of a similar change in depth on our southernmost seismic line. However, we suggest instead that it reflects a spreading episode predating the separation of Australia from Antarctica. The tectonic implications of this hypothesis are significant: all reconstructions to date have employed a bathymetric contour to fit the Kerguelen Plateau to the Broken Ridge, whereas it now seems appropriate to use the crustal-depth discontinuity to mark the northeastern boundary of the Kerguelen Plateau crustal province in reconstructions of Australia and Antarctica.

Our only geological sampling was achieved using free-fall grabs, surely the most suspenseful way to go rock hunting at sea! Two adjacent sites on a prominent fault scarp on one of our seismic lines in the central southern plateau yielded less than 1 kg of rock. At the first site, the main rock types recovered were saprolitic fine-grained intermediate and basic volcanics, and fresh medium-grained granular granitic rocks. At the second site we recovered volcanic rocks similar to those recovered at site 1, plus a variety of granitic rocks, cataclastic granodiorite, a phyllite with a crenulation cleavage, quartz sandstone, and rare scoria. The volcanic rocks were angular and had thick coatings of manganese oxide, which suggests that they were scree material and had lain at their sampled site for some time. The granitoid samples, however, were partly rounded with thinner coatings of manganese oxide, suggesting that they were possibly reworked from another location, and had lain at the sample site for a shorter time. The association of granitic rocks, fine quartz sandstone, and phyllite with a crenulation cleavage implies a continental rather than an oceanic environment. This tantalising conclusion must be tempered by the possibility that these rocks were ice-rafted, perhaps during a previous ice-age. It seems that the final answer will only be arrived at after a systematic drilling program is undertaken. Happily, just such a program is tentatively scheduled for 1988 aboard the *JOIDES Resolution*.

For further information contact any of the following at BMR: Jim Colwell, Doug Ramsay, Mike Coffin, Hugh Davies, Peter Hill, Chris Pigram, or Howard Stagg.

Structural and tectonic styles in the Eromanga Basin

Analyses of the structural pattern and style apparent in seismic profiling records provide the key to interpreting regional tectonic processes (Harding & Lowell, 1979: *American Association of Petroleum Geologists, Bulletin* 63(7), 1016–1058). Such analyses by BMR of seismic data from the central Eromanga region have indicated two dominant structural trends. The earlier one is a northeasterly trend evident in the Devonian sequence of the Adavale Basin and Barcoo Trough, and the later one is a northwesterly trend affecting both Palaeozoic and Mesozoic sequences. Both trends can be interpreted in terms of transpressional tectonic processes affecting the basement.



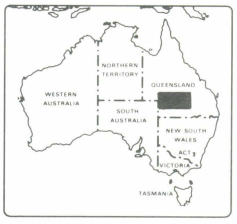


Fig. 6. Seismic traverses and petroleum exploration/ stratigraphic drillholes in the central Eromanga region. A = Adavale; B = Blackall; C = Charleville; E = Eromanga; J = Jundah; Q = Quilpie; W = Windorah; Y = Yaraka.

Since 1980, BMR has recorded 1400 km of six-fold CDP regional seismic data along traverses in the central part of the Eromanga Basin. With the co-operation of the Geological Survey of Queensland and exploration companies, BMR researchers have also examined a considerable number of other seismic sections, and, in addition, BMR staff have digitised and reprocessed many older single-fold recordings to assist with the regional study. The traverses examined in this study, totalling about 10 000 km, are shown in Figure 6. We report here the results so far of fault mapping within the central Eromanga Basin, and present preliminary interpretations of the regional displacement field, the tectonic controls on the fault patterns, and the distribution and style of structures due to post-Cretaceous reactivation.

Structural styles

Harding & Lowell *(op. cit.)* made a basic distinction between structural styles affecting basement and those which do not. Structures not affecting basement are detached normal faults (growth faults), decollement thrust-fold assemblages, salt structures, and shale structures. Structures affecting basement include wrench-fault assemblages, compressive and extensional fault blocks, basement thrusts, and regional warps. The recognition of these various structures on seismic records is important in the identification of structural styles, though some of them may originate in more than one tectonic environment.

Typical structures evident on seismic records in the central Eromanga region are illustrated in Figure 7a and b: an asymmetric ramp anticline within the Devonian sequence of the Adavale Basin, and a similar structure extending through Palaeozoic and Mesozoic sequences. Structures such as these clearly indicate the involvement of basement (i.e., the pre-Devonian rocks below the Gumbardo Formation). Laboratory experiments modelling structures due to deformation in a compressional tectonic environment have produced similar asymmetric ramp anticlines (Fig. 8), whose amplitude, style, and structural complexity are a function of the amplitude of movement in basement; the deformation is a by-product of crustal shortening.

Folds and faults within the Jurassic–Cretaceous Eromanga Basin sequence, including most of the hydrocarbon-bearing structures, can readily be shown to result from relatively small-scale reactivation of pre-Permian structures, most of which can be related to specific faults or fault zones in the basement. For these reasons, we mapped faults at the top-Devonian unconformity to determine the regional structural pattern and style, and to gain a better understanding of the regional displacement field during both pre-Permian faulting and post-Cretaceous reactivation. In addition, we have categorised the faults according to dip, and direction and amount of displacement. The results are shown simplified in Figure 9.

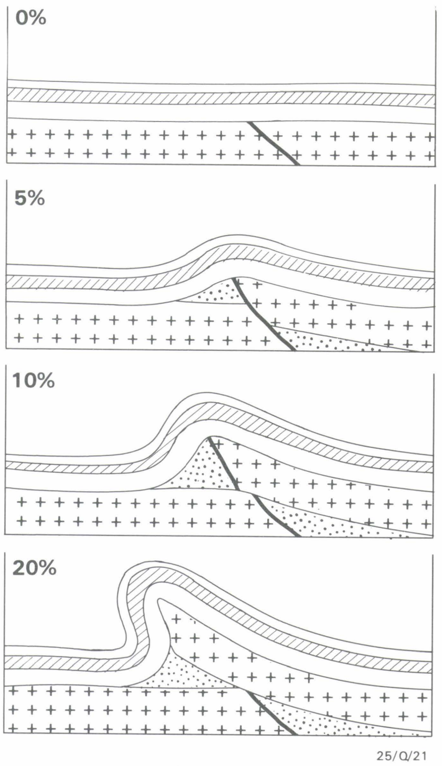


Fig. 8. Stages in the formation of a fold developed experimentally above a ramp; the percentage shortening during each stage is indicated (after House & Grey, 1982 *American Association of Petroleum Geologists, Bulletin* 66, 830-842).

Broadly, the central Eromanga region comprises two distinct structural domains separated by the north–south-trending Canaway Ridge. To the west, faults are relatively uniformly spaced, and have small to moderate displacements and northwesterly trends. To the east, fewer faults with substantially larger throws and a range of strikes are apparent, though a northeasterly trend seems to prevail.

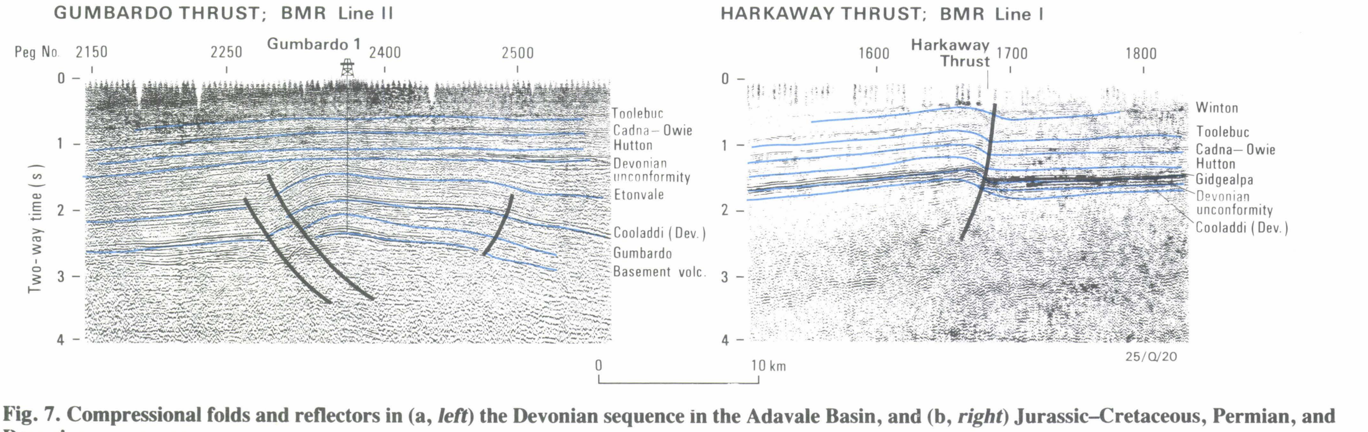


Fig. 7. Compressional folds and reflectors in (a, *left*) the Devonian sequence in the Adavale Basin, and (b, *right*) Jurassic–Cretaceous, Permian, and Devonian sequences.

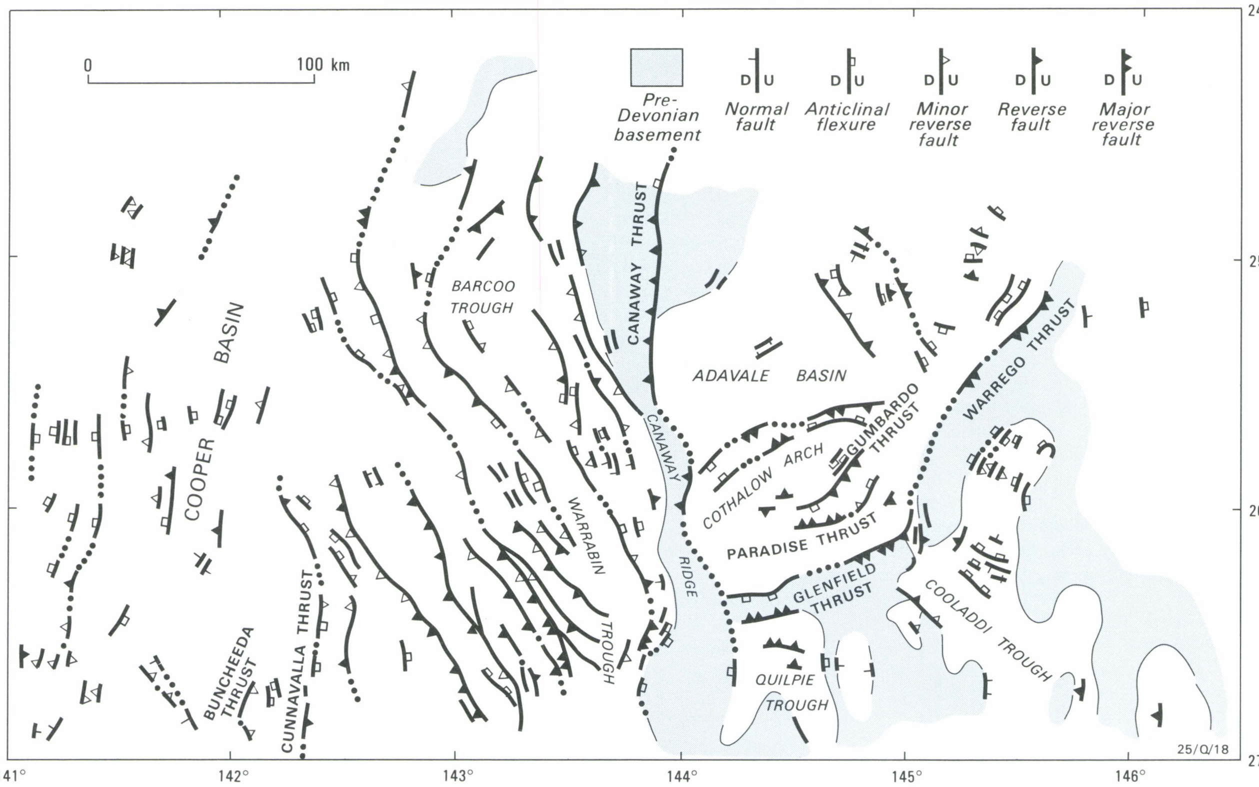


Fig. 9. Fault patterns at the top-Devonian unconformity in the central Eromanga Basin region. Reverse faults vary in amplitude from anticlinal flexures (no throw), to minor reverse faults (throw less than 100 ms), reverse faults (throw between 100 and 500 ms), and major reverse faults (throw more than 500 ms).

Most of the non-vertical faults are reverse faults. In the western domain, many of the faults are sinuous, and the amounts of displacement across them commonly vary with changes of strike direction. In contrast, a number of faults in the eastern domain shown extreme variations in throw along their strike. For example, either side of the Gumbardo arch, major reverse faults pass into gentle anticlinal flexures; the disposition of these two bounding faults — the Gumbardo Thrust, whose throw increases to the east, and the Paradise Thrust, whose throw increases to the west (Fig. 9) — strongly suggests that the Gumbardo arch has rotated about a roughly vertical axis, generally in a left-lateral (anti-clockwise) sense (Fig. 10).

In places, the Canaway Ridge is bounded on both sides by steep reverse faults which have been repeatedly activated. The various features of the ridge strongly suggest that it is mainly a strike-slip fault zone with an important transpressional component. Other northwesterly trending faults in the western domain also have a strike-slip character, and so do a number of fault zones in the eastern domain — e.g., the Warrego Thrust and the Cothalow Arch.

Tectonic interpretation

The fault and displacement patterns within the Devonian sequence beneath the central Eromanga Basin are diagnostic of a broadly transpressional tectonic regime during the Carboniferous. In many places subsurface features can be linked directly with those mapped at the surface. One important northeasterly trending structure is the Glenfield–Warrego Thrust system (Fig.9), which parallels the major gravity lineament associated with the edge of identified Precambrian basement — the Diamantina gravity gradient — about 400 km to the northwest. Veevers & Powell (1985: *in* Phanerozoic Earth history of Australia, *Clarendon Press, Oxford* 340–347), using a Rio Grande Rift analogue, suggested that northwesterly-southeasterly directed regional lithospheric compressive stresses affected the central Eromanga Basin basement during the Silurian. These stresses are consistent with the seismic data, and with transpressional reactivation — some time in the Carboniferous — of faults which they generated; that is, with northeasterly trending left-lateral shear movements.

To the west of the Canaway Ridge, we have been able to interpret a number of subdomains bounded by roughly northwesterly trending faults. Within these subdomains, thrust-faults indicate northeast–southwest shortening throughout the Palaeozoic and Mesozoic sequences.

The structural style west of the Canaway Ridge strongly suggests that the trends result from right-lateral movement due to transpressional stresses within basement in a broad zone between the Canaway Thrust and the Cunnavalla Thrust, possibly even as far west as the Buncheeda Thrust (Fig. 9). The influence of these transpressional stresses probably can be traced northward from the Canaway Thrust across the Maneroo Platform through the Stormhill–Westland–Darriveen Fault system, and southward from the Cunnavalla and Buncheeda Thrusts along the western edge of the Wompah Anticline.

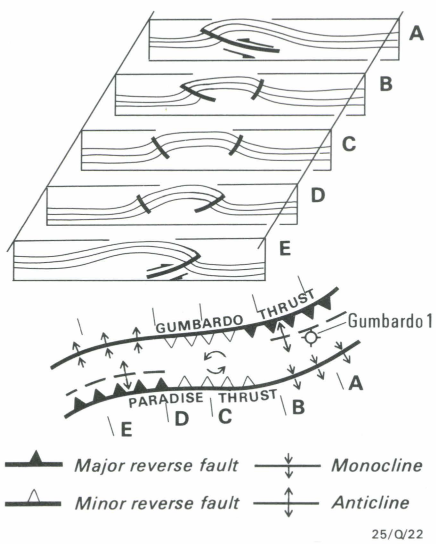


Fig. 10. Sections through the rotational break-through structure near Gumbardo No. 1 well.

In order to further test this transpressional model, the fault pattern needs to be mapped over a larger area to the north and south. Such mapping would rely entirely on exploration industry data, and we would welcome the opportunity to work collaboratively on those data. The recent exploration drilling successes in the Kenmore and Tintaburra areas illustrate the importance of the structures described in this article for the economic future of the Eromanga Basin. Understanding the processes involved in their evolution is regarded as an important research objective by BMR.

For further information contact Drs Doug Finlayson, Jim Leven, Gordon Lister, or Mike Etheridge at BMR.

Farewell

John Ferguson

John Ferguson resigned in April of this year from his position as Chief Scientist at BMR, in order to return to private consulting.

John had two periods at BMR: 1974–81 — first as a Science 3, then as a Science 4 (including one year on exchange at Pancontinental Mining Ltd); and — after a year spent establishing his own prospecting/consulting company, Spar Resources — he returned in late 1982 to take up the position of Chief Scientist in the newly created Division of Petrology & Geochemistry. His research during these periods concentrated mainly on alkaline ultramafic rocks, uranium mineralisation, and cryptoexplosion structures.

John brought with him to BMR the extensive experience that he had accumulated while studying alkaline rocks in Greenland (where he did his Ph.D. on the Kvanefjeld Illímaussaq Complex), South Africa, and Canada. His interest in kimberlites led, initially, to his study of the kimberlite-like basaltic breccia pipes of southeastern Australia, and, more recently, to the initiation — in collaboration with exploration companies — of current BMR research into the diamondiferous lamproites and the diamonds of Ellendale and Argyle. The results of much of this research in Western Australia will be presented at the Fourth International Kimberlite Conference in Perth in 1986.

An interest in uranium mineralisation inevitably drew John's attention to the Pine Creek Geosyncline. His high point in uranium research came in 1979 with the International Uranium Symposium on the Pine Creek Geosyncline (held in Sydney), which he helped to organise. Individually or in collaboration with colleagues, he contributed eight papers to the symposium, and was the editor of the published proceedings. On his return to BMR in 1982, he became the Australian representative on various working groups, advisory groups, and technical committees of the International Atomic Energy Agency.

Another interest that John brought with him to BMR was research into the origin of cryptoexplosion structures. In collaboration with scientists from Australia and overseas, he undertook research on several of these enigmatic features in Western Australia and the Northern Territory.

BMR benefited considerably from John's unique range of experience and specialist skills when he was appointed the inaugural Chief Scientist of the Division of Petrology & Geochemistry. As such, he was charged with establishing for the Division a program of work compatible with BMR's new role of developing an integrated, comprehensive, scientific understanding of the geology of Australia as a basis for minerals exploration. The relevance to the exploration industry of the new projects he initiated is borne out by the cordial relations that the Division enjoys with the collaborating companies, by the success of 'The Early to Middle Proterozoic of northern Australia' workshop at the BMR Symposium last year, and by the maps and research publications of the Division.

BMR takes this opportunity of thanking John for his many contributions to the organisation, and of wishing him well in the future.

Database directory

BMR has recently published a directory of government geoscience databases in Australia. The directory is the result of a questionnaire that was distributed to government geoscience organisations in Australia in 1984. It has been produced to facilitate access both to the large resources of geoscience data created and/or held by those organisations, and to make those organisations aware of each other's database activities.

BMR has responsibility for co-ordinating government geoscience database activity in Australia as part of its overall national database function. This responsibility was endorsed by the Australian Mines and Energy Council in 1984, following a recommendation by the Government Geologists' Conference.

The directory contains information on 253 databases in 37 Commonwealth and State government departments and authorities. Of these databases, 57 are reference (bibliographic) databases and 196 are source databases containing both numeric and factual data. About two-thirds of the databases are either fully or partly computerised, and computerisation is proposed for several others. Only three of the databases are publicly available on-line. However, information in 60 per cent of the databases is publicly available, in whole or in part, in other ways.

The directory has been published as BMR Report 269, and it can be purchased from the BMR Bookshop in Canberra, the AMF Bookshop in Adelaide, and Australian Government Publishing Service (AGPS) Bookshops in all capital cities. The price is $9.50 (plus postage — 530g).

More details from Mr Paul Shelley, BMR.

Microbiologically enhanced oil recovery

Since 1980, the Baas Becking Geobiological Laboratory in collaboration with the Resource Assessment Division of BMR has been investigating the feasibility of microbiologically enhancing the recovery of oil (MEOR). This research is supported by NERDDC and by oil companies both directly and through AMIRA.

The technique is, at least superficially, simple. Selected organisms are introduced into the reservoir, where they produce a surfactant which reduces the interfacial tension between water and oil — thus reducing the capillary forces. High capillary forces constitute one of the main parameters responsible for the retention of residual oil in reservoirs, and thus for the low average global oil recovery — about 30 per cent. Despite its apparent simplicity, however, the technique cannot be considered for use unless various parameters of the reservoir being investigated — for example, petrophysics, mineralogy, microbiology, and environmental stresses — are understood; some of these parameters may have to be modified for some reservoirs.

A microorganism able to reduce the oil-water interfacial tension from about 50 mN m^{-1} to 0.6 mN m^{-1} has been isolated in the Baas Becking Laboratory. Application of the microbiological techniques by the Laboratory to simulated systems have resulted in a maximum oil recovery from experimental cores of 56 per cent of oil in place, a marked improvement on the 40 per cent recovery by water displacement. When the method was applied to a virgin core, the recovery was 66 per cent. Comparative tests with natural field cores from Alton (Surat Basin) produced a recovery of 70 per cent (Table 2).

The cost of each additional barrel produced by MEOR has been estimated by the University of London to be less than US$0.50, which is considerably less than that produced by other enhancement techniques; the cost of each additional barrel obtained by chemical enhancement, for example, has been estimated by overseas operators to be at least US$15.00.

Proved and probable commercial Australian oil deposits not recoverable with present technology represent more than three billion barrels. The value of such deposits at US$25 per barrel is more than US$75 billion. Therefore there is a strong incentive to improve, even if only marginally, the oil recovery in Australia: an increase in recovery of only 0.1 per cent represents a revenue of US$75 million.

Research on this project during the next two years will involve continuation of the search for useful bacteria, and, in addition, the following topics:

- evaluation of the concentration of surfactant that will be required for optimal recovery from a given reservoir;
- the development, from laboratory and field data, of a numerical model for MEOR; and
- application of numerical simulation to a variety of Australian reservoirs so that we can predict the effects of MEOR.

As currently planned the research will be complete by the end of 1987.

For further information, contact Dr Dan Bubela (Baas Becking Geobiological Laboratory) at BMR.

New source for industrial minerals' prices

In March 1985, BMR made a computerised database (IMPRI) available for public acces through the international computer time-sharing network — IP Sharp Associates Pty Ltd. IMPRI provides ready access to annual average 'unit values' of industrial mineral imports and exports. (The annual average unit value is the aggregated value of all shipments made during the year divided by the aggregated quantity shipped over the same period.)

IMPRI contains the annual average unit values of imports and exports of 37 industrial minerals (Table 1) for which market prices are not readily available on a f.o.b. (free-on-board) basis. The unit values of most minerals go back as far as 1950. Sources of data are the Australian Bureau of Statistics and the US Bureau of Mines.

Trade journals publish some prices as a range to reflect variations in chemical of physical quality, quantities purchased, etc.; however, most prices quoted include shipping costs (c.i.f.) to Europe and are therefore of limited interest in Australia. Average unit values contained in IMPRI are based on the value of the mineral product and do not include shipping costs.

IMPRI is maintained by BMR's Mineral Commodities Section, which collects, monitors, and publishes prices of metals as an integral part of its mineral commodity studies.

IMPRI can be used to provide tables and graphs (Fig. 11) of selected data, price equivalents in foreign currencies, real prices, etc., which can then be stored for future reference or further processing. This can be achieved by linking IMPRI to other databases on IP Sharp's network.

More details from Mr Brian Elliott, BMR.

Table 1. Mineral commodities for which annual average unit values of imports and exports are available in the IMPRI database

Australian unit values		
Commodity exports		
• Gypsum	• Rutile	• Talc
• Ilmenite	• Salt	• Zircon
• Monazite		
Commodity import		
• Sulphur		
United States unit values		
Commodity exports		
• Bentonite	• Kaolin	• Potassium sulphate
• Boron	• Mica	• Quartz
• Diatomite	• Phosphate	• Sodium carbonate
• Felspar	— superphosphate	• Sulphur
• Industrial diamond	— elemental phosphorus	• Talc
Commodity imports		
• Asbestos	• Graphite	• Rutile
• Barite	• Gypsum	— titanium metal
• Chromium	• Ilmenite	— titanium dioxide
• Ferrochromium	• Magnesia	— pigments
• Fluorite	• Manganese	• Salt
• Ferromanganese	• Monazite	• Silicon
• Ferrosilicon	• Peat	• Zircon
• Ferrovanadium		

Table 2. Oil recovery tests by water and bacterial medium displacement

Recovery techniques	*Residual water saturation (% PV)*	*Water displacement characteristics*		*Bacterial medium displacement characteristics*		*Total oil recovery all processes (% OIP)*	*Remarks*
		Water throughout (PV)	*Oil recovery (% OIP)*	*Medium throughput (PV)*	*Additional oil (% OIP)*		
a. Simulated core of sintered discs: pore volume 108 ml; absolute water permeability 120 md							
Water displacement	26	22	40	—	—	40	Maximum recovery at 4+2 PV
Water followed by sterile medium	25	22	41	18	1	42	Maximum recovery at 4+2 PV
Water followed by inoculated medium	26	22	42	18	14	56, 54, 54*	Maximum recovery at 4+2 PV
Sterile medium displacement in virgin core	25	22	48	—	—	48	Maximum recovery at 4 PV
Inoculated medium displacement in virgin core	24	—	—	18	66	66	Maximum recovery at 4 PV
Water followed by reverse flow with water	24	22+20	40+0	—	—	40	Water displacement reversed after 22PV
Water followed by reverse flow with sterile medium	24	22+20	40	18	1	41	Flow reversed after 22 PV
Water followed by reverse flow with inoculated medium	24	22+20	39	18	8	47	Flow reversed after 22 PV
b. Alton field core: pore volume 78 ml; absolute water permeability 125 md							
Water followed by inoculated medium	63	12	49	14	21	70	Maximum recovery at 3+2 PV

* Results of 3 independent experiments. PV = pore volume; OIP = oil in place.

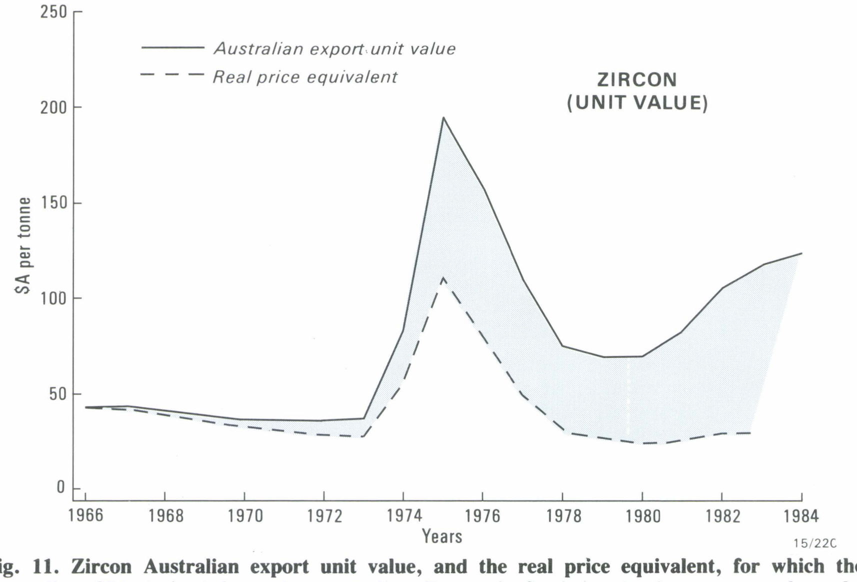


Fig. 11. Zircon Australian export unit value, and the real price equivalent, for which the Australian CPI derived from the Australian Economic Statistics database was used as the deflator.

Reviews

Selected recent publications

Morphotectonics of passive continental margins, edited by C.D. Ollier; *Zeitschrift für Geomorphologie*, supplementband 54, 1985: 117 pp, 43 figs. 5 tables; ISBN 3 443 21054 6; £22.70 from Blackwells, Oxford, England.

In this slim volume, Ollier and associates have pointed their fingers at an extremely interesting phenomenon: passive margin mountains. Though Australians are familiar with the Eastern Highlands — comprising the Great Escarpment, which runs along the length of the eastern coastline, and the associated gentle anticlinal warp defining the continental drainage divide — probably most of us do not think of them as passive margin mountains.

Passive margin mountains are not mountain ranges in the Alpine sense, since they are commonly defined by scarps (related to normal faults formed at the time of continental breakup) which have slowly retreated inland, and by a characteristic topography of incised uplifted (pre-mid-Triassic?) planated surfaces. Consequently, owing to this incision and scarp retreat, the degree of topographic roughness of these mountain ranges has increased drastically since the peneplain was uplifted. Even though they are generally only 1.5-2 km high, passive margin mountains define some of the greatest landforms on planet Earth.

In addition to the Eastern Highlands, other examples of passive margin mountains discussed in this volume include the High Veld and the adjacent Drakensburg in South Africa, the Ghats in peninsular India, the Guyana Highlands in South America, and the Transantarctic Mountains. Ollier points out that the morphology of many of these ranges has been explained by local variations in climate and/or structure, but as a group their association with passive margins seems to require an origin of more global import. With this view I concur, and current work on the mechanism of continental extension may provide the solution to these enigmatic phenomena.

Unfortunately, supplementband 54 of *Zeitschrift für Geomorphologie* does not seriously address the geophysical characteristics of passive margin mountains. Be that as it may, geophysicists will now have to seriously address the significance of this geomorphological contribution to the database on passive margins.

Reviewed by Dr Gordon Lister of BMR.

Australian Geoscience, 1984. Annual report of the Australian Geoscience Council Inc., compiled and edited by John Roberts; *BMR Report* 268; 1985; 50 pp, 8 figs., 19 tables, appendix; ISBN 0 644 04049 1, ISSN 0084-7100; available free on request to the BMR Bookshop or the AMF Bookshop.

The Australian Geoscience Council is but a few years old and still feeling its way towards a raison d'etre and a general philosophy of broad objectives, together with a policy for their achievement. The various Earth-science bodies which together make up the Council have, indeed, such a wide spectrum of interests that, while they have in common a concern with matters relating to the Earth as a source of materials and an interest in its physical properties, they are not infrequently in conflict over means and ends.

The Council claims two principal roles: firstly, keeping Australian scientists informed of developments across the whole Earth-science field; and secondly, uniting their interests in a single-minded approach to public and political relations. Both are commendable objectives, but their achievement is totally dependent on adequate communication mechanisms both within the profession and with governments and the public, involving a public relations skill for which the profession has hitherto displayed little aptitude.

The annual report, now to hand for the calendar year 1984, is the means by which the Council hopes to reach its constituent organisations, and thence their members. By courtesy of both the Minister for Resources & Energy and the Director of BMR, it is published this time in the *BMR Report* Series (No. 268), and is available free on request from BMR, from AGC, and from the member organisations. In addition to reports from the President, the Secretary, and the Treasurer, the document contains an extensive review of the status of the geosciences in Australia, taking each subdiscipline in alphabetical turn (some twenty-nine of them!) and outlining current developments, important publications, and research programs. Then follows a review of the activities of the many institutions and organisations which are involved in the professional promotion of geoscience projects, covering the Australian Mineral Foundation, BMR, CSIRO, and the geological surveys of the States and the Northern Territory.

Other reviews and articles cover: expenditure on geoscience research in Australia ($71.5 million 1983-84); noteworthy mineral and hydrocarbon

(continued in column 1, p.8)

Characterisation of Australian petroleum accumulations

Australian identified petroleum accumulations are the subject of a comprehensive study by the Petroleum Branch of the Resource Assessment Division in co-operation with petroleum companies and State departments of mines. The aims of the study, which started in 1984, are:

(i) to provide an understanding of the characteristics and distribution of Australian petroleum accumulations;

(ii) to provide assistance for future exploration for additional petroleum reserves; and

(iii) to enhance basic geological and geochemical research.

The modus operandi of the study is to compile basic data on a basin–accumulation–trap–petroleum-bearing unit hierarchy (Fig. 12). For the Amadeus Basin the compilation has shown that at least 17 petroleum accumulations comprising 29 traps and 41 petroleum-bearing units have been identified.

Data used in the compilations are being drawn from the continuing petroleum exploration and development programs in sedimentary basins in which the detailed assessments of individual petroleum accumulations have been released by the operators and State departments of mines.

Administrative and technical data on each petroleum accumulation are then presented in the form of computerised and graphic summary sheets. These data sheets — accompanied by a concise text on each basin's geological setting, structures and traps, reservoir and source rocks, petroleum characteristics, and petroleum resources and development, and by a recommended bibliography — will be published in a new BMR monograph series entitled *Australian Petroleum Accumulations*.

So far, the data for four basins — the Amadeus, Gippsland, Bass, and Otway Basins — have been assembled into draft reports, and compilation of data for the Surat–Bowen, Eromanga–Cooper, and Bonaparte Basins is continuing.

For further information, contact Dr Stanley Ozimic at BMR.

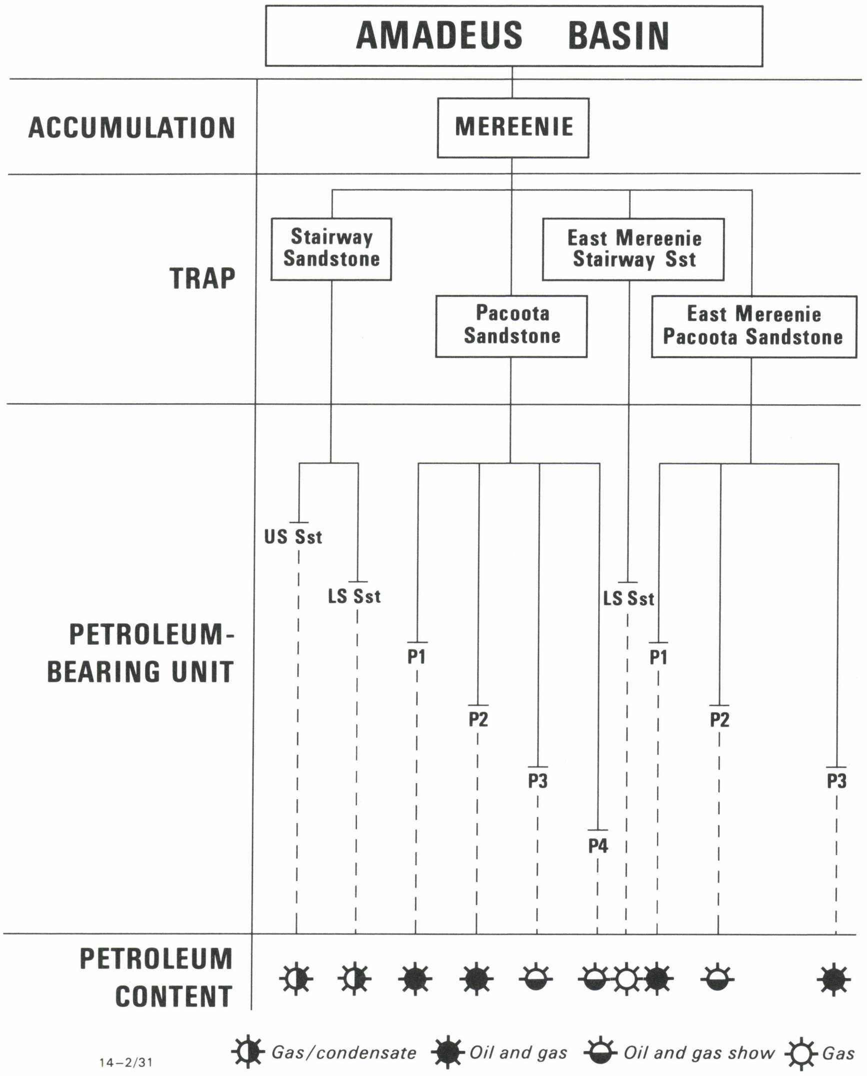


Fig. 12. Hierarchical presentation of the Mereenie petroleum accumulation in the Amadeus Basin.

Recent publications — reviews

(continued from p. 7)

discoveries in 1984; a summary of the history of palaeontology in Australia; laboratory research on petroleum generation; geoscience in teaching institutions (with tabulations of enrolments, 1983 graduates, and post-graduate students); a discussion of a questionnaire sent to geoscientists seeking to quantify the impact of the mobility of the profession on personal and family life; and finally an 'Expanding Geoscientific Acronym Dictionary' (EGAD!) covering to date some three hundred and fifty organisations, projects, and functions.

An appendix tabulates data on the AGC member societies, including their objectives, activities, publications, awards, and linkages with other associations.

This is the Third Annual Report of the AGC, the first to be published in the present form, and it is hoped that it will achieve a wide circulation. Members of the geoscience professions should feel a glowing sense of *esprit de corps* on browsing these pages, even if the public, or more significantly, the politicians, may prove harder to convince.

The compiler and editor of the present document is John Roberts, of the School of Applied Geology, University of New South Wales.

Reviewed by the Australian Mineral Foundation: AMF Informative Book Review Series No. 951.

BMR's new numerical reservoir simulator

The estimation of oil and gas reserves, and the prediction of the performance of a reservoir, often entail solving complicated partial differential equations which define the flow of all fluid phases in a reservoir. These equations cannot always be solved analytically without using many simplifying assumptions to reduce the complexity of the problem. Some of these simplifying assumptions may lead to an unrealistic solution to the problem.

An alternative way to solve these partial differential equations is by the use of numerical methods. Since the development of high-speed digital computers, numerical simulation using finite-difference techniques has been widely accepted by the scientific community, and simulators have become a conventional tool for solving reservoir engineering problems.

The Reservoir Engineering Group of BMR has acquired the necessary hardware to perform numerical simulation by accessing the Vectorised Implicit Program (VIP), which is a software package developed by J.S. Nolen & Associates Inc. VIP, which is sorted in a mainframe computer located in Melbourne, is a black-oil simulator capable of simulating a system where gas, oil, and water phases are present in any proportions.

In VIP, a finite-difference grid, replicating the structure of the field, may be constructed in either rectangular (x–y–z) of radial (r–θ–z) co-ordinates using either one, two, or three dimensions. Each block within the finite-difference grid is designed to contain a specified type of rock, defined by sets of relative permeability and capillary pressure values. Similarly, each block is assigned to a particular set of pressure-volume-temperature values (PVT) for the calculation of fluid properties.

The output from the simulator — such as the prediction of reservoir pressure, water encroachment, and gas/oil ratio — can be compared with the field production history, if any, of the actual reservoir being studied. If the agreement is not satisfactory, input data such as permeabilities, porosities, and fluid properties can be varied within the limits of the expected values from one run to the next until the agreement is satisfactory. The simulator can then be used to estimate oil and gas reserves for the field under study, and to predict the future performance of the field. Also, oil and gas reserves estimated by the model can be optimised by observing the sensitivity of the model output to various well completion and reservoir drainage options.

The Reservoir Engineering Group of BMR has already found the VIP reservoir simulator to be a valuable tool for estimating oil and gas reserves in a variety of fields throughout Australia. VIP now complements BMR's existing capability to monitor the development of Australia's oil and gas reserves.

For further information, contact Mr Graeme Morrison or Mr Lieng Nguyen at BMR.

PASSCAL

A new high-resolution seismic study of the continents

In December 1984 a consortium of over 50 American research institutions and universities (the Incorporated Research Institutions for Seismology, IRIS) announced proposals for an exciting new initiative in high-resolution seismic studies of the continental lithosphere. The *Program for Array Seismic Studies of the Continental Lithosphere* (PASSCAL) aims to apply techniques — developed by the oil exploration industry for defining geological structures in three dimensions (Fig.13) — to the deeper and more obscure parts of the continental lithosphere in North America. The program will be submitted to the National Science Foundation for funding over a 10-year period beginning in 1985–86. The budget calls for expenditure of US$1.6M in 1985–86, increasing to a steady-state annual expenditure of about US$13M in 1990–91. Because of BMR's commitment to seismic studies of the continental lithosphere in Australia, the American program has aroused great interest.

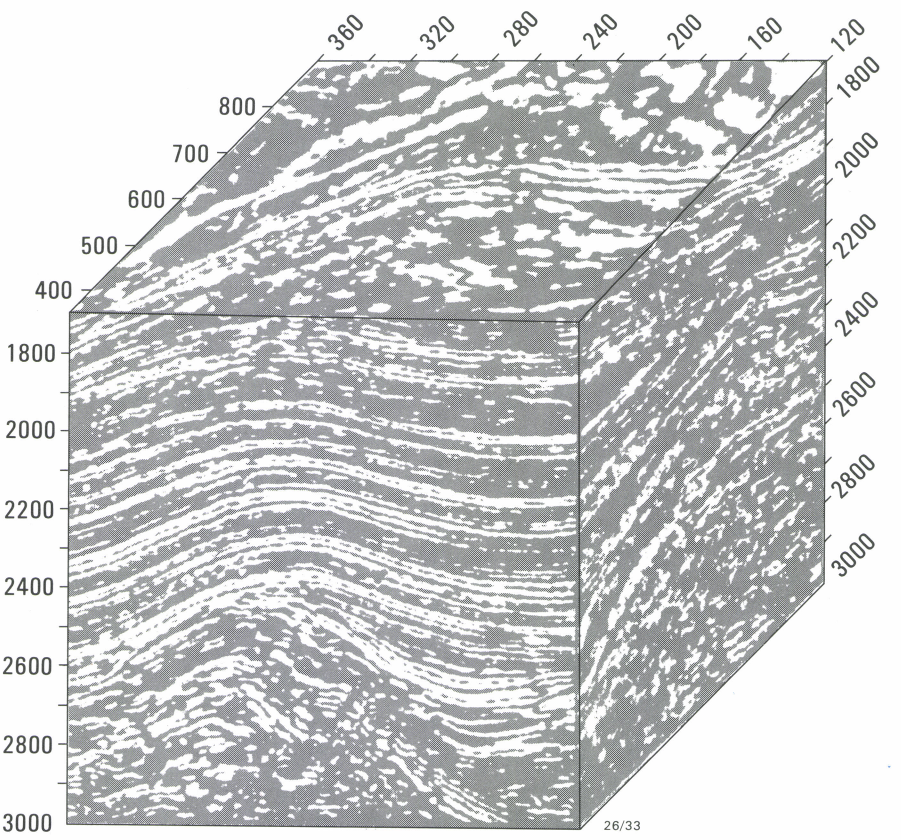


Fig. 13. This example of a three-dimensional fold structure (oil target) in sedimentary strata imaged from seismic reflection data at two-way times between 1700 and 3000 milliseconds is a data subset from a much larger three-dimensional tomographic data bank. It illustrates the detail of a three-dimensional seismic image that PASSCAL will provide from targets deeper in the lithosphere. (Reproduced with the permission of Sierra Geophysics, USA.)

By conducting surveys with two-dimensional arrays of seismic sources and recording points, and applying the increased power of computers to collect, store, process, and image the vast number of digital data thus collected, PASSCAL will improve on the technique most commonly used to generate seismic data — that is, shooting and recording along a single line. Such an improvement has put within the seismologist's reach the possibility of looking at targets in three dimensions deep within the Earth, much as an astronomer scans the universe using electromagnetic radiation, or the medical specialist scans the human body using ultrasonics — hence the term 'seismic tomography' has arisen.

Background

Most Earth-scientists will be familiar with the US Consortium for Continental Reflection Profiling (COCORP) seismic program, which has been under way for over 10 years and has had many outstanding successes in probing the structure of the continental lithosphere. In particular, this program has highlighted the large scale of many overthrust and decollement structures extending deep within the lithosphere. Similar reflection profiling research programs, have also been undertaken by Britain, France, Australia, and Canada. The reflection profiling technique relies heavily on impedance contrasts at structural/stratigraphic boundaries reflecting P-wave energy, impinging at near-normal incidence from a vibrator or explosive source, back to a one-dimensional seismic array with an aperture of less than 10 km. As with much pioneering research, part of COCORP's success is that it has raised as many problems as it has solved for the continental lithosphere — problems associated with the many reflectors in the lithosphere which have not yet been interpreted satisfactorily, and the controversial question of rock compositions deep in the lithosphere.

At the core of PASSCAL is the development of 1000 portable, six-channel, digital seismographs, each being — in effect — a self-contained data acquisition system which can be deployed for a minimum of 10 days. The flexibility offered by self-contained systems frees the seismologist from the need to be tied to a centralised data acquisition system via an electric cable, optical fibre, or radio telemetry link. A recording array can easily be set up in two-dimensions with an aperture which can be expanded, at will, from a few hundred metres to hundreds of kilometres, even in rugged terrain.

A further important aspect of PASSCAL is that it will not only use near-normal incidence P-waves but also take advantage of the multiplicity of other seismic phases traversing the target area using vibrator, explosive, and earthquake sources. Thus, PASSCAL is expected to determine not only the three-dimensional structure of targets from vertical incidence and wide-angle reflected phases but also the detailed P-wave and S-wave velocity structures, seismic attenuation, and anisotropy — all crucial to the determination of compositions in the deep lithosphere.

Figure 14 illustrates a possible configuration for looking at targets in the lower crust. The PASSCAL proposals state that one-dimensional seismic reflection profiling will still have a significant part to play in lithospheric studies, but PASSCAL will greatly extend the scope of seismic imaging the deep lithosphere.

PASSCAL systems development

Considerable thought has already been put into the design of the seismic data acquisition systems. Research institutions, oil industry representatives, and instrument manufacturers have been actively pursuing design goals since 1983, drawing on experience throughout North America and Europe. The Commission on Controlled Source Seismology of IASPEI (International Association of Seismology and Physics of the Earth's Interior) sponsored a design workshop in December 1983 which assessed all aspects of instrumentation based on existing technology. At the heart of each recorder will be a microprocessor-controlled data acquisition system which can be re-configured quickly and easily according to various survey requirements. One objective is to keep the unit costs for a six-channel recorder to below $A24 000 — i.e., about $A4 000 per channel (compared with about $A10 000 per channel for recently acquired seismic profiling equipment in Australia).

With the data-gathering capacity of 1000 instruments, no single institution could be expected to manage PASSCAL. The organisation of research will be undertaken by a management committee set up by IRIS. The PASSCAL instrumentation is regarded as a national facility, akin to other facilities such as particle accelerators, telescopes, and deep-sea drilling vessels. Equipment maintenance and support will be the responsibility of an appointed technical staff, but principal investigators and students from the co-operating institutions would be responsible for the scientific aspects of projects. Not all 1000 instruments need to be deployed on a single project; instrument subsets of 50–100 instruments may well be used on the simpler investigations.

PASSCAL will also require a data-management centre in addition to in-field processing facilities. The data generated by PASSCAL is potentially enormous; certain investigations are expected to generate 700 Gbyte of raw data from $3x10^7$ seismic traces. Part of the data-handling problem will be solved by having an in-field processing system for every 50 instruments, but a central data-management and archive system will be required to serve research seismologists in the longer term.

Targets

A number of proposed research projects which would greatly benefit from PASSCAL have already been identified. These include 1) lithospheric investigations along the trans-Alaskan oil pipeline route, where 28 tectonostratigraphic terranes have been identified; 2) detailed characterisation of structures at the southern Appalachian site for deep continental drilling; 3) the detailed lithospheric structure of the Ouachita orogenic system, Arkansas; 4) detailed studies of the Long Valley Caldera, California, and the associated deep-seated magmatic processes; 5) a complete geophysical transect of the Appalachian orogen in the Maine–Quebec region; and 6) the detailed study of hydrothermal systems at the Newberrry Craters, Oregon.

International co-operation

PASSCAL recognises that developments of a similar nature are taking place in Europe, Canada, Australia, and other countries. There are plans to encourage international co-operation through a PASSCAL Council of Foreign Associates. In Australia, BMR will be keeping in touch with PASSCAL developments. BMR's current program of explosion seismic research into the Australian continental lithosphere has many elements in common with the PASSCAL proposals. Any co-operation with instrument development, survey design, data-management techniques, and interpretation will certainly be beneficial to the Australian Earth-science community.

References

Proceedings of the workshop on portable digital seismograph development, Los Altos, California, 30 Nov.-2 Dec. 1983 (Convenors: R.P. Meyer, & R.F. Mereu). *Commission on Controlled Source Seismology, IASPEI*, February 1984.

Reports on portable digital seismograph development, Engineering Notes 1 (Compiler: R.P. Meyer). *Commission on Controlled Source Seismology, IASPEI*, April 1984.

PASSCAL — Program for Array Seismic Studies of the Continental Lithosphere. *Incorporated Research Institutions for Seismology*, December 1984.

For further information, contact Dr Doug Finlayson at BMR.

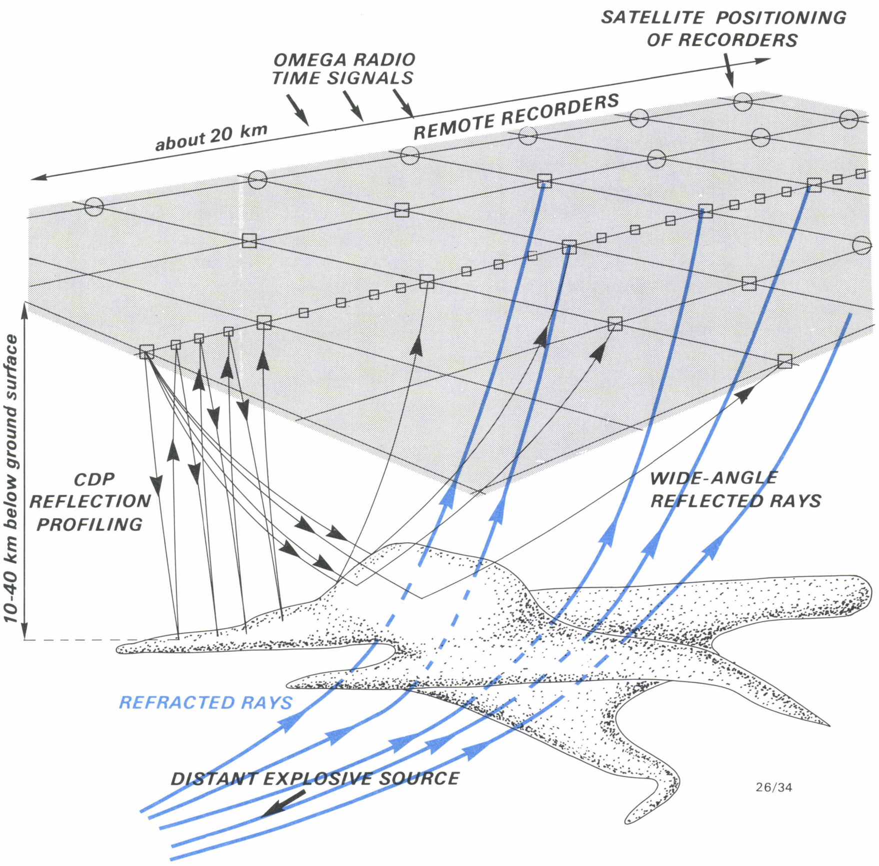


Fig. 14. Sketch of possible shot and recorder configuration for investigating features in the lower crust.

BMR's marine tau–p studies in preparation for a survey of the Exmouth Plateau

Marine tau–p studies allow depth–velocity information from the deep crust to be extracted from time–distance records mapping seismic arrivals from expanded-spread profiles (ESPs) up to 100 km long. This method of mapping from one domain to another removes the horizontal component of travel path, and gives a representation of refraction and wide-angle reflection velocity versus intercept time. This mapping can then be inverted to give depth–velocity data. In the tau–p domain, tau corresponds to refraction intercept time, and p is slowness — or the inverse of velocity. Centres of ESP spreads are joined by wide-aperture seismic reflection profiles, which give improved-quality deep seismic reflection information. The combined use of ESP and wide-aperture seismic reflection data can assist in resolving crustal structure.

In March 1986, BMR's Division of Marine Geosciences & Petroleum Geology will carry out a two-ship ESP and wide-aperture seismic reflection survey with scientists of the Lamont–Doherty Geological Observatory, a world leader in marine tau–p technology. For the ESPs, Lamont's RV *Conrad* will be the shooting ship, and BMR's RV *Rig Seismic* the receiving ship.

In preparation for this survey, BMR has developed a capability in processing ESP data. This began with a visit to the Lamont–Doherty Geophysical Observatory in New York, and discussions with scientific personnel regarding the processing of ESP data. Subsequently, software in the Marine Division's seismic reflection processing package has been applied and where necessary adapted to produce tau–p mapping of a test tape obtained from Lamont. An Nth-root coherence algorithm has been added to further enhance deep data, and the tau–p mapping has been inverted to give depth–velocity information. This capability is currently being refined, and forward modelling of the depth–velocity data is being investigated to round off the interpretational capability.

The Exmouth Plateau two-ship survey should provide greater understanding of the overall structure of the plateau, and of rift margins in general, which will have repercussions for petroleum evaluation of the Exmouth Plateau and other rift margins.

For further information, contact Dr Paul Williamson at BMR.

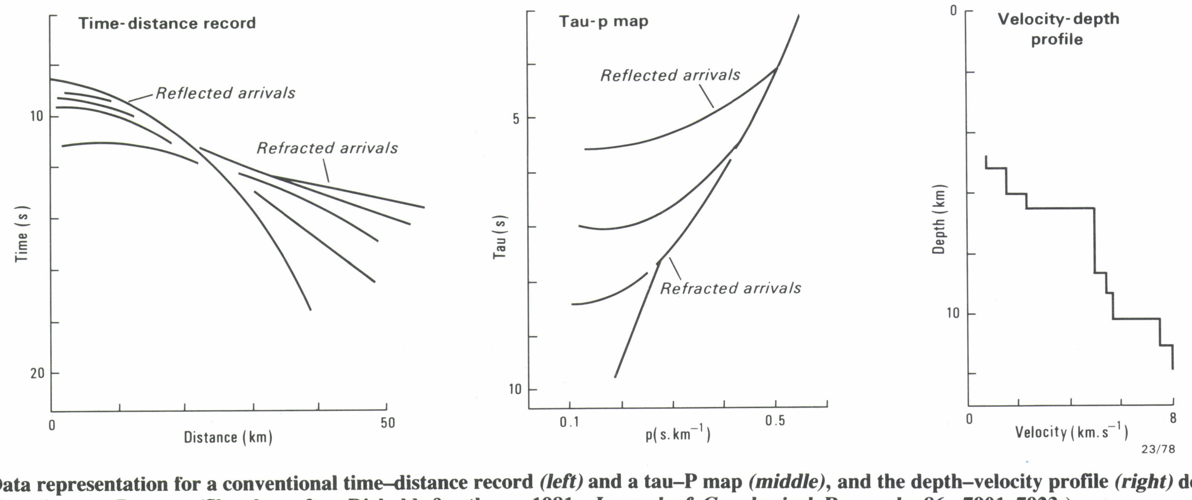


Fig. 15. Data representation for a conventional time–distance record *(left)* and a tau–P map *(middle)*, and the depth–velocity profile *(right)* derived by inverting the tau–P map. (Sketches after Diebold & others, 1981: *Journal of Geophysical Research*, 86, 7901–7923.)

Central Eromanga region

New ideas on the maturation history and development

Geochemical analyses of samples of potential source rocks from subsidised wells in Australia are providing BMR with an extensive database for investigating the nation's sedimentary basins. Though the data are used primarily to determine hydrocarbon potential, some of them are invaluable for resolving the thermal history and development of the basins. Source-rock data from 53 wells have been combined with other geological and geophysical data in a multidisciplinary investigation of the central Eromanga region.

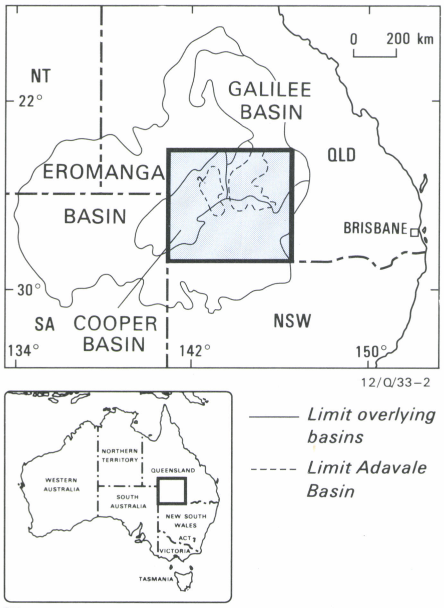


Fig. 16. Location of the central Eromanga region (blue screen) in relation to the Eromanga, Cooper, Galilee, and Adavale Basins.

The central Eromanga region, in the southwest corner of Queensland, contains up to 9.5 km of sedimentary rocks ranging in age from Early Devonian to Late Cretaceous. This sedimentary pile accumulated in four basins — the Eromanga, the Cooper, the Galilee, and the Adavale Basins.

The region has had a complex history owing to the tri-level stacking of the basins. The Devonian Adavale Basin, at the base of the stack, is partly covered by parts of the Permo-Triassic Cooper and Galilee Basins; the whole region is blanketed by the Jurassic–Cretaceous Eromanga Basin (Fig. 16). The cumulative effects of variation in sedimentary thickness in each basin, shifting of depocentres from basin to basin, differences in degree of deformation, and lateral variation in geothermal temperatures have produced complex patterns of rock maturity across the region.

Maturity ratings

Maturity ratings derived from vitrinite reflectance measurements and supplemented by data from headspace gas and Rock–Eval analyses were used to determine the maturation history of each of the basins. The maturity ratings — by which rocks are classified in their oil generation potential — are immature, mature, or overmature, depending on the degree of thermal alteration of their organic matter. Examination of vertical and lateral variations of the maturity ratings of rocks in different parts of the region and within a single basin have provided new ideas on the development of the basins in the region.

Thermal history and basin development

Eromanga Basin

The Eromanga Basin reflects the most widespread period of sedimentation. Its sedimentary pile — around 1000 to 3000 m thick — is thickest in the western part of the central Eromanga region (Fig. 17). As well as the sedimentary thickness varying laterally from west to east, so too does the geothermal gradient; the highest temperatures are in the west. The high maturity of rocks in the western part of the region relative to those in the eastern part results from combined higher temperatures and deeper burial west of the Canaway Fault.

The high geothermal gradients in the west are a relatively recent phenomenon that postdates deposition of the Eromanga sequence: moderate temperatures prevailed over most of the region until the mid-Tertiary, when the temperature rose to the present high values.

Cooper and Galilee Basins

The mature to overmature rocks of the Cooper Basin are a sharp contrast to the immature rocks of the Galilee Basin (Fig. 18). Sedimentary thickness, generally less than 1000 m, is similar for the two basins, but is much thinner than that of the overlying Eromanga and underlying Adavale Basins.

During the Permian and Triassic, high palaeotemperatures were localised within the Nappamerri Trough (southern Cooper Basin). Significant present differences in maturity between the basins are largely the results of (1) deep burial of the Cooper Basin during the Cretaceous, and (2) the present geothermal gradients, which are high above the Cooper Basin and relatively low above the Galilee Basin.

Adavale Basin

Unlike the Eromanga Basin, sedimentation in the Adavale Basin was concentrated at its eastern end, in the eastern half of the region; the maximum thickness approaches 8.5 km at the southeastern end of the basin. The original thickness

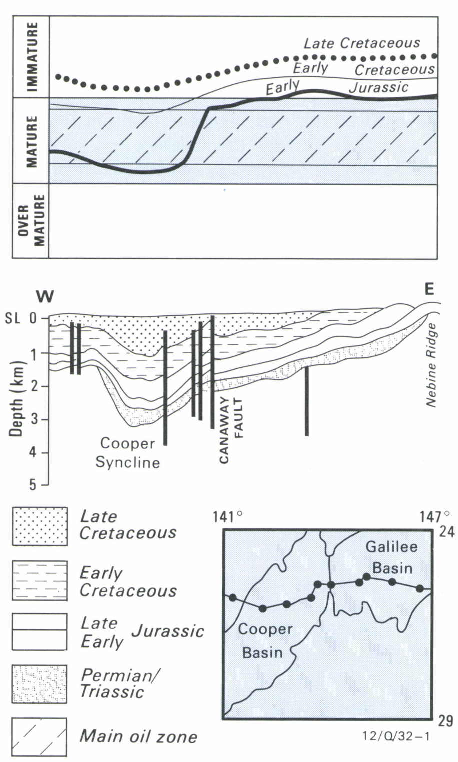


Fig. 17. The level of maturity of source rocks of different ages relative to the variation in their depths of burial and (not shown) the geothermal gradient in the central Eromanga region.

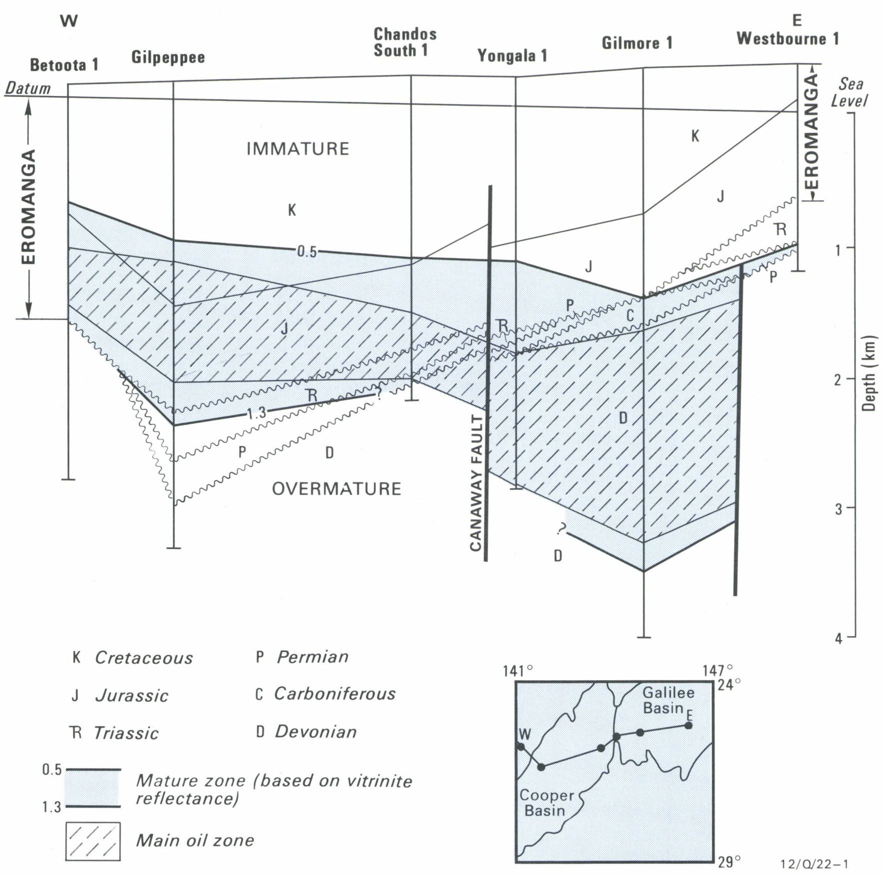


Fig. 18. Maturity ratings of rocks from west to east across the central Eromanga region.

may well have been far greater, as the maturity data suggest significant erosion and removal of sediment at the mid-Devonian unconformity. Although the basin was intensely deformed in the Late Devonian and Carboniferous, palaeotemperatures in the eastern Adavale Basin appear to have been highest during the Early and Middle Devonian. Maturity profiles suggest that temperatures in the Devonian were higher than those at the present day, and probably higher than the palaeotemperatures that prevailed during deposition of the sediments in the younger overlying basins.

These studies have confirmed that depocentres have migrated significantly and that palaeotemperatures have varied considerably with time. They are helping to reveal the timing of generation of hydrocarbons, and will help to delineate the more prospective source areas.

For further information, contact Ms Virginia Passmore at BMR.

In-situ crustal stress measurements

The Division of Geophysics, in collaboration with the CSIRO Division of Geomechanics, has recently constructed a new hydrofracture system for the measurement of in-situ crustal stresses in cored boreholes. This system has been used recently at a number of sites near Canberra, and has proved to be extremely successful. As funding permits, the system will be used Australia-wide to study variations in the regional stress field and to assist in assessing earthquake risk.

The hydrofracture technique uses two separate down-hole instruments to determine the horizontal stress field in the rocks around a borehole. The fracture tool determines the magnitudes of the principal horizontal stresses by isolating a short portion of borehole and hydraulically inducing a vertical fracture in the borehole wall. The impression tool determines the orientation of the stress field by recording the azimuth of the induced fracture.

The fracture tool (Fig. 19), built by BMR's Engineering Services Unit, comprises three functionally distinct parts: the upper and lower sealing packers, the test section, and the electronics assembly. The sealing packers are commercial units made of rubber and steel with a construction similar to that of a modern steel-belted radial tyre. Application of hydraulic pressure to the interior of these packers causes them to inflate and be pressed firmly against the borehole wall. In this way the intervening portion of the hole, termed the test zone, becomes effectively isolated from the remainder of the hole. The test section of the fracture tool is little more than a steel-housing containing a number of ports through which water can be injected into the test zone.

The electronics assembly contains a solenoid valve, a flow meter, two pressure transducers, and the associated electronics for these components. The flow meter monitors the motion of fluid into or out of the test section of the fracture tool, while the pressure transducers, which are mounted in the pressure lines leading to the packers and test section, provide sensitive measures of the pressure in the packers and the test zone.

Power to and signals from the tool are passed through a seven-conductor coaxial cable that also acts as the means of suspension for the tool. Two high-pressure hoses are used to connect the packers and test section to surface pumps.

The system is operated by inflating the packers and isolating the test zone from the rest of the borehole, and then by slowly increasing the pressure in the test zone and packers until a vertical fracture forms (see Fig.20). The creation and propagation of this fracture results in a drop in pressure in the test zone, and in the movement of water past the flow meter into the borehole. This fluid flow is a particularly sensitive indicator of the propagation of a fracture since water is virtually incompressible; no detectable fluid flow occurs with increasing pressure before the fracture forms.

From results such as those illustrated in Figure 20, the magnitudes of the maximum and minimum horizontal stresses can be determined. The directions of these stresses are then determined with the aid of the impression tool. This tool consists of an up-hole-reading magnetic compass system joined to an inflatable packer covered with a replaceable sleeve of very soft rubber. When this packer is inflated against the borehole wall, it records an imprint of the wall's features, particularly any fractures into which the rubber intrudes. From such impressions the orientation of induced vertical fractures, and hence the orientation of the horizontal principal stresses, can be determined.

The up-hole control system, pumps, valves, winches, and power supplies are mounted in a single truck, which makes field deployment of the hydrofracture system relatively simple.

Examples of results recently obtained at Berrigan (NSW) with the new hydrofracture tools in granite at depths between 69 and 167 m are listed in Table 3, together with two results obtained in the same locality by earlier workers using the alternative overcoring technique at shallow depths (< 5 m). There are two notable features in the results in Table 3. Firstly, there is a good agreement and a high level of consistency in both the magnitudes and directions of the stress estimates obtained by the overcoring and hydrofracture techniques. Secondly, there is a marked trend towards an increasing horizontal compressive stress magnitude with depth.

Table3. Stress measurements at Berrigan

Depth (m)	σ_H (Mpa)	σ_h (MPa)	Bearing of σ_H (E° of true N)	Technique
3.5	11.4	5.6	74	Overcoring*
3.8	12.1	9.5	80	Overcoring*
68.8	9.6–10.2	5.1–5.3	70	Hydrofracture
100.0	8.5–12.3	4.9–6.0	75	Hydrofracture
125.0	11.6–13.1	6.1–6.3	70	Hydrofracture
154.0	10.2–11.9	5.7–6.3	72	Hydrofracture
167.0	14.0–16.8	7.8–8.7	73	Hydrofracture

* Results from Denham & others (1979: *CSIRO Division of Geomechanics, Technical Report* 84).

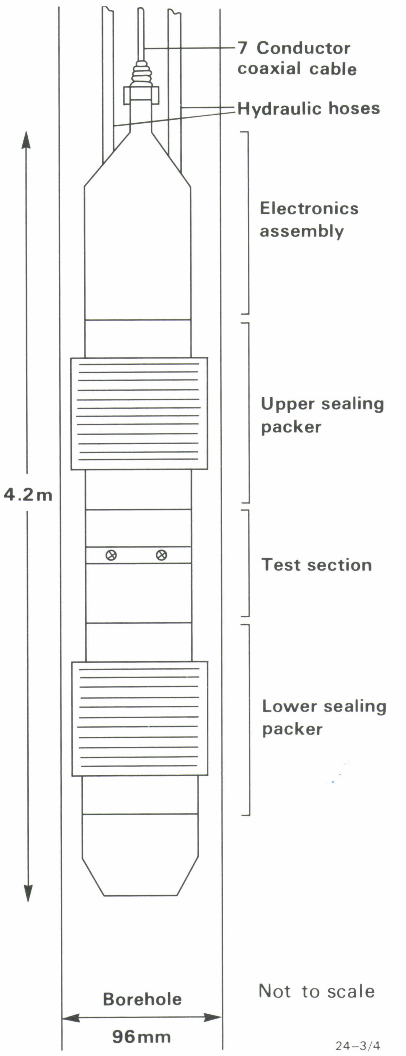


Fig. 19. Schematic diagram of the fracture tool built by BMR's Engineering Services Unit. The tool is depicted here with the sealing packers uninflated — as they are when the tool is being positioned in the hole.

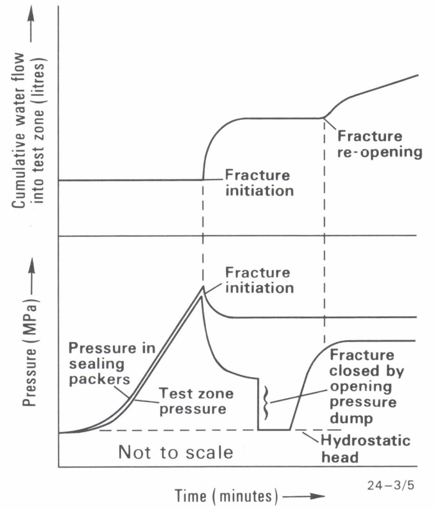


Fig. 20. Schematic diagram of the results of a typical hydrofracturing test. A vertical fracture is formed in the wall of the borehole in the test zone by gradually increasing the water pressure in the test zone and the hydraulic pressure in the sealing packers. This fracture initiation in impermeable rock is a function of the tensile strength of the rock and the horizontal principal stresses. Once the fracture has formed, the pumps are turned off, and the pressure falls as the fracture propagates. The so-called 'shut-in' pressure determined from this part of the test is a direct measure of the minimum horizontal principal stress (σ_h). The subsequent fracture-reopening pressure, determined after the fracture has been closed by venting the test-zone pressure to atmosphere, allows an estimate to be made of the maximum horizontal principal stress (σ_H).

The relatively high compressive stresses recorded at Berrigan have apparently persisted for some time, because there is ample evidence of ground deformation features such as pop-ups and stress-controlled jointing in the granites. Of even greater significance in this regard was the occurence of an earthquake of magnitude 5.5 on the Richter scale near Berrigan in 1938. This demonstrated potential for seismicity, when taken in conjunction with the relatively high stresses now recorded, suggests that further seismic activity can be expected near Berrigan in the future.

The new hydrofracture system is currently limited to an operating depth of 200 m in HQ (i.e., 96 mm diameter) or slightly larger boreholes. However, should suitable boreholes be available in future, there are no serious difficulties expected in accessing depths as great as 1 km.

For further information, contact Dr Prame Chopra at BMR.

A new advance in dating weathered profiles

BMR has recently redetermined Australia's apparent polar-wander path for the late Mesozoic and Cainozoic periods. The new path, and its implications for plate tectonics of the Australian–Antarctic–Indian region, mantle dynamics (true polar wander), and the nature of past geomagnetic fields, will be discussed in a series of three papers, of which the first two are in press. The motivation for this work was to improve palaeomagnetism as a tool for age dating of chemical weathering processes.

Dating by polar wander

Palaeomagnetic dating of weathered profiles is based on apparent polar wander (APW): the position of the palaeomagnetic pole as it was at the time of weathering is determined by measuring the mean direction of remanence in the iron-enriched parts of the profile; this position is plotted on the apparent polar-wander path, and the age is obtained by interpolation between dated poles on the path (Fig.21). Clearly, continents whose paths have the longest segments for the period of weathering — i.e., have drifted most rapidly — offer the best prospects for dating. For the Cainozoic, these are Australia, India, and possibly Africa.

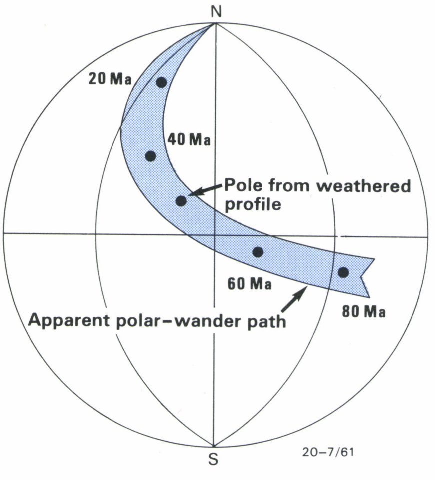


Fig. 21. Principle of palaeomagnetic dating by apparent polar wander. The age of the weathered profile is estimated by interpolating its pole position between dated poles on the idealised path.

The concept of dating rocks by measuring their remanence directions goes back to the early 1960s, before widespread use of the various isotopic dating techniques. Palaeomagnetism offered at that time rough age estimates, but the low sensitivity of the available magnetometers restricted it to the more strongly magnetised igneous rocks. The first attempts to apply the palaeomagnetic technique to weathered profiles appear to have been made in Australia by F.H. Chamalaun in the mid-1960s and by B.R. Senior and P. Wellman in the early 1970s. These studies demonstrated the feasibility of the method; however, they were of reconnaissance nature and remained unpublished. The first published studies appeared in the mid-1970s, and from then until the early 1980s the number of papers on palaeomagnetic dating of weathering phenomena in Australia, including weathered profiles, grew steadily to six. Several other studies have been reported in a preliminary way, but since 1982 no new papers have been published.

The studies indicate that intense chemical weathering in Australia was not restricted principally to the mid-Tertiary, as was once believed, but occurred as well during at least two other periods since the Early Cretaceous: in the latest Cretaceous or earliest Tertiary (when the host ironstones of Queensland's boulder opal were formed) and in the latest Tertiary. Most reports note the presence of both normal and reversed magnetisations in the same weathered unit and, less commonly, even within the same sample of weathered material. This phenomenon suggests that the remanence has been generally acquired over a period of at least 0.3 Ma — the mean time interval between successive Cainozoic reversals.

Current limitations of the method

Like most other methods, palaeomagnetic dating by apparent polar wander contains ambiguities and has limitations. These are, principally, (i) an uncertainty concerning the phase of the weathering process that is being dated, and (ii) poor age resolution.

If the major weathing periods have extended over several million years, as seems likely, do the magnetic ages signify their onset, termination, or an intermediate stage? Some insight on this problem may be gained by considering how remanence is acquired during weathering. For dating, the important magnetic minerals are the iron oxides — hematite and (the less common) maghemite. Goethite, an iron hydroxide, while moderately magnetic and also very common in chemically weathered rocks, can be remagnetised at relatively low temperatures — such as those encountered at the exposed surface of an outcrop on a hot, sunny day — and is therefore unsuitable for dating; its contribution to remanence is eliminated in the laboratory at the early stages of thermal demagnetisation. Lepidocrocite and feroxyhyte, two other moderately magnetic hydroxides, are not usually reported in significant amounts in weathered profiles. No other magnetic minerals are known to be produced in weathering. In a chemical process such as weathering, the remanence is acquired shortly after nucleation of the magnetic minerals, but it remains unstable until the grains have grown to a certain critical size. This so-called superparamagnetic threshold grain-size is about 0.03 μm for both hematite and maghemite. Thus the remanence that is being dated appears to be mainly due to iron oxides rather than hydroxides, and, moreover, to those oxide grains that have experienced some growth. This suggests that the magnetic age represents a relatively mature stage of profile development, possibly a dehydration phase at the end of intense weathering.

A much more serious problem with the palaeomagnetic dating method has been its poor age resolution, which has so far limited the dating to broad age bracketing. Consequently it has not been possible to determine with any certainty if the intense chemical weathering during the Cainozoic has been associated with periods of specific climate — for example, by linking the dates to oxygen isotope records in deep-sea sediments or to palaeobotanical assemblages.

The low age resolution is partly inherent in the palaeomagnetic method itself, because the remanence directions cannot be easily estimated more precisely than within a few degrees; as an overall average for the Cainozoic Era, an error of 1° in the remanence direction contributes an error of 0.5 Ma to the age. Even so, the main uncertainties in dating have come from the Cainozoic pole path, in which significant anomalies were revealed in the late 1970s when the Australian poles were compared with corresponding poles for India and the eastern Indian Ocean. The recognition of these anomalies accounts, at least partly, for the lack — since the early 1980s — of published palaeomagnetic dates for weathering.

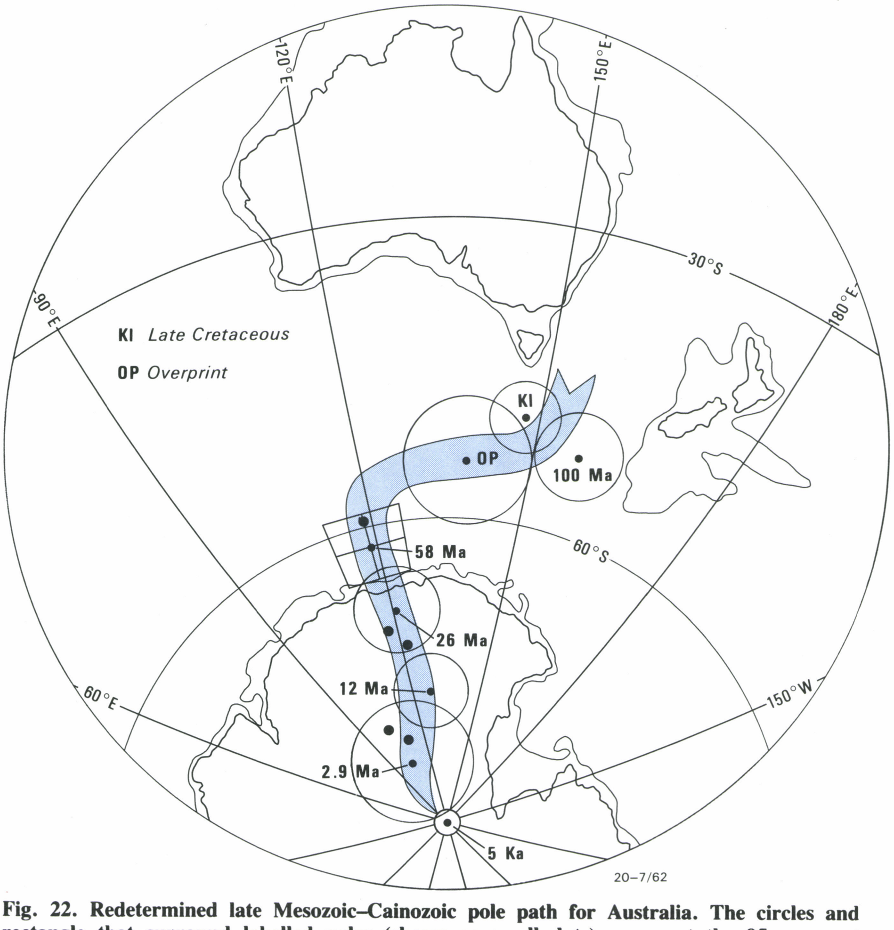


Fig. 22. Redetermined late Mesozoic–Cainozoic pole path for Australia. The circles and rectangle that surround labelled poles (shown as small dots) represent the 95 per cent confidence limits of the positions of the poles. The poles without labels (larger dots) have been derived from weathered profiles.

A new pole path

The recently completed study of late Mesozoic–Cainozoic palaeomagnetism of Australia has identified some of the sources of error in the Australian path. Having adopted an appropriate sampling scheme, we hope that these errors and some others — such as the inclination error in remanence to which sediments are prone — have been avoided in the new path (Fig.22). The new poles certainly agree with independent measurements on weathered profiles.

Further work remains to be done in order to consolidate the new path; indeed, some is already in progress to reduce the excessively large confidence circle for the late Tertiary pole, and preliminary measurements have been made to fill a large gap where poles are absent in the early Tertiary. Nevertheless, the new path, coupled with an improved understanding of past geomagnetic fields within Australia that has been derived from it, should lead to a considerable improvement in dating Cainozoic weathering phenomena.

For further information, contact Dr Mart Idnurm at BMR.

Reservoir fluid (PVT) analysis

In *BMR Research Newsletter* 1, a brief article on enhanced oil recovery described how reservoir fluid analysis (PVT) equipment, loaned to the University of New South Wales by BMR, was being used for phase studies in carbon dioxide miscible displacement research.

In further co-operative research between the University and BMR, the PVT apparatus is also being used to analyse samples of oils and gas condensates. These are obtained from various petroleum productive reservoirs in Australia, generally as either bottom-hole or surface separator samples.

The main purpose of these analyses is to provide basic volumetric, phase, and viscosity data of reservoir fluids. Not only will these data help us to analyse and understand petroleum production behaviour, particularly the recovery characteristics, but they will also enable us to make more precise assessments of Australia's recoverable reserves of petroleum.

The type of analysis carried out on a given sample depends on the character of the fluids as they exist in a reservoir; thus, significantly different tests are conducted on oils and gas condensate systems. However, the equipment used for the two types of analyses is generally interchangeable: the major difference is the type of 'visual cell' used for each analysis. This cell permits visual inspection of fluid phase characteristics during pressure–volume tests, and enables the bubble point of an oil or the dew point of a gas condensate to be viewed through a thick glass port in the cell. Tests are carried out at pressures and temperatures which range from subsurface reservoir to surface separator/stocktank conditions. Typical configurations of equipment used in these analyses are illustrated in figures 14, 15, and 20 of Kobayashi & Ruska (1958: The design of experiments for the study of petroleum fluids, *Ruska Instrument Corporation, Houston, Texas, Publication* 2302).

A typical PVT crude-oil testing program covers the following measurements:

- fluid compressibility,
- fluid saturation pressure (bubble point),
- gas/oil ratios,
- viscosity,
- fluid density,
- fluid characteristics under differential and flash liberation processes from reservoir to stocktank, and
- component analyses of gases and liquids.

More details from Mr Brian McKay, BMR.

BMR's contribution to the Circum-Pacific Map Project

BMR has been participating in the Circum-Pacific Map Project since 1976. The project — whose headquarters are at USGS, Menlo Park, California — is producing an integrated series of maps of the Pacific basin showing the relationship of geology, tectonism, and geophysics to known energy and mineral resources. There will eventually be eight series of thematic maps at 1:10 000 000 scale, and selected compilations of the entire basin at 1:17 000 000 scale (Fig. 23).

Australia and Oceania are the major part of the southwest quadrant of the basin. BMR provides the panel chairman for this quadrant; he coordinates data collection for and compilation of some of the maps. BMR has completed the southwest quadrant 1:10 000 000 'Geologic map', which it prepared concurrently with compilation of the 'Tectonic map' by Dr Erwin Scheibner (Geological Survey of New South Wales). Both maps should be published in time for the Fourth Circum-Pacific Conference, which will be held in Singapore in August 1986.

At present BMR is compiling 1:10 000 000 mineral and energy resources maps, and aims to have drafts on display at the Conference. The 'Mineral resources map' will be somthing better than a locality map, but not quite a metallogenic map, as its background will be primarily lithologies associated with the occurrences. The occurrences of 40 commodities will be shown in three size ranges, which reflect production and reserves; worked out mines will not be shown. The 'Energy resources map' deals with coal, oil shale, oil, and gas, and emphasises sedimentary basins.

Other 1:10 000 000-scale thematic maps of the southwest quadrant have already been compiled and published by project headquarters; they are the 'Geographic', 'Base', 'Plate tectonic' and 'Geodynamic' maps. Each of these themes, and also a 'Preliminary tectonostratigraphic terrane map' (to which Scheibner contributed) and a map of 'Manganese nodules, seafloor sediment, and sedimentation rates' — all depicting the Pacific basin at 1:17 000 000 scale — have also been published.

The maps may be ordered from the AAPG Bookstore, P.O. Box 979, Tulsa, Oklahoma 74101, USA; all orders must be prepaid, and prepayments must include the appropriate shipping and handling charges (see below). The maps that are currently available, and the cost of each in US$, are:

		Cost (US$)
Complete set:	Geographic (6 maps; #836)	40
	Base (6 maps; #837)	20
	Plate tectonic (6 maps; #838)	40
Northwest quadrant:	Geographic (#860)	12
	Base (#861)	6
	Plate tectonic (#874)	12
Northeast quadrant:	Geographic (#862)	12
	Base (#863)	6
	Plate tectonic (#872)	12
	Geologic (#840)	12
	Mineral resources (#853)	12
	Geodynamic (#846)	12
Southeast quadrant:	Geographic (#864)	12
	Base (#865)	6
	Plate tectonic (#873)	12
	Geodynamic (#847)	12
Southwest quadrant:	Geographic (#866)	12
	Base (#867)	6
	Plate tectonic (#833)	12
	Geodynamic (#848)	12
Antarctica region:	Geographic (#868)	12
	Base (#869)	6
	Plate tectonic (#834)	12
Pacific basin sheet:	Geographic (#870)	12
	Base (#871)	6
	Plate tectonic (#835)	12
	Manganese nodule/ seafloor sediment (#859)	12
	Tectonostratigraphic terranes (#858)	12

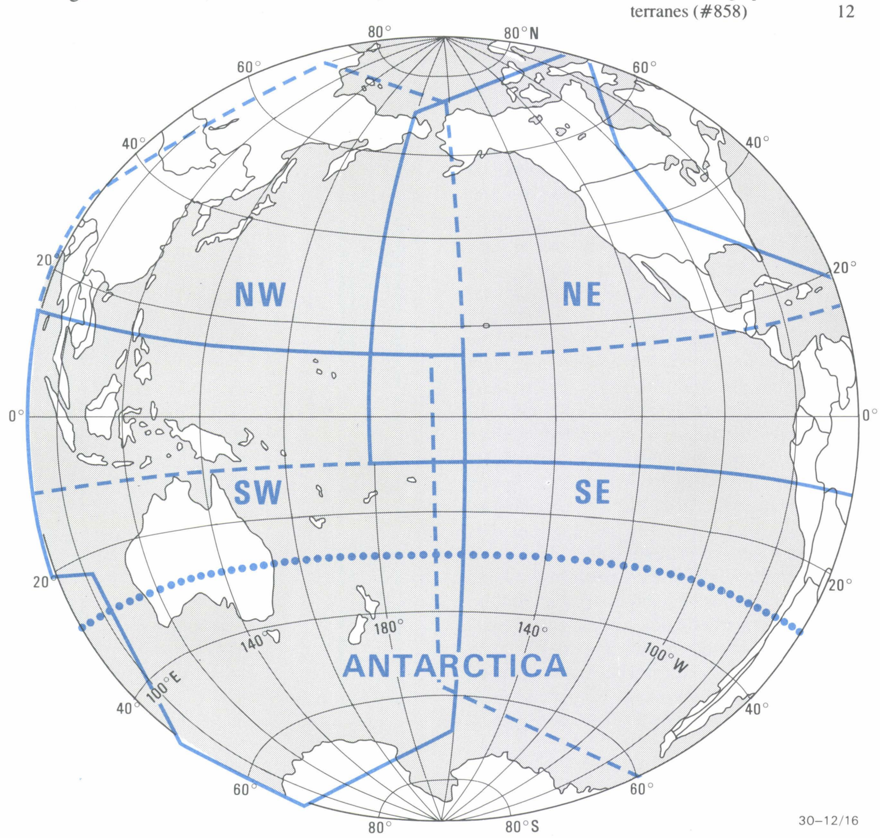


Fig. 23. Index map of the five 1:10 000 000 Circum-Pacific Map Project sheet areas; the edge of the Antarctica sheet area coincides with latitude 28°S. A 1:17 000 000 map covers the entire area shown.

The air freight and handling charges for these maps sent to addresses outside North America are:

If the order is:

less than US$	9.99	US$ 6.00
10.00 to	19.99	12.00
20.00 to	39.99	24.00
40.00 to	59.99	36.00
60.00 to	79.99	48.00
80.00 to	99.99	60.00
100.00 to	119.99	72.00
120.00 to	139.99	84.00
140.00 to	159.99	96.00
160.00 to	179.99	108.00
180.00 to	199.99	120.00
200.00 and over		contact AAPG

The Australian Mineral Foundation is making arrangements to stock and sell many of these maps. Enquiries should be addressed to the AMF Bookshop, Private Bag 97, Glenside, South Australia 5065; telephone (08) 797821.

For further information, contact Mr Fred Doutch at BMR.

Crustal geophysics research in Europe

During a recent visit to Europe, Dr Mike Etheridge attended the biennial European Union of Geosciences (EUG) meeting at Strasbourg (France) and a conference on extension tectonics at Durham (UK). Papers presented at both meetings emphasised the important role of deep crustal seismic reflection profiling in developing models for the structure and evolution of the continental lithosphere.

Most western European countries are carrying out deep seismic profiling, either alone or in collaboration with their neighbours. Great Britain has a wholly marine program run by the BIRPS (British Institutions Reflection Profiling Syndicate) group, based largely in the British Geological Survey and Cambridge University. The results of the initial surveys off northwest Scotland have been published, and other surveys off the west coast of Britain and in the English Channel have been completed. Very extensive, gently dipping structures that extend from the surface to and even into the upper mantle have been imaged on many of these lines. A number of these structures correspond to the surface expression of major Caledonide and Variscan thrusts. They appear to have been reactivated as normal faults that controlled the formation of Mesozoic to Tertiary half-grabens during the regional extension that also gave rise to the North Sea basins.

Deep seismic profiling is at an earlier stage in continental Europe, where lines across most of the major tectonic features have been only recently completed or are about to be shot.

The most striking and widespread feature of all profiles presented at these meetings is a well-defined lower crustal layer up to 20 km thick. This layer is characterised by numerous horizontal to gently dipping discontinuous reflectors, and, where refraction has been carried out, compressional velocities in excess of 6.8 km s^{-1}. The reflectivity of the lower crustal layer is variously interpreted as being due to:

1) numerous sill-like intrusions of mafic to ultramafic rock,
2) tectonically induced layering formed by penetrative stretching of the lower crust during one or more periods of extension, or
3) stacked supracrustals and infracrustals resulting from one or more episodes of thrusting.

A number of papers presented at the conference on extension tectonics emphasised the similarity between structures in the Basin and Range Province (western USA) and those imaged on a number of seismic profiles across passive continental margins and some sedimentary basins. The structures in the Basin and Range are dominated by rotational listric and planar normal faults, and by gently dipping crustal-scale detachment faults, which formed during substantial extension of the continental lithosphere. The inference from the foregoing is that continental extension is an important mechanism for initiating sedimentary basins, especially those associated with passive continental margins. Thermomechanical modelling of continental extension structures described at the conference forms the basis for understanding the subsidence and maturation history of extensional basins.

For further information, contact Dr Mike Etheridge at BMR.

Publication of Project Investigator–1 charts

BMR is about to publish a series of six colour charts depicting the main results of Project Investigator–1, a low-level aeromagnetic survey flown over the Australian–Antarctic Discordance (AAD) of the Southeast Indian Ridge. Knowledge of the seafloor tectonics of this anomalous zone, characterised by relatively deep and disrupted seafloor topography, has been considerably advanced by the study. The survey was conducted jointly by the United States Naval Research Laboratory (NRL) and the Australian Defence Science and Technology Organization (DSTO), with some assistance from BMR.

Two Orion aircraft were used to cover a 1000-km section of the ridge with north–south flight lines spaced about 20 km apart. Coverage extended north to about Magnetic Anomaly (MA) 7 (25.5 Ma) and south to MA6 (19.5 Ma; Fig.24). The crenulated geometry of the AAD has been interpreted as having developed from a combination of continuous asymmetric spreading and propagating rifts which caused sudden changes in transform offset. The propagators are postulated as having been driven by aesthenospheric flow toward the AAD from adjacent parts of the spreading axis to the east and west. The observed change in transform trend between 7 and 4 Ma, indicating adjustment to a new plate rotational pole, may have initiated rift propagation.

Five of the charts illustrate features of the AAD: interpreted magnetic lineations, seafloor ages and structures, magnetic profiles, magnetic anomaly contours, and bathymetry; the sixth chart illustrates revised plate tectonics of the Southern Ocean (including the AAD).

For further information, contact Mr Peter Hill at BMR.

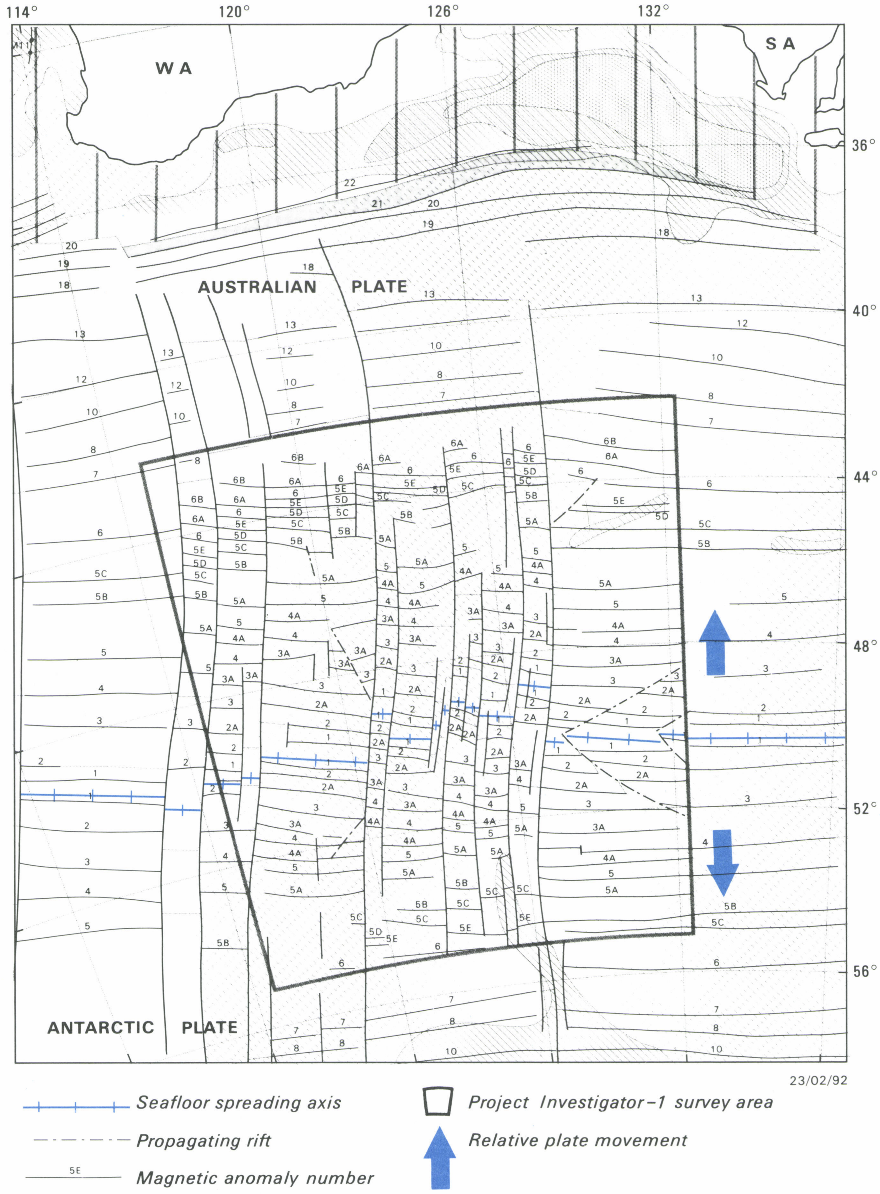


Fig. 24. Part of the revised plate tectonics chart of the Southern Ocean compiled from Project Investigator–1 data. The base-map is derived from the plate tectonics map published in 1979 in the *BMR Earth Science Atlas of Australia* Series.

Highlights of a recent phosphate workshop and symposium, SE USA

Three BMR scientists accompanied a delegation of seven Australian geoscientists from government, industry, and universities attending the Eighth International Field Workshop and Symposium of IGCP Project 156 (Phosphorites), held in southeastern USA in May this year. The meeting combined an initial seminar on the 'Neogene phosphorites of the southeastern United States', with field visits to the phosphate districts in North Carolina and Florida. This included a cruise board the Duke University/University of North Carolina Consortium RV *Cape Hatteras*, which has been extensively used for phosphate research and for the delineation of offshore phosphate resources. The meeting concluded with a conference entitled 'The genesis of Neogene to modern phosphorites'.

An absorbing contribution to the conference was the presentation of results emerging from research into contemporary phosphogenesis on the Peru–Chile continental shelf. In this region, under the influence of the upwelling Humboldt Current, carbonate fluorapatite is being precipitated today as pellets and crusts 1–20 cm below the sediment/water interface. Phosphate is apparently released to the sediment by bacterial degradation of organic matter, and apatite grains form below a filamentous mat of sulphur/sulphide-oxidising bacteria in an anoxic environment. The release of phosphorus from the organic matter seems to be associated with the conversion of fulvic acids to humic acids, but the exact processes are as yet not fully understood. Similar processes seem to be operating today in regions of high organic productivity associated with oceanic boundary currents off the coast of southwest Africa and California.

The role of bacteria in the formation of apatite seems not to have been accorded the recognition it deserves in the interpretation of ancient phosphorites. However, with the assistance of documented bacterial biochemical markers, it may be possible to reinterpret the formation of several Late Proterozoic and Early Cambrian deposits, especially those associated with algal stromatolites.

Although there is no observed direct evidence for it, bacterial activity, may have contributed to the formation of the Neogene phosphorites that the participants examined in North Carolina and Florida. There, Early to mid-Miocene and Pliocene pelletal phosphorites, dated on the basis of benthic foraminifera, were deposited during rising sea-level cycles associated with fluctuations of the Gulf Stream and its associated gyres. Control of phosphate deposition by sea-bottom topography was demonstrated by a combination of seismic stratigraphy and oceanographic modelling. The source of the phosphate is apparently again associated with abundant organic matter. Vertebrate organic phosphate — such as fish debris — seems not to be a primary source of the phosphate in these deposits.

The models of phosphogenesis demonstrated during this meeting do have significance for the interpretation of ancient phosphorites, such as the large Middle Cambrian deposits of the Georgina Basin, northern Australia. In particular they raise important scientific questions about the Georgina Basin deposits: where was the boundary current generating primary apatite deposition located?; what sea-level variations occurred?; what was the composition of the Cambrian biomass?; and are there any bacterial biomarkers in the phosphogenic sediments?

The meeting was impressive from both a scientific and economic aspect. The scale of the mining operations is enormous, the phosphate resources are massive, and the ease of exploitation is staggering. However, despite these features, the phosphate companies are finding it increasingly difficult to maintain their operations owing to the joint problems of environmental constraints and the enormous cost of land in areas like central Florida.

In conclusion the meeting was well organised and extremely informative.

For further information, contact Drs John Shergold, Peter Cook, or Peter Southgate at BMR.

Review

The Canberra Geomagnetic Workshop, May 1985

During the 14–15 May 1985, BMR's Geomagnetism Section and the Research School of Earth Sciences at the Australian National University jointly organised a Geomagnetic Workshop, which was held at RSES and sponsored by the Specialist Group on Solid Earth Geophysics of the Geological Society of Australia.

The program ot talks highlighted the causes, effects, and applications of geomagnetic phenomena ranging from those related to motions in the Earth's liquid core to those generated within the magnetosphere. Twenty-one papers were presented to an audience of nearly 60 participants from universities, from the exploration industry, and from BMR and other government organisations; several participants came from overseas.

After welcoming remarks by the organisers, and an opening message from Professor Ian Gough, the President of the International Association of Geomagnetism and Aeronomy, the morning session commenced with a group of papers on very rapid time variations (pulsations) of the geomagnetic field — their origin, application to the determination of magnetospheric plasma properties, and low-latitude distribution (K.D. Cole, La Trobe University; B. Fraser, F. Menk, University of Newcastle). These were followed by accounts of work on longer-period variations: an analysis of solar and lunar magnetic tides at midnight (R.J. Stening, University of New South Wales), the use of Sq induction to model Earth conductivity (D.E. Winch, University of Sydney), and an analysis of declination observed on abnormal quiet days (E.C. Butcher, La Trobe University). The final papers for the first day highlighted the use of land magnetometer array studies in the determination of conductivity anomalies in the Canadian Cordillera, Java, Tasmania, and South Australia (D.I. Gough, University of Alberta; F.H. Chamalaun, Flinders University; W.D. Parkinson, retired, University of Tasmania; A. White, Flinders University).

An 'Oriental Magneto–Banquet' — with excellent food, speeches and slides extending entertainment well into the evening — provided an appropriate conclusion to the first day.

The first session on the second day commenced with three papers describing the work of RSES with land magnetometer arrays across Australia, and the recent co-operative project of RSES and Scripps Institution of Oceanography along a magnetotelluric traverse from southeast Australia across the Tasman Sea (F.E.M. Lilley, I.J. Ferguson, N.L. Bindoff, ANU). The marine emphasis continued with talks on a study of the magnetic slope anomaly off Morocco (H.A. Roeser, Bundesanstalt für Geowissenschaften und Rohstoffe, Federal Republic of Germany), and on BMR's activities in the Southern Ocean between Australia and Antarctica, where particular emphasis was given to the Kerguelen Plateau and the anomalous zone of the Australian–Antarctic Discordance of the Southeast Indian Ridge (P.J. Hill, BMR). This last talk also discussed the problems associated with producing an Australian Geomagnetic Reference Field for magnetic surveys, a topic which was referred to in more detail later. An account of state-of-the-art processing of satellite magnetometer data (B.D. Johnson, Macquarie University) followed, and a discussion of possible ground control through third-order magnetic observations undertaken by BMR (J.C. Dooley, retired, BMR) concluded the morning session.

After lunch at the Black Mountain Palaeomagnetic Laboratory, a facility owned by ANU and

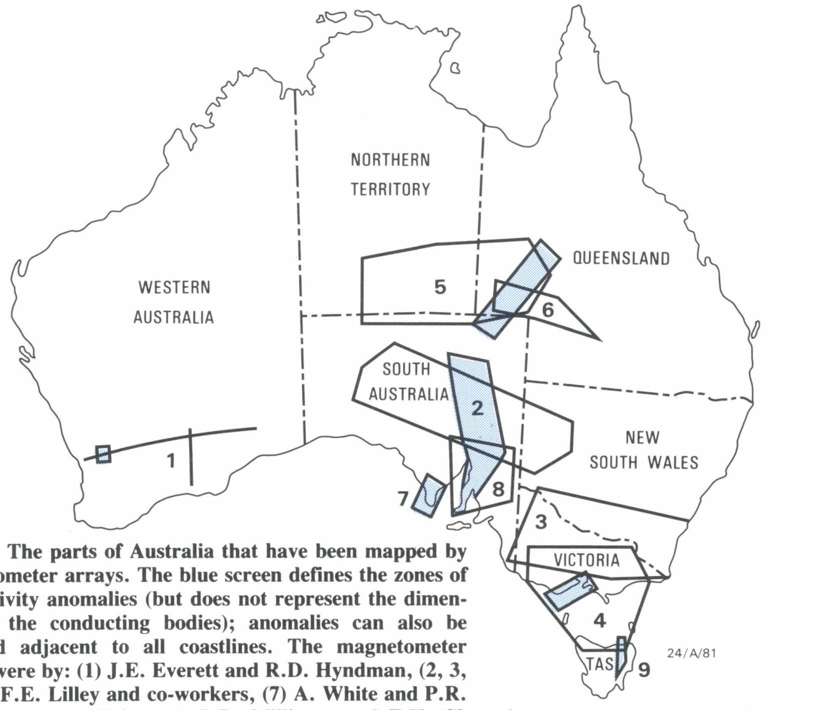


Fig. 25. The parts of Australia that have been mapped by magnetometer arrays. The blue screen defines the zones of conductivity anomalies (but does not represent the dimension of the conducting bodies); anomalies can also be expected adjacent to all coastlines. The magnetometer arrays were by: (1) J.E. Everett and R.D. Hyndman, (2, 3, 4, 5, 6) F.E. Lilley and co-workers, (7) A. White and P.R. Milligan, (8) A. White and P.R. Milligan, and F.H. Chamalaun, and (9) W.D. Parkinson.

shared with BMR, the final session concentrated on the production of the 1:1 000 000 airborne map of Australia (V. Anfiloff, BMR), the Canadian Geomagnetic Reference Field for epoch 1985 (L. Newitt, Energy, Mines and Resources, Canada), and the problems in deriving an appropriate Australian Geomagnetic Reference Field, and its relationship with the International Geomagnetic Reference Field (C.E. Barton, BMR). The formal presentations concluded with an entertaining overview of the past and present models for the origin of the Earth's main field (P.L. McFadden, BMR).

On the final afternoon, many participants accepted the opportunity for a sunset visit to the Canberra Magnetic Observatory, which is operated by the Geomagnetism Section of BMR and provides continuous digital information of the vector field. On display at the observatory was the new digital fluxgate magnetometer designed and built at the School of Earth Sciences, Flinders University, and described during the Workshop by F.H. Chamalaun; four of these magnetometers are presently being evaluated for long-term stability against the observatory standard .

As well as the papers presented, extended abstract of recent work in geomagnetism were also invited from other participants. These have all been collated into *BMR Record* 1985/13.

Magnetometer arrays

Many of the papers presented at the Workshop are relevant to the exploration industry. One such pertinent example is that presented by Ted Lilley (ANU), who suggests that magnetometer array data — with their ability to delineate areas of induction effects due to the transient external field variations — are useful in the accurate reduction of magnetic survey data, particularly airborne and seaborne. As he points out, in areas where strong induction effects occur, significant errors can be introduced into the data — even over distances as little as 10 km from the base-station.

In the few areas of the continent which have been mapped by magnetometer arrays (Fig.25), several zones of conductivity anomalies have been delineated. These anomalies have an impact on airborne magnetic surveys by limiting the distance over which a single base-station control may be used.

An ambitious experiment which will play an important role in completing the magnetometer-array coverage has recently been proposed by F.H. Chamalaun. Provided that sufficient support can be found, a continent-wide array of at least 50 of the new digital magnetometers will be deployed simultaneously for a period of two months or longer. This will be done by Flinders University in collaboration with BMR; it will be combined with studies of the daily magnetic variation, with mapping of the geomagnetic field at fixed observatories and magnetic repeat stations, and with aeromagnetic surveys undertaken by BMR. Among the results of this experiment will be a better understanding of the spatial and temporal behaviour of disturbances of the magnetic field, and a broad-scale picture of the regional inductive response of the continent. Both these objectives are important for providing better baseline control for regional aeromagnetic surveys.

In conclusion, the Geomagnetic Workshop proved to be an enjoyable and lively gathering which demonstrated clearly the overlapping interests of the exploration industry, universities, and government science organisations.

For further information, contact Mr Peter Milligan or Dr Charlie Barton at BMR.

BMR's Intergraph workstation

BMR has recently installed an Intergraph high-resolution colour-graphics workstation linked to a VAX computer. This facility will provide an enhanced capability for computer-assisted drafting, three-dimensional computer modelling, and the development of analogue databases. The system will be used primarily by the Division of Continental Geology and the Special Projects & Geoscience Services Branch for the development and production of palaeogeographic maps and other maps. However, it is also expected to have applications to many other areas such as basin analysis, hydrogeology, stratigraphy, and possibly image processing.

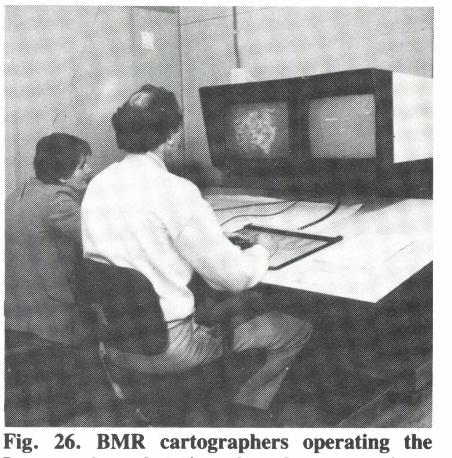


Fig. 26. BMR cartographers operating the Intergraph workstation; the colour screen is on the right.

The workstation (Fig.26) consists of two high-resolution visual display units — one black and white and the other colour — mounted at the rear of a large digitising table (150 x 105 cm) with a digitising accuracy of 0.1 mm; the operator can create and interact with the display through a multi-button cursor and menu-driven software. The station is connected by a high-speed Telecom line to a Digital Equipment Corporation VAX–785-based Intergraph Graphics System housed at the contract drafting firm of Cangraphics Pty Ltd in Fyshwick, ACT. Graphics files created are recorded on tape at Cangraphics, returned to BMR, reformatted on the HP computer, and plotted on the Calcomp plotter.

For further information, contact Mr Steve Holliday at BMR.

Australia/USSR Earth-science co-operation

Australian and USSR representatives meeting in Moscow in May this year agreed to reactivate the existing Science and Technology Agreement between the two countries. A program is now being developed for the year 1985–86.

A significant part of the Agreement will promote co-operation in the Earth sciences, for which seven man-months during 1985–86 have been allocated in each country.

The fields in which co-operation will take place were developed by representatives of BMR, CSIRO, the National Committee for Earth Sciences of the Australian Academy of Science, and the Australian Geoscience Council. The fields identified are:

- Regional tectonics
- Structure of the Earth's crust and mantle
- Palaeontology, stratigraphy, and palaeoclimatology
- Biogeochemistry
- Petrology, geochemistry, and metallogenesis
- Geophysics

The Australian Department of Science has forwarded to the USSR proposals for a number of projects from which the 1985-86 program is expected to develop. These projects (and their proposers) are listed below:

- Exploration geophysics (CSIRO)
- Proterozoic oil and gas (BMR)
- Mineralogy and geochemistry (CSIRO)
- Study of giant manganese deposits (Monash University)
- Studies of seismic data and tectonics related to Russian superdeep boreholes (various agencies)
- Extension tectonics (BMR)
- Devonian and earliest Carboniferous correlation (Macquarie University)
- Electromagnetic methods (Macquarie University)

Industry may wish to contribute to some of the projects when they are approved.

The Academy of Science of the USSR, and the Ministry of Geology, will co-ordinate Russian participation in the Earth-science component of the Agreement; BMR will co-ordinate the Australian participation. In subsequent years, the Department of Science will circulate widely in Australia information on the Australia/USSR Agreement — as with all bilateral co-operative agreements in science and technology between Australia and other countries.

For further information, contact Dr John Truswell at BMR.

Honour

Liz Truswell

BMR takes this opportunity of publicly congratulating Liz Truswell, Principal Research Scientist in the Division of Continental Geology,

who was recently elected a Fellow of the Australian Academy of Science — one of only four women among an eminent group of 228 Australian scientists 'whose research is judged to be of the highest standard'.

Liz is a specialist in the application of palynology to problems in geology, palaeobotany, and palaeoclimatology. She is distinguished for her work on the history of climate and vegetation in Australia during the Tertiary, and for the integration of this work with palynological studies from deep-sea sediments. She has also made important contributions to the stratigraphic palynology of the Late Carboniferous and Permian periods, synthesising information on the evolution of sedimentary basins both in Australia and the Antarctic. She is also a specialist in the area of Antarctic geology, palynology, and vegetation history during the Tertiary, utilising samples and data from oceanographic cruises to the Wilkes Coast and the Ross Sea.

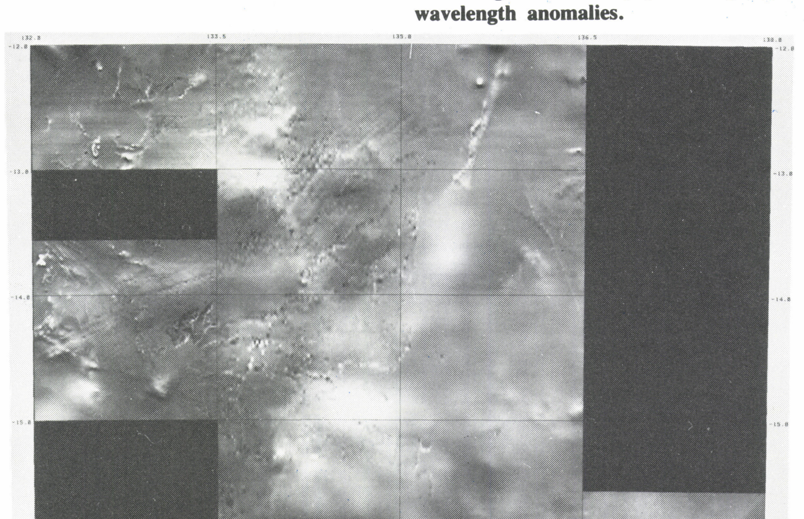
New image-processed magnetics for the 'Top End'

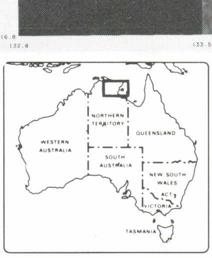
In the April 1985 issue of the *BMR Research Newsletter*, we illustrated (at reduced scale) a recently published total magnetic intensity greyscale pixel map of the Albany 1:1 000 000 Sheet area (WA), and demonstrated with selected examples how this kind of presentation aided an interpretation of the magnetic features; in particular, the pixel maps show many more quite subtle linear features than the contour and profile maps. We take this opportunity of announcing the availability of pixel maps of magnetic data for another 1:1 000 000 Sheet area, and comment briefly on some of the features apparent in them.

To facilitate regional interpretation of the magnetics in the McArthur Basin, we have produced new maps for the Roper River 1:1 000 000 Sheet area by regridding the BMR magnetic database; Figure 27 shows the greyscale total magnetic intensity pixel map of this Sheet area. The amplitude of magnetic anomalies has been scaled over 1400 nT in 256 divisions, giving an effective interval of about 5 nT; the highest amplitudes are represented by white, and the lowest by black. Areas with no digital data or where problems were incurred in processing are shown blank.

Two quite different survey specifications were used in the Roper River 1:1 000 000 Sheet area: lines were spaced 1500–1600 m apart in the 1:250 000 Sheet areas in the western quarter, whereas those in the eastern three-quarters were 3000 m apart. All survey lines were flown east–west at a ground clearance of 150 m. The pixel data in the area with the wider line spacing have a much more stippled appearance than those in the area with the closer line spacing; for this reason, caution is needed when interpreting narrow elongate linear and curvilinear anomalies in the eastern three-quarters of the Sheet area. The stippled nature of the pixel map presentation could be reduced by using a larger grid cell size than the standard 0.25 minute (roughly 450 m) chosen, or by various other means — including filtering or smoothing. However, these processes have the disadvantage of damping the anomalies.

Over much of the eastern part of the area the magnetic field is very smooth; short-wavelength anomalies due to near-surface sources are mostly confined to the west. Furthermore, the amplitude range of the visible short-wavelength anomalies is quite small relative to the full dynamic range represented by both long and short-wavelength anomalies. Thus the Roper River area is particularly well suited to the application of enhancement techniques to reveal short-wavelength anomalies.





Roper River 1:1000000 Standard map sheet

Fig. 27. Roper River 1:1 000 000 Sheet area total magnetic intensity pixel map reduced to 1:6 500 000 scale for presentation.

We have used the east–west gradient to particular advantage. To illustrate this we draw attention to two features: dykes (short wavelength) and probable plutons (long wavelength), which are shown in the simplified interpretation map (Fig. 28) that we have derived from both the total magnetic intensity pixel map (Fig. 27) and the east–west gradient pixel map.

Plutons in the basement

The new pixel map (Fig. 27) highlights long-wavelength magnetic anomalies which appear as near-circular to elliptical white features 20–50 km across. These mostly occur over the eastern three-quarters of the area, and have the characteristics of deeply buried magnetic plutons (Fig. 28). They do not have a marked high or low gravity anomaly. Some of them may be caused by strongly magnetic small plugs, at considerable depth, that may be the feeders of the extensive basic dyke swarms and/or volcanics in the area. Others may be caused by magnetic granites.

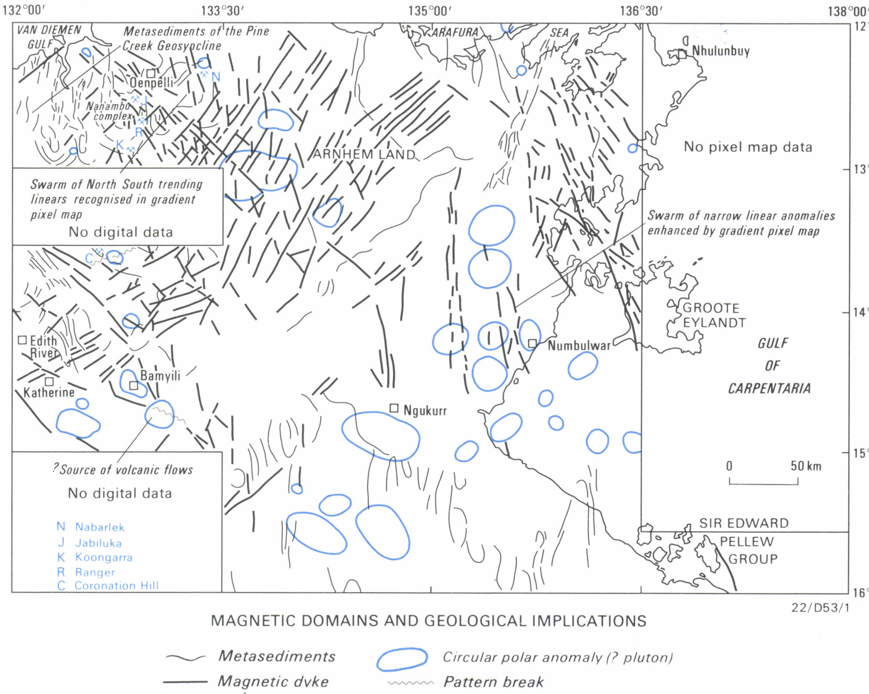


Fig. 28. Magnetic interpretation of the Roper River 1:1 000 000 Sheet area derived from the total magnetic intensity pixel map, and from the gradient pixel map, which enhances short-wavelength anomalies.

Dykes

Narrow magnetic linear anomalies due to dolerite dykes criss-cross the Roper River Sheet area. Most of these anomalies have northwesterly and northeasterly trends, and appear to be confined to the western half of the area. In the relatively flat area in the northeast a few similar trends are evident.

Use of the gradient pixel map (not illustrated) reveals many more linear anomalies throughout the area — particularly in the flat area in the east, where a suite of north–south linear anomalies is evident; these are shown in Figure 28. In the west, similar features with weakly developed north–south trends, which might have been overlooked had not those in the east been so evident, are also apparent in the gradient pixel map.

Exploration applications

The lithostratigraphic setting of the Ranger and Jabiluka uranium deposits within an extensive belt, 30 km wide, of long northwest-trending dykes (Fig. 28) invites speculation about the relevance of fracture systems to gold and uranium mobilisation in the Pine Creek Geosyncline. We suggest that the fracture systems accompanying the dykes, and the thermal capacity of the dykes themselves during emplacement and cooling, be applied to hydrothermal models of mineral mobilisation and emplacement in favourable hosts; such models need not invoke dykes as a source of mineral deposits. Another model for consideration is that dykes controlled palaeodrainage, and that uranium and/or gold derived by leaching of adjacent country rock was deposited in favourable sites.

For further information, including how to obtain copies of the digital maps, contact Dr David Tucker, Mr Vadim Anfiloff, or Mr Ian Hone at BMR.

GPS surveying for the Earth sciences

The Global Positioning System of satellite geodesy (GPS) will enable geophysicists to accurately survey most of their own fieldwork with significant savings in exploration costs. Other applications of GPS in the Earth sciences offer widespread benefits to both exploration and research. A report 'Geodetic measurement of crustal deformation in the Australian region' was recently submitted to the Australian Academy of Science by a Working Party of the National Committee for Solid-Earth Sciences. This report emphasises the advantages of implementing a vigorous program of geodesy using space technology — GPS, Very Long Baseline Interferometry (VLBI), and Satellite Laser Ranging (SLR) — for scientific purposes in Australia. The report also clearly shows that applications of GPS would provide greater accuracy to surveying and navigation if tracking and base-stations were set up.

By the end of the eighties, GPS applications in BMR are expected to provide:

- real-time navigation of vehicles, ships, and aircraft to an accuracy of tens of metres;
- determination of latitude, longitude, and elevation of geophysical field survey stations on site to an accuracy of less than 1 m equivalent in just a few minutes;
- precise geodetic measurement of crustal deformation to within a few centimetres.

GPS is intended primarily as a real-time navigation system for military and civilian purposes. Data broadcast by the GPS satellites for precise real-time navigation (the Precise or P code) are of such strategic importance that they are likely to be encrypted and their use restricted to military and selected civilian users when the full constellation of 18 satellites is in orbit in 1988. Other data broadcast by the GPS satellites are capable of giving less accurate navigation (the Coarse/Acquisition, Clear/Access, or C/A code), and will continue to be freely available. Various GPS receivers use one or other of these codes to determine point positions, but other receivers measure the phases of the broadcast carrier waves, and do not require a knowledge of either code to determine by Doppler the most precise geodetic positions.

At present, seven satellites are in orbit, and six of them have atomic clocks so that they are suitable for use with all GPS receivers. Their orbits are such that the satellites cluster over USA for test and survey purposes for some hours each day, and fortunately for us they also cluster over Australia. The availability of the P code and satellite ephemerides has enabled GPS measurements using different types of receivers to be made for survey and research purposes overseas; some measurements are now being made in Australia.

The accuracy and speed of measurement using GPS make it far superior to its predecessor, the Transit Doppler system. As with Transit and other satellite systems, GPS will be usable day and night in all kinds of weather, and does not require visibility between survey points because surveying is ground-to-sky at each point. Simultaneous measurement of distances to multiple GPS satellites leads to effective cancellation of receiver clock errors, considerably improving the accuracy of point-positioning of a single receiver. The full constellation of 18 satellites in six near-circular high-inclination orbits will provide mutual visibility of at least four satellites from almost anywhere in the world at all times. Their high altitude (20 200 km) will improve baseline measurement accuracy, and substantially reduce atmospheric drag errors in the ephemerides which give the locations of the satellites in space. Forecast ephemerides are broadcast by the satellites, and more accurate post-processed ephemerides are available later. If, as has been recommended, Australia installs a regional tracking network, higher-accuracy forecast and post-processed ephemerides will have guaranteed availability. Relative positioning of a field receiver to a fixed base cancels errors in the satellite clocks, as well as those in the receivers, and over moderate distances reduces errors caused by tropospheric and ionospheric refraction; this technique provides the highest precision in GPS surveying.

Although four satellites are normally used to position a point, this requirement can be reduced to three, either by attaching a caesium or rubidium atomic clock to the receiver, or by fixing for computational purposes the altitude of the antenna of the receiver — e.g., at the height above sea level of the masthead for a shipborne receiver. Two satellites are adequate when the receiver has both an atomic clock and fixed antenna altitude; windows with two satellites visible already total 17 hours per day in Australia.

Surveying accuracies are usually specified in parts per million (ppm), commonly with a minimum error limit. Navigation of ships requires accuracies of 10–100 ppm, equivalent to 10–100 m in 1000 km. The same order of accuracy is adequate for horizontal co-ordinates for regional geophysical surveys (1–10 m in 100 km), but the vertical accuracy for some surveys — e.g., gravity — must be better. Crustal deformation studies seek accuracies of 0.01–0.1 ppm with centimetric accuracy between Australia and Antarctica and millimetric accuracy across the Southwest Seismic Zone. If these higher accuracies can routinely be obtained, then GPS can supersede, on the basis of cost, terrestrial geodetic techniques over shorter distances for any semi-detailed and detailed survey. Raw GPS accuracies are better than 10 ppm, and the more effective surveys achieve an accuracy of 1 ppm. Research indicates that 0.1 ppm with centimetric precision will soon be achieved; that 0.01 ppm with millimetric precision will be accomplished in the longer term; and that corrections necessary for removing systematic errors in order to ensure accuracies of the same orders could be determined.

Gravity data obtained and compiled by BMR contribute to determinations of (1) accurate GPS orbits, particularly corrections applicable in the Australian region, and (2) the shape of the geoid in order to evaluate geoid-spheroid separations. These separations must be evaluated precisely if they are to be used for calculating precise heights above mean sea level from the ellipsoidal heights given by GPS. BMR has commenced research into ways of determining the shape of the geoid more accurately in co-operation with several other institutions with geodetic interests.

The rate of introduction of GPS into Australia will accelerate rapidly as the present high cost of receivers reduces dramatically over the next few years. User groups have been meeting in the ACT/NSW and Queensland regions for some months, and the National Mapping Council is setting up a committee to consider GPS. Examples of GPS surveys completed or planned this year include navigation of geophysical survey vessels and aircraft, surveying of power lines, location of geophysical field stations and of oil rigs, and first-order geodetic surveying at the State and federal levels.

For further information, contact Mr Brian Barlow at BMR.

3rd ICGI

BMR is a co-sponsor of the Third International Conference on Geoscience Information, which will be held in Adelaide from 1 to 6 June 1986.

The Conference has as its theme 'Geoscience information as a resource'. Its aim is to bring together members of the international geoscience community — both geoscientists and information scientists/librarians — to exchange information pertinent to the generation, integration, dissemination, storage, and use of geoscientific source (numeric) and reference (bibliographic) data and information on an international and regional basis.

For further information, write to:

The Secretary
Organising Committee Third ICGI
Australian Mineral Foundation
Private Bag 97, Glenside
SOUTH AUSTRALIA 5065,

telephone (08) 79 7821, or telex AA87437.

8th AGC

The Organising Committee extends a cordial invitation to all interested persons to attend the Geological Society of Australia's Eighth Australian Geological Convention, which will be held at Flinders University, Adelaide, from 16–21 February 1986.

The Convention has as its theme 'Earth resources in time and space'. Its objective is to present a broad spectrum of papers from industry, educational institutions, and government departments; these will reflect present and future activities associated with the exploration, evaluation, and exploitation of mineral, energy, and water resources — particularly in Australasia.

For further information write to:

Secretary 8th AGC
PO Box 292, Eastwood
SOUTH AUSTRALIA 5063,

telephone (08) 274 7580, or telex AA88692.

Available soon
BMR 85

BMR 85 is the yearbook of the Bureau of Mineral Resources, Geology and Geophysics, covering geoscientific research, resource assessment, and database development for the year 1 July 1984 to 30 June 1985.

BMR 85 summarises the first full year's results of investigations in the Amadeus Basin, the object of an enterprising new multidisciplinary project by BMR in collaboration with scientists from other government institutions, universities, and industry.

BMR 85 outlines plans for an exciting program of research beginning in 1987 for the Baas Becking Geobiological Laboratory.

BMR 85 synthesises the main results of long-running projects — now concluded — on unconformity-related uranium deposits, on continental shelf basins in the Bass Strait region, and on the gold-tungsten province of the Davenport (NT) region.

BMR 85 discloses BMR's new initiative to establish a national capacity to provide information on underground nuclear explosions, and an international data centre to transmit and process seismological data.

BMR 85 describes the scope of new projects — just started — on the Otway Basin, Lord Howe Rise, Kerguelen Plateau, extension tectonics in Australia, and evolution of the Australian Proterozoic.

BMR 85 is all of these things — and a lot more.

BMR 85 will be available by November from the BMR Bookshop.

Hydrocarbon indications off western Tasmania

BMR and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) have carried out a co-operative geophysical, geological, and geochemical study of Tasmania's western and southern margins during three geoscience cruises aboard the Federal Republic of Germany's research vessel *Sonne*. A full cruise report is now available from BGR (Hinz & others, 1985: *BGR Report, Sonne Cruise SO–36,* No. 2); it reveals a close relationship between the nature of the seismic profiles and accumulations of hydrocarbon gases in the surface sediments. A brief report will be presented at the PESA Second South Eastern Australia Oil Symposium in November 1985, and published by PESA.

The seismic stratigraphy for the western margin of Tasmania has been set up by making tentative ties to the exploration wells — Prawn No. 1, Clam No. 1, and Cape Sorell No. 1 — and correlating the Neogene section with DSDP Site 282. Fourteen unconformities have been recognised, following detailed processing of BMR line 40–22/23 (1982 Bass Strait geophysical survey), and some of these can be dated from a knowledge of southern margin tectonics and eustatic sea-level changes. Pre-rift, syn-rift, and post-breakup sequences can be identified, and seismic facies ranging from continental rift-fill, through shelf and shelf-edge progradation, to open marine are present.

A shipboard geochemical report by M. J. Whiticar & others, in the BGR cruise report, shows very high concentrations of hydrocarbon gases in two areas: west of Clam No. 1 well off northwest Tasmania, and west of Cape Sorell No. 1 off central western Tasmania (Fig. 29). The technique employed was to sample 37 unconsolidated samples from 19 cores, to degas them in a vacuum/acid apparatus, and to determine gas yield and molecular composition with a gas chromatograph. These properties, and carbon-isotope ratios which will be measured at BGR, enable thermogenic hydrocarbons to be distinguished from biogenic hydrocarbons, and their maturity ascertained. Without the isotope ratios, full interpretation is generally hazardous; however, the cores off Tasmania yielded a good quantity of gas which contains such a high proportion of higher gases and has such a uniform composition that it is clearly largely of thermogenic origin. In the 19 cores from west Tasmania the total C_1–C_5 yield averages 318 ppb, of which methane averages 74 per cent.

BGR has made a detailed geochemical study of the hydrocarbons contained in 16 cores taken on an 8 km grid on the continental slope immediately west of Cape Sorell No. 1; continental shelf sediments are unfortunately too coarse-grained for successful piston coring. The locations and gas concentrations of six cores on or near *Sonne* seismic profile SO36B–46 are shown in Figure 29. The hydrocarbon concentration in core 14 is very high by any standards: its total gas by weight of 1032 ppb comprises methane 468 ppb, ethane 189 ppb, propane 92 ppb, iso-butane 64 ppb, n-butane 52 ppb, iso-pentane 30 ppb, and n-pentane 138 ppb.

Gas values increase up the continental slope (Fig. 29), and are at their highest above fault blocks which lie near the surface. The gas is probably derived from Cretaceous and Palaeogene source rocks, from which it has migrated up the faults to the surface. Free oil was observed in the Cretaceous–Paleocence interval in Cape Sorell No. 1 well, so it appears that oil and gas could be widespread beneath the west Tasmanian slope and shelf, which must therefore be a good exploration target.

For further information, contact Dr Neville Exon or Mr Barry Wilcox at BMR.

13th CMMI Congress

The Australasian Institute of Mining and Metallurgy will host the 13th Congress of the Council of Mining and Metallurgical Institutions, which will be held in Singapore from 11 to 16 May 1986.

The Congress has as its theme 'The twenty-first century — mining for mankind'. Its aim is to bring together all persons interested in the minerals industry for the presentation of information and for discussion on the trends in technology and science in the minerals industry for the 21st century.

For further information, write to:
The Honorary Secretary, 13 CMMI Congress
c/- The Australasian Institute of Mining and Metallurgy
PO Box 310, Carlton South
VICTORIA 3053,
telephone (03) 347 3166, or telex AA33552.

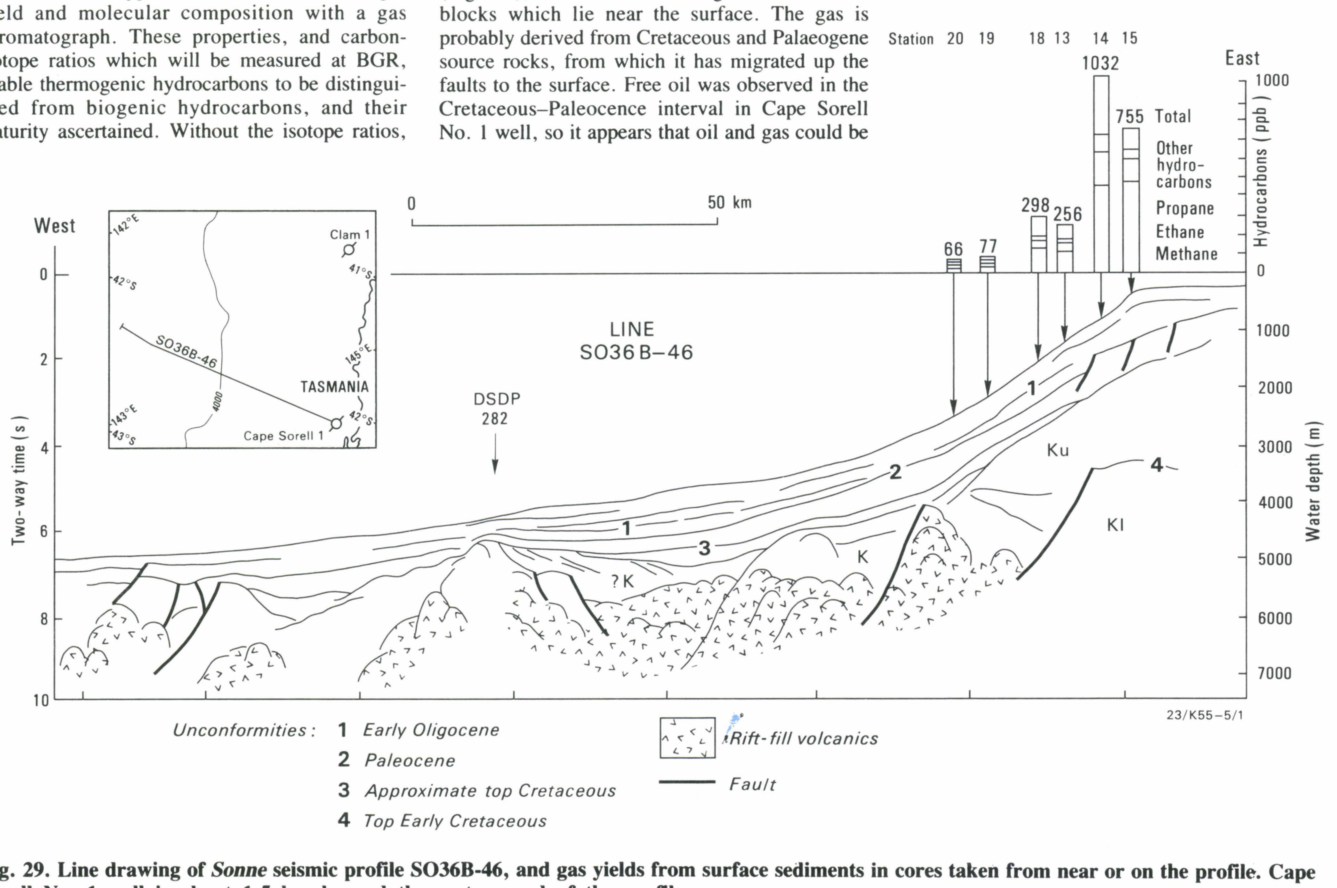


Fig. 29. Line drawing of *Sonne* seismic profile SO36B-46, and gas yields from surface sediments in cores taken from near or on the profile. Cape Sorell No. 1 well is about 1.5 km beyond the eastern end of the profile.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
Cnr Constitution Avenue and Anzac Parade, Canberra, ACT
Postal address: GPO Box 378, Canberra, ACT 2601
Telephone: 062-49 9111 *Telegrams:* BUROMIN *Telex:* 62109
Director: Professor R. W. R. Rutland
Editor, BMR Research Newsletter: G. M. Bladon
Drafting, this issue: C. Knight, M. Steele

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