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ABSTRACTS

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ABSTRACTS

TWELFTH BMR SYMPOSIUM

17-18 MAY 1983

CANBERRA

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* Speaker

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1 Pancontinental Petroleum Ltd
2 University of Tasmania, joining BMR shortly
3 University of Trondheim, Norway. Consultant to BMR

Introduction to marine geoscience in BMR

D A Falvey

The Division of Marine Geosciences & Petroleum Geology came into existence on 1 July 1982. It has drawn staff from the previous specialist areas of marine geology, marine geophysics, and marine micropalaeontology.

The Division conducts multidisciplinary research in three major programs:

1. Fossil fuels - the investigation of shelf and continental-margin sedimentary basins (stratigraphy, evolution, and crustal framework) as a basis for understanding the geological processes controlling passive-margin formation. This will help develop an understanding of the genesis and distribution of petroleum offshore and provide a basis for exploration and assessment. In addition to these explicitly resource-related projects, a major sub-program is concerned with study of modern marine processes - particularly the evolution of the Great Barrier Reef. This will provide an understanding of reef evolution as a basis for environmental management and pollution and hazard monitoring.

2. Minerals - the investigation of offshore mineral resources, in the context of margin and spreading-ridge evolution, as a basis for exploration and assessment. Work under this program is currently restricted to studying metalliferous sediments and deep-sea processes.

3. Overseas programs - these are conducted in two major sub-programs: (i) the study of the island arcs of the Australia-Pacific active plate margin, with particular reference to the evolution and resource potential of fore-arc and intra-arc sedimentary basins (this is conducted by BMR, in conjunction with ADAB, primarily in response to specific development aid requests from Pacific island nations); (ii) the study of the continental margin offshore Antarctica and the Heard-Kerguelen Plateau as a basis for resource assessment.

In addition to these field programs, the Division is also active in research and development of advanced marine geophysical systems covering such fields as data acquisition, data processing, and database management.

Stratigraphic and structural framework studies of the Bass Basin: preliminary results

J C Branson , K L Lockwood, M A Etheridge & A S Scherl

The Bass Strait Study aims to (1) describe the geological history of the Bass Basin; (2) provide regional correlation between the Otway, Bass, and Gippsland Basins, and (3) present a regional interpretation of the development of the continental margins that flank Bass Strait. A geophysical survey conducted under contract to BMR in March-May, 1982, recorded 3209 km of multichannel seismic data, together with gravity and magnetics.

The results of the research into recording and processing techniques, together with preliminary results from the continental margins, have been discussed elsewhere (Lockwood & others, 1982; Branson, 1982). Public release of the data will be made later in 1983.

The Bass and Gippsland Basins have much in common, but display significant differences that may have important consequences for hydrocarbon reservoir formation. The Bass Basin contains much the same sedimentary sequence and early structures as the Gippsland Basin, and Nicholas & others (1981) have argued that hydrocarbon generation should have taken place from various parts of the Bass sequence. The Gippsland Basin reservoirs are primarily associated with Mid to Late Eocene structures that were apparently formed during a dextral wrench phase related to the Rosedale and parallel fault systems. This deformational phase was, at best, only weakly developed in the Bass Basin, but a number of other potentially suitable structural traps have been drilled, and favourable reservoir characteristics are present. The shortage of hydrocarbon discoveries in the Bass Basin is therefore considered to be at least partly a function of plumbing history. In this respect, a major difference between the basins is that the Gippsland was facing open ocean during Tasman Sea rifting, whereas the Bass was isolated by basement ridges around its whole perimeter. Detailed studies of the Bass Basin sedimentological and structural history are therefore aimed at elucidating its hydrological history as well as providing the basis for fresh exploration guidelines.

Studies of the seismic stratigraphy in the Bass Basin recognise alluvial, fluvial, upper-delta plain, lower-delta plain, marine, and volcanic environments throughout the Cretaceous and Tertiary, even below the extensive Eocene coal measures. Analysis of the movements of fault-blocks early in the Bass Basin history has also commenced, and a regional synthesis of this information will be the basis of a comprehensive basin formation model.

Two possible models of early basin development are being investigated: (1) extensional basins, and (2) wrench-fault basins. Extensional basins contain recognisable features such as normal faults and half-grabens parallel to the basin margins, wrench faults perpendicular to basin margins, tilted wedges of pre- and syn-rift fault sediments, and late 'thermal' broad-basin subsidence. Wrench-fault basins contain features such as corners to the basin with complex intersections of faults and unconformities, irregular basin margins, braided wrench zones, small thrusts, talus breccia and rapid facies changes at the margins, and volcanic floor with remnant marginal blocks.

For the extension model, fault-block geometry and the age range of sediment wedges allow computation of the amount and history of extension of the basin floor. An example of this type of modelling is described from the southeastern Bass Basin, where a 50 km-wide zone has undergone approximately 30% to 40% extension (= 1.3 to 1.4) over about 20 Ma in the Late Cretaceous. These calculations are based upon planar, rotational faults, which produce the maximum extension with a minimum of internal block deformation. This pattern also avoids space problems encountered with substantially curved (listric) faults.

The wrench-fault basin requires parallel offset faults that may reach the surface and terminate within the region. Models for these basins can produce elevation of the basin flanks. Models with flanking fault movements of 10 km can induce a tectonic subsidence of 1500 m at the depocentre. This tectonic subsidence is of the same magnitude as the extensional model.

Overall, this study will lead to a significant improvement in our knowledge of the tectonic and environmental history of the sedimentary basins of the region. This, in turn, will permit the more sophisticated thermal and hydrological modelling so important to the development of rational exploration.

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Evolution of the Great Barrier Reef province

P J Davies & P Symonds

The evolution of the Great Barrier Reef province has been determined from modern process studies in conjunction with shallow- and intermediate-focus seismic reflection profiling. Throughout much of its history the province was dominated by terrigenous sedimentation; the reefs are Pleistocene features, the development of which drastically changed slope sedimentation patterns.

The principal control on sedimentation has been the relative position of sea-level. During low-sea-level periods, fluviatile processes affected the shelf, while wave- and tide-dominated deltaic progradation affected the upper slope. Three periods of low sea-level in the Late Oligocene, the Late Miocene, and Pleistocene produced massive progradation. During high-sea-level periods, sedimentation was confined to coastal deltaic progradation, and transgressive onlap of the continental slope concomitant with extensive upper-slope erosion.

The reef facies appeared first as a fringing reef, probably in the Eocene, but was established as an extensive shelf-dominating facies during Pleistocene high-sea-level periods. Reef establishment had a profound effect on slope sedimentation processes and products; during low sea-level, the passages between the reefs channelled fluvial sediments onto the slope as point-source inputs, producing canyoning of the upper slope and deposition of fans on the mid and lower slope; during high-sea-level periods, reef-derived, fine-grained carbonates and organic material formed organic-rich drapes on the upper and mid slope.

Low sea-level, shelf-edge deltaic sands and prodelta muds prograded 8 km (0.38 km thick) in the Late Oligocene, 6 km (0.7 km thick) in the Late Miocene, and 4-20 km (0.6 km thick) in the Pleistocene. In contrast, modern coastal deltaic progradation has occurred and is occurring at a rate of 1-2 km.10^{-3} yrs due to a point-source annual fluviatile input of 3.5 million tonnes by the Burdekin River. High-sea-level reef accretion has occurred at rates of 1-10 m.10^{-3} yrs vertically; massive leeward progradation of 40-120 m.10^{-3} yrs contrasts with slight windward growth of 1-2 m.10^{-3} yrs. Total sediment shed from the reefs is of the order of 0.3 tonnes per metre of reef edge per year; nearly 60% of this load is organic carbon and much of it settles on the upper and mid slope. The Plio-Pleistocene witnessed an explosion in sediment production during both high and low sea-levels.

Much of the Great Barrier Reef appears to be only 150-200 m thick, yet grew during periods of high sea-level when there was rapid production of calcium carbonate; however, the growth periods were short in comparison to the intervening low-sea-level periods, during which time subaerial erosion of the order of 7-14 $cm.10^{-3}$ yrs could decimate a reef which had accreted 20 m of carbonate during the preceding high sea-level. The Great Barrier Reefs are therefore composite features - remnant reefs laid upon remnant reefs and separated by angular unconformities. Each unconformity is equivalent to a period of shelf-edge low-sea-level progradation.

Regional sedimentary basin framework of the Prydz Bay area, offshore Antarctica

H.M.J. Stagg

A BMR marine geophysical survey in early 1982 indicated that much of Prydz Bay is underlain by a sedimentary basin that is an extension of the onshore Lambert Graben. Severe seismic multiples preclude an accurate estimate of the total sediment thickness, but interpretation of the seismic and magnetic data suggest it could be of the order of 5 km.. Overall, the basin has a north-northeast trend, roughly orthogonal to the continental margin.

In the south of Prydz Bay, two seismic series are evident, separated by a mild erosional unconformity. The lower series ranges from poorly- to well-stratified, has minor folding and faulting, and is probably the expression of continental and perhaps shallow-marine breakup sediments. The upper series is generally well-stratified, becoming prograded near the shelf edge, and probably represents shallow-marine post-breakup sediments. The seabed is a distinct unconformity, and it would appear that both upper and lower series sediments have been bulldozed off by advances of the Amery Ice Shelf during glacial maxima and that present sedimentation rates are very low. The glacial advances deposited a thin sequence of tillites in the northeast part of the bay.

Indo-Antarctic breakup has been tentatively dated as Early Neocomian (130 Ma); the east-west orientation of breakup labels the Lambert Graben-Prydz Bay structure as a possible failed rift arm. There is no direct information on the age and nature of the sediments under Prydz Bay but Permian conglomerate, sandstone, and coal which crop out at Beaver Lake, to the south, may correspond to the breakup series. Analogies may also be drawn with fault-bounded intracratonic basins in India which may have been juxtaposed prior to breakup and which contain Permian to Triassic continental strata. The upper series probably consists of Upper Cretaceous and Cainozoic sands and shales, with tillites near the top of the section.

Sedimentary basins in active island volcanic arcs: Tonga, Vanuatu, and Solomon Islands

N F Exon & D A Falvey

Thick offshore sedimentary basins lie either between linear oceanic trenches and island arcs (fore-arc basins) or within island arcs (intra-arc basins). East of Tonga the Pacific Plate is subducted beneath the Australian Plate, and the Tonga Platform just west of the Tonga Trench is a fore-arc basin nearly 1500 km long and 200 km wide. Off Vanuatu the Australian Plate is being subducted beneath the Pacific Plate at the New Hebrides Trench, and a series of intra-arc basins, 1300 km long and 150 km wide, has developed between the twin island chains to the east of the trench. Off the Solomon islands the situation is similar: the Australian Plate is being subducted, and there is a series of intra-arc basins 1000 km long and 150 km wide lying to the north-east of the trench between twin island chains.

Three (1982) cruises of the USGS vessel R V Lee investigated these basin areas under the auspices of a Tripartite Agreement between Australia, New Zealand, and the United States. On each cruise more than 2500 km of multichannel seismic data, other under-way geophysical data, and bottom samples were gathered.

The cruise results, in conjunction with earlier work, have led to a considerable increase in our understanding of the basins and their petroleum potential. On the Tonga Platform a westward-dipping Cainozoic sequence 3 km thick rests on basement rocks - probably Eocene island-arc volcanics. The Cainozoic sequence consists of limestone, marl, and volcanoclastic sediment; most were laid down in deep water. A major unconformity corresponds to the early Pliocene opening of the Lau Basin, which separated the Tonga Platform from the Lau Ridge. The volcanic arc formed the eastern Tonga Platform in the Palaeogene, but moved westward in the Pliocene. The best petroleum prospects appear to be buried mounds that may be Miocene reefs.

In Vanuatu (where the arc basement may be as old as Late Eocene) and the Solomon Islands (where basement is Late Cretaceous or early Tertiary) subduction was initially to the west, and thick Oligocene and Miocene volcanoclastics and limestones accumulated in the fore-arc basins. In the Late Miocene a structural ridge formed in the fore-arc region and the direction of subduction reversed. Volcanoclastics and limestones continued to accumulate in the new intra-arc basins. There is now 5 km of normally faulted Cainozoic section between the island chains, and a major unconformity may represent the period where subduction reversed.

Possible carbonate build-ups of probable Miocene age are present in the Solomons, but have not been found in Vanuatu, downgrading Vanuatu's petroleum potential. However, in Vanuatu there are shallow-water perched basins east of Santo and Malekula, which could have entrapped hydrocarbons that were generated in the deep Central Basin to the east.

Subduction of a spreading axis beneath an island arc: magmatic, tectonic, and economic consequences in the western Solomon Islands

R W Johnson

A tectonically unique area where an active ridge-transform sequence is being subducted almost orthogonally beneath a presumed oceanic island arc, is represented in the Woodlark Basin/New Georgia Group area of the western Solomon Islands. The Woodlark Basin spreading axis began opening about 3.5-4 million years ago, and has since been developing at an average total spreading rate of about 6-7 cm per year. New seafloor in the basin abuts the fore-arc slope of the New Georgia Group beneath which it is consumed northeastwards at about 10 cm per year. Presumably, therefore, the New Georgia Group, and possibly the sedimentary succession in New Georgia Sound (The Slot) behind the arc, are underlain by a subducting thermal anomaly. This unusual tectonic configuration is of considerable interest in addressing questions of arc-magma genesis. In particular, does the underthrust youthful crust and thermal anomaly contribute to magma compositions that are significantly different from those in 'normal' island arcs? What implications does this have for 'porphyry' Cu-Au mineralisation? Further, does subduction of the thermal anomaly significantly raise the depth of petroleum-hydrocarbon conversion from organic material in the sediments of New Georgia Sound?

A suite of volcanic rocks from the New Georgia Group has been studied, both petrologically and geochemically, in conjunction with the Solomon Islands Geological Division, and these data have been supplemented by results on seafloor samples dredged by the *Kana Keoki* (Tripartite cruise 820316, Leg 4) in May-June 1982. The most striking types of volcanic rock in the New Georgia Group are picrite and picritic basalt which are found together with less-magnesian basalt, two-pyroxene andesites, hornblende andesites, and biotite tonalite. Some of these rock types were also recovered in the *Kana Keoki* dredges, but other rocks - not yet located in the islands - include unusual types such as orthopyroxene-rich magnesian andesite ('boninite'), basalt high in Na_2O/K_2O (about 65:1) and TiO_2 (2.3 wt %), and dacite from a newly-discovered volcano on the floor of the Woodlark Basin. The emplacement of such a variety of rock types - including some with island-arc characteristics - so close to the presumed line of subduction is a puzzling aspect of the triple-junction geology, and apparently relates to subduction of the spreading axis. However, heat-flow values are not high in New Georgia Sound, and the picrites appear to be olivine-accumulative rocks rather than high-Mg magmas produced by large degrees of mantle partial melting. A pronounced shift of the main volcanic axis towards the presumed line of subduction is the only obvious indication that ridge subduction has strongly influenced magma genesis beneath the island arc.

The Division of Geophysics and its research programs

M W McElhinny

Research in the Division of Geophysics is directed towards the study of the structure and characteristics of the crust and upper mantle. Use is made of the most sophisticated modern techniques of seismology, magnetics, gravity, and electrical geophysics to probe the structure of the Australian continent and to detect present and past movements of the crust. Emphasis is placed on multidisciplinary studies of large geological structures, especially major sedimentary basins and metallogenic provinces. The focus of such studies is the Australian Continental Reflection Profiling Program (ACORP) involving deep seismic profiles of the Australian continent.

The functions of the Division include the operation of an Australia-wide network of seismic and magnetic observatories. These form part of a worldwide network aimed at locating earthquakes and monitoring changes in the Earth's magnetic field. The Division undertakes airborne radiometric and magnetic surveys as a basis for mineral and petroleum exploration and carries out research into geophysical exploration techniques and applications.

Australia-wide airborne geophysical mapping - future program

G A Young

Reconnaissance magnetic and radiometric mapping of the Australian continent is vital to BMR in fulfilling its role to 'develop a comprehensive understanding of the geology of the Australian Continent', and to industry for mineral and petroleum exploration.

Since 1951 BMR has used its own aircraft to geophysically survey the Australian continent and thus create the necessary regional magnetic and radiometric database to support the search for minerals, including petroleum; to delineate the extent and depth of sedimentary basins; and to provide assistance to mapping in 'hard-rock' mineral provinces.

Primary strategic objectives are:

1. to complete basic survey coverage of the Australian continent by 1989;
2. to complete production of full suites of maps at scales between 1:250 000 and 1: 1 000 000 by 1990;
3. to undertake a comprehensive program of research into the regional geology and mineral potential of sedimentary basins and mineral provinces, involving the interpretation of airborne magnetic and radiometric data in conjunction with other geophysical data.

Secondary objectives are:

4. to use the BMR aircraft to carry out more detailed and specialised surveys, to solve specific geological problems and assist in resource-related research projects;
5. to test, and where appropriate further develop, new technologies in surveying, data processing, and interpretation.

With reference to objectives 1 and 2, the aeromagnetic coverage of Australia as at December 1981 will be presented as the basis of surveys programmed for completion by December 1983, and that being considered for progressive completion by December 1985 and by December 1987. Most of the work so programmed falls into three major regions:

- Northeast Queensland, to be flown by the end of 1984;
- Pilbara Block, and Hamersley and Bangemall Basins, WA, likely to be flown by end of 1986;

- Clarence-Moreton and Maryborough Basins, NSW/Qld, also likely to be flown by end of 1986.

Maps at 1:250 000 and 1:1 000 000 scales that show survey results will, in general, be released within one year of a survey being flown.

Consideration is being given to the production of a final series of magnetic maps at scales of 1:2 500 000 and 1:1 000 000, the first of which would cover the region south of latitude 24°S and be published in the mid to late 1980s. Both map series would be colour contour maps containing sufficient detail to adequately depict the major magnetic lineations and other regional features. A by-product would be a computer database containing gridded magnetic data, levelled to a common datum and incorporating all available data at the highest possible data density.

The benefit of having such a digital database (as compared to analogue data only) will be demonstrated with reference to the reprocessing of some early BMR data.

Earthquake risk in Australia

D Denham

Although the earthquake hazard in Australia is smaller than that in countries such as Japan, which are situated near active plate-margins, it is significant. During the last 30 years, earthquake damage in Australia has amounted to more than $15 million and every year it is usual for at least one earthquake to cause some damage.

Most Australian earthquakes are caused by compressive forces acting in the upper crust. Because they are all shallow (less than 30 km) those of moderate size (4.5 to 5.5 on the Richter Scale) are likely to cause damage if they occur near areas of habitation.

To properly assess the risk from earthquakes we need to know where, and how frequently, they are likely to occur. At present, the coverage of seismograph stations is adequate for this purpose in most of the four southeastern States, but in Queensland and Western Australia there are deficiencies in the network.

In addition to knowing the frequency of occurrence of earthquakes, we need to know the ground response so that the risk can be quantified for engineering purposes. Until recently we have had to rely on results from overseas for these estimates, but we now have enough Australia data to make significantly better estimates than those obtained in 1976, when the first attempt was made to provide a continent-wide assessment of earthquake risk.

An omni-directional downhole EM probe

R Cobcroft

Recognising the importance of borehole geophysics in the future of metalliferous exploration, BMR has developed and tested a three-axis (omni-directional) downhole EM probe capable of operating to a depth of 500 m in holes as small as BQ (60 mm dia) and having superior sensitivity and target characterisation compared with existing single-axis probes.

The primary field is set up by a sinusoidal audio frequency current flowing in a large loop on the surface. The downhole omni-directional probe permits the measurement of the axes and the orientation of the polarisation ellipse resulting from the interaction of primary and secondary fields. These measurements are invariant with probe orientation, are simple to interpret, provide a good guide to the location of subsurface conductors, and permit the use of complex transmit loops to enhance target detection.

The results of a program of field tests in eastern NSW, Tasmania, and near Broken Hill are discussed and demonstrate the superiority of the omni-directional probe over the traditional single-axis probe in detecting and defining subsurface conductors.

Gravity, magnetic, and radiometric characteristics of the Davenport Geosyncline, NT

I G Hone

The Davenport Geosyncline consists of a strongly folded sequence of sedimentary and volcanic rocks, the Hatches Creek Group, which is between 1810 and 1660 Ma old and located between Tennant Creek and Alice Springs. The geophysical characteristics of the geosyncline are being studied in conjunction with a joint BMR-NTGS investigation of the detailed stratigraphy, structure, geological history, tectonic setting, and mineral potential.

The Hatches Creek Group, which has been divided into three divisions on the basis of lateral facies changes, volcanic content, and depositional environment, lies unconformably on the Warramunga Group to the north and the Arunta Block to the south, and is unconformably overlain by the Georgina and Wiso Basins to the east and west. It is intruded by many gabbro, dolerite, and granophyre sill-like bodies, especially in the lower parts, and by granite. The sedimentary rocks of the Group - quartz-rich sandstone and subordinate conglomerate, siltstone, shale, and carbonate - are interlayered with mafic (basaltic) and felsic (dacitic and rhyolitic) lavas and pyroclastics.

Gravity and magnetic expressions of the Hatches Creek Group resemble those of the Tomkinson Creek Beds which lie north of Tennant Creek, suggesting the two are correlatives. The two occur as flanks of an anticlinal structure having the Tennant Creek Block as its core.

Residual gravity patterns over the Hatches Creek Group broadly correlate with the distribution of the Lower, Middle, and Upper divisions of the Group, highest values occurring over the lower parts which contain the greatest proportion of mafic volcanics and intrusives, and the lowest values occurring over the upper parts which contain few intrusives. Strong lows occur over granites. The broad station spacing of the reconnaissance gravity survey of Australia was infilled to adequately define gravity features for interpretation. Gravity anomalies indicate that the granites intruding the Hatches Creek Group are small steep-sided plutons extending to considerable depth, whereas granites intruding the Warramunga Group to the north are broader.

Newly acquired aeromagnetic data outline magnetic layers within volcanic units and sills. Granites do not have magnetic contact aureoles. Detailed aeromagnetic surveys are very effective mapping tools, and units can be traced for considerable distances and structures outlined under cover, and the thickness of cover rocks determined. Results of aeromagnetic surveys show that the Hatches Creek Group extends well beyond its exposed limits.

The granites, granophyres, and felsic volcanics are relatively radioactive. Occasional radiometric anomalies occur over the sandstones - possibly from leaching of radioactive minerals from acid volcanics.

Wolframite deposits near Hatches Creek may have as a source the granite a few kilometres to the south. This granite has only a small area of exposure but is shown by gravity to be the upper extremity of a pluton at shallow depth. The Devil's Marbles Granite, which is close to the wolframite deposits of the Wauchope Mineral Field, is also seen to be the upper extremity of a larger pluton at shallow depth.

The 1982 BMR seismic survey - Adavale Basin

M J Sexton

BMR conducted a seismic survey in the Central Eromanga Basin in Queensland from July to late November 1982. The survey was a continuation of the work undertaken in 1980 and 1981 to investigate the structure, stratigraphy, geological and tectonic evolution, and petroleum potential of the area.

The survey obtained 485 km of 6-fold CDP seismic reflection data in the Adavale Basin, Cooladdi Trough, and Pleasant Creek Arch area (Fig 1). Gravity observations were made at 667-metre intervals along all traverses.

Data quality is generally fair to good; and although processing is still incomplete, several interesting features are apparent. Suspected pre-Eromanga sediments east of the Pleasant Creek Arch have been confirmed. Confident lithologic correlations can be made for the Cooladdi Trough and the structure of the Gilmore gasfield is clearly defined.

Interpretations are proceeding, using where possible modern company seismic data, well log information, and an extensive network of seismic data reprocessed at BMR. This will allow structure-contour and isopach maps to be made for the study area and enable a reappraisal of the petroleum potential of the area.

Note: Copies of the sections at a scale of 10cm/s will be available from the Copy Service, Government Printer (Production), PO Box E84, Queen Victoria Terrace, ACT, 2600, after July 1983.

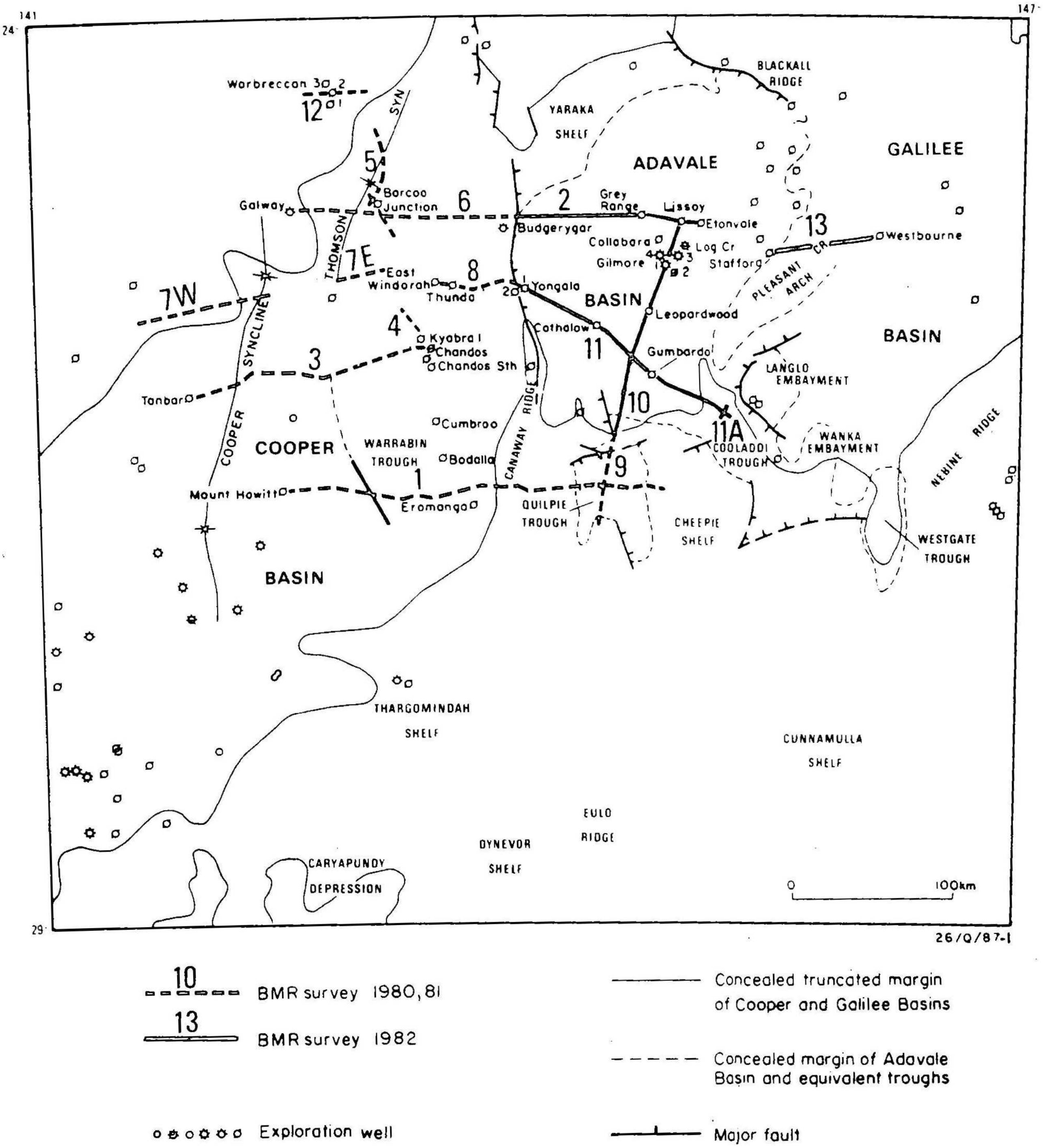

Fig. 1 Central Eromanga Basin, BMR Seismic traverses 1980, 1981, 1982

Magneto-telluric soundings over a Precambrian boundary in Australia

J P Cull

The Early Proterozoic Willyama Complex crops out over a substantial area near Broken Hill. However, Adelaidean cover is widespread and the eastern limits of the complex are obscured by the Phanerozoic strata of the Murray-Darling Basin. Consequently, geophysical techniques must be used as an aid to regional mapping.

Vertical contacts are readily located in terms of a lateral variation in apparent resistivity. Adequate data can be obtained by magneto-telluric surveys, which give structural details at a fraction of the cost of seismic surveys. Consequently an MT traverse was established across the eastern margin of the Willyama Block to investigate the nature of the contact between the complex and the younger, unmetamorphosed strata. Data were obtained at 14 sites, from Broken Hill to Ivanhoe.

Apparent resistivities presented as pseudosections reflect the major structural units identified from surface geology. Continuity between sites can be demonstrated from similarity in apparent resistivities between successive sites. Lateral changes are generally gradational but a major discontinuity is evident between Broken Hill and Menindee. A characteristic divergence is generated in orthogonal components of apparent resistivity. A corresponding response has been obtained using 2D models.

The foliated Willyama Complex can be represented using a succession of steeply dipping beds generating the required anisotropy at depths from 15-35 km. On this assumption the Early Proterozoic basement appears to extend at least as far east as Menindee. However, resistivities assigned to surface layers are not sufficiently constrained to allow accurate estimates of depth.

Research in the Division of Continental Geology

P J Cook

Research in the Division of Continental Geology is directed towards understanding the nature and origin of onshore sedimentary basins and systems which may host fossil fuels, mineral deposits, or groundwater resources; determining the characteristics and origin of fossil fuels; establishing the effects of surface processes on the bedrock of Australia; studying the application of remote-sensing techniques to regional geological studies, and understanding the geological factors governing the quality and quantity of groundwater resources.

The BMR program on fossil fuels is addressed through Divisional projects concerned with the palaeogeographic distribution of resources, the characterisation and controls on the distribution of fossil fuels, and the biochronological framework of resources. A second group of projects concerned with onshore sedimentary basins analysis includes projects on the Proterozoic McArthur Basin, the Late Proterozoic/Palaeozoic Amadeus Basin, Late Palaeozoic/Mesozoic Basins (Clarence-Moreton and Eromanga), and Cainozoic Basins (Lake Eyre and Lake George).

A series of Divisional projects are concerned with minerals. These are directed towards determining the characteristics and controls on the distribution of sedimentary mineral resources, and understanding the weathered zone and its related resources by the use of remote sensing and other techniques.

The third program is concerned with groundwater. Because of limited staff, this is a relatively small Divisional program at the present time. directed mainly towards Murray Basin and Eromanga Basin hydrogeology in SE Australia.

Sea-level changes and Cainozoic sedimentation in the Murray Basin

C M Brown

Recent work by BMR, in cooperation with State Surveys, has resulted in a revised interpretation of stratigraphic relationships in the Murray Basin and leads to the conclusion that fluctuations in supply, preservation, and erosion of sediment in the basin can readily be accommodated by eustatic models. These involve global changes in relative sea-level and related intrabasinal isostatic adjustments associated with sediment loading. The Murray Basin sedimentary record may be subdivided into three and possibly four depositional sequences, each consisting of a package of genetically related formations, separated by surfaces of erosion or non-deposition. The Cainozoic history of the basin has been characterised by slow relative subsidence rates, low rates of sediment supply, and mineral compaction rates. Depositional sequences show an apparently close correlation with the 'second-order cycles' (supercycles) of relative rise and fall in global sea-level as recorded by Vail & others (1977), and Vail & Hardenbol (1979) (summarised in Fig 1). Framework tectonics provide the primary control on development of the basin; however, within this context sediment accumulation appears to have been sensitive to secondary eustatic and palaeoclimatic influences, and to consequent fluctuations in erosive and depositional potential of the fluvial systems that drain the basin. Laterally extensive intercalations of fluvio-deltaic, paralic, and shallow-marine sediments appear to have been deposited during periods of high global sea-levels, whereas non-preservation because of erosion/non-deposition appears to have occurred during major periods of lowered sea-levels. Jones & Veevers (1982) have proposed an alternative model of tectonic cycles. They interpreted depositional cycles in the Murray Basin to be the erosional products of cycles of tectonic uplift and Cainozoic volcanism in the SE Highlands of Australia, and correlated periods of non-depositional hiatus in the basin with proposed periods of 'tectonic settling' and diminished erosion in the highlands. Interpretation of the new Murray Basin data in terms of eustatic influences is believed to provide a more acceptable model.

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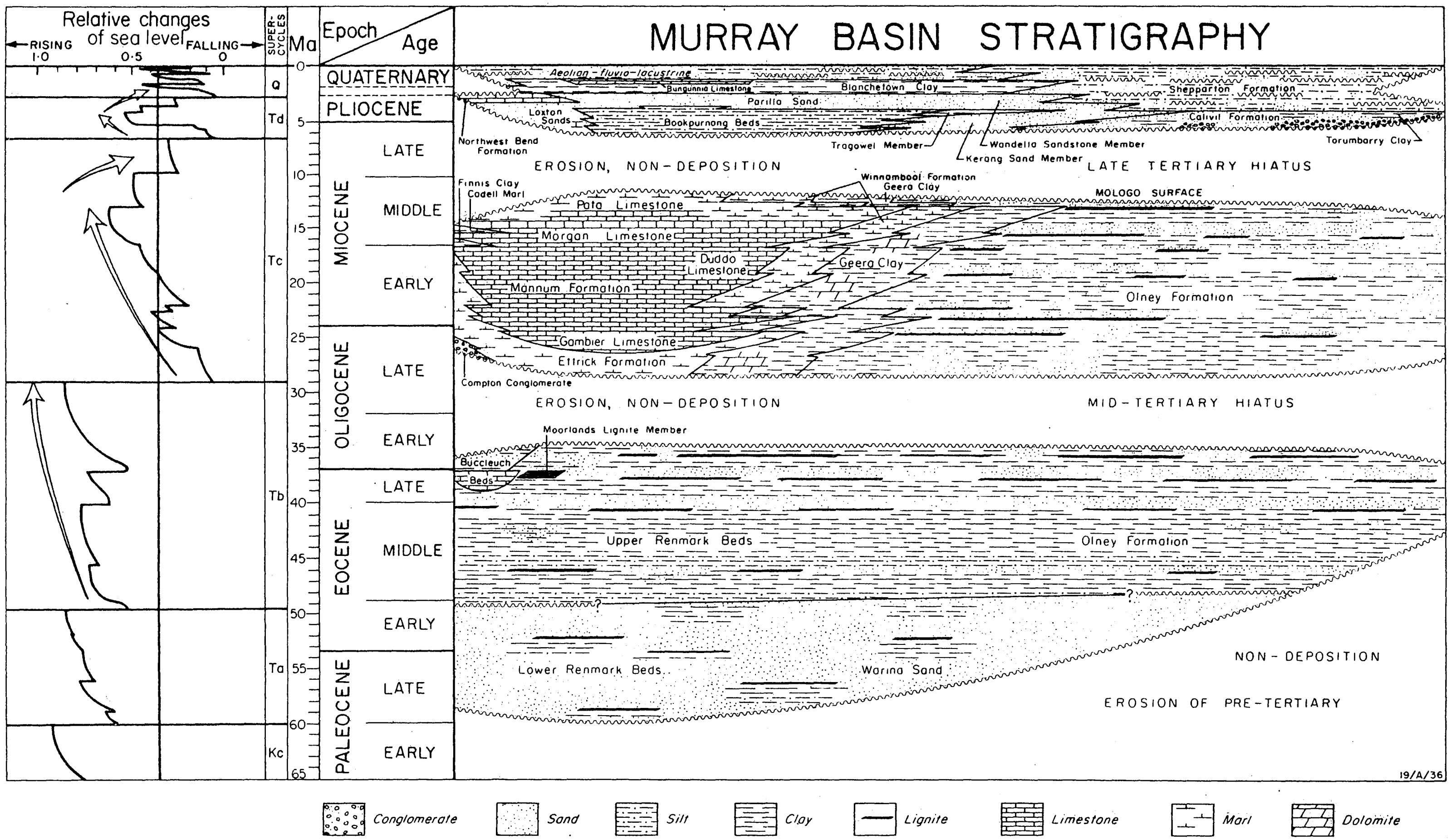

Figure 1

Eustatic interpretation of Murray Basin stratigraphy. Relative changes in sea level shown on the left are from Vail & others (1977)

Interpretation of conodont colour alteration and thermal maturation in the Amadeus Basin

J D Gorter[1] & R S Nicoll

The Amadeus Basin contains 11 500 m of Late Proterozoic to Late Devonian sediment, generally thickening northward across the basin towards the MacDonnell Ranges. A complex series of anticlinal structures, some of them fault-bounded, in the north-central part of the basin contains accumulations of hydrocarbons in sediments of Early Ordovician, Cambrian, and Late Proterozoic ages. Hydrocarbons have been produced from the Ordovician in two fields - the Palm Valley gas field and the Mereenie gas and oil field.

Study of conodont colour alteration to define organic maturation levels and trends is based principally on samples collected from the Early Ordovician (Arenig) Horn Valley Siltstone from both outcrop and subsurface localities. Additional faunas have been recovered from the overlying Early-Middle Ordovician Stairway Sandstone and Stokes Formation.

The conodont colour alteration isograds in the Amadeus Basin appear to be primarily related to events of the Alice Springs orogeny, when the thick mass of molasse sediments (Pertnjara Group) resulting from erosion of the uplifted Arunta Block was deposited. Anomalies in the conodont colour isograds appear to be related to erosion associated with the Rodingan orogeny and also possibly to the effect of salt structures.

1 Pancontinental Petroleum Ltd

Morpho-tectonics, palaeodrainage, and regolith studies

C D Ollier

The deep weathering of rocks is developed to an exceptional extent in Australia, and is of considerable economic importance to mining and mineral exploration companies. Some weathered material is itself of economic value; more often the weathered zone is a barrier between explorers and their target. The weathered zone and its cover together comprise the regolith: regolith is a general term for the mantle of unconsolidated rock material, whether residual or transported, that covers the bedrock. We are concerned with its description, regional distribution, and age.

Because of the great age of landscapes in Australia, regolith can also be very old, and hence there are many deep weathering profiles in the continent.[1] Many Australian landscapes are etchplains in varying degrees of stripping, that is erosion of the weathering profile down to the level of fresh bedrock. Weathering is still taking place, but present day weathering is not the cause of the deep-weathering profiles, which were formed under different climates and a long time ago.

Regolith can be dated by several methods. Associated sediments can give a stratigraphic age if dates can be obtained from the youngest sediments that are weathered, and from the oldest unweathered sediments overlying an earlier weathered surface. In eastern Australia volcanic rocks can provide an age, using the K-Ar method. Some old basalts are very deeply weathered, and may be overlain by relatively fresh younger basalt. Palaeomagnetism may be applied to suitable materials in a weathering profile, and possibly reveal the age of weathering. Where these straight-forward geological and physical methods cannot be applied, more devious geomorphic techniques may be used.

Some weathering profiles have been related to erosion surfaces. There is much controversy over the origin, number, and spatial and temporal relationships of erosion surfaces, and a major task is to map and understand the major features of erosion surfaces in relation to regolith. Elsewhere, regolith may be related to drainage patterns. An understanding of the palaeodrainage may then help to place the associated regolith in a time-scale. Australian palaeodrainage can be traced in places back to Permian times, and there have been many changes of drainage pattern and style since then, so there is a good chance of establishing a reasonably full drainage pattern history helping to establish a regolith history.

Many major features of Australian drainage patterns result from changes brought about by tectonic movement. Some rivers apparently existed before uplift of features such as the Flinders Ranges horst or the Eastern Highlands; some may even be older than the break-up of Gondwanaland and the formation of the continental edges of Australia.

Tectonic movements also created Cainozoic sedimentary basins. The sedimentary history of these basins reflects not only the local tectonics but that of the surrounding region, so the sedimentary record should be matched by an erosion history in the catchment, including stripping of old regolith.

Regolith formation is on the same time-scale as sedimentary basin formation, mountain building, and continental drift, and its study bears on many other aspects of geology and geomorphology.

Morphotectonics of Australia and remote sensing

R F Moore & C J Simpson

Morphotectonics (the study of the interrelationships of major landforms and tectonic processes) is undergoing a resurgence of interest with the application of digital image-processing techniques. The detection and verification of major structures on a continental scale is an important preliminary phase in morphotectonic studies. It is demonstrated that digital image-processing techniques applied to topographic spot-height or digital terrain data over continental Australia help in the detection and study of those geomorphological features which apparently relate to the tectonic framework of the continent, and reveal features previously unknown. Manipulation of pseudocolour, gradient, synthetic-reflectance, and bit-plane images can provide specific information unattainable from conventional topographic maps. Information derived from such images is of value in regional geomorphic studies, and in the analysis of linear, curvilinear, and circular features. The method also provides an excellent medium for merging other digital data sets of direct relevance to morphotectonics. The technique can be used at different scales, in areas of any size. Digital image processing allows the integration and analysis of remotely-sensed imagery and photographic, topographic, and geophysical data to help discover and confirm the existence of morphotectonic features.

Regional groundwater movement and hydrocarbon migration in the Eromanga Basin

M A Habermehl

In the Eromanga Basin, which is a constituent sedimentary basin of the hydrogeological Great Artesian Basin, confined aquifers occur in continental quartzose sandstones of Jurassic and Cretaceous age. A thick argillaceous sequence of sediments of marine origin and Cretaceous age forms the main confining unit.

Large-scale groundwater movement, interpreted from potentiometric maps based on data from flowing artesian waterwells in the basin, is generally directed to the west, southwest, and south in the main part of the basin. In the western part regional groundwater movement is towards the southeast and south; in the most northern part a northerly flow direction exists. Epeirogenic uplift of the eastern recharge areas and lowering of the southwestern area during Late Cretaceous and Tertiary times established the present flow regime. The hydraulic gradient steepened slightly in the late Quaternary as the spring levels in the southwestern margin were lowered. Groundwater development by flowing artesian waterwells since about 1880 caused significant changes to the potentiometric surface. The artesian groundwater which is of meteoric origin, as shown by environmental isotope analysis, moves only slowly. Residence times of the water are large, but groundwater salinities are low, generally between 500 and 1500 mg/l total dissolved solids, and increase only slightly along the flowpaths. Hydrochemical differences characterise different aquifers and regional groundwater flow patterns, particularly in the southwestern part, where groundwater derived from the eastern recharge area is characterised by $Na\text{-}HCO_3\text{-}Cl$ and water from the western recharge area by $Na\text{-}Cl\text{-}SO_4$. Waters in the central part of the basin are mainly of the $Na\text{-}HCO_3\text{-}Cl$ and $Na\text{-}HCO_3\text{-}Cl\text{-}SO_4$ type.

Hydrocarbons have been generated in the marginally mature to mature fine-grained Jurassic and Cretaceous sediments since Late Cretaceous time. Most Jurassic-Lower Cretaceous sandstones are reservoir rocks, and some commercial and sub-commercial oil and gas discoveries have been made in them. Migration of the hydrocarbons has probably been influenced by the artesian groundwater flow. Gas samples were taken at the surface from about 60 long-established (several decades) flowing artesian waterwells (which were 'randomly' drilled in contrast to petroleum exploration wells) in the central part of the Eromanga Basin in 1980. Methane concentrations from the upper, main Lower Cretaceous-Jurassic aquifer (Cadna-owie Formation/Hooray Sandstone) range up to about 510 000 microlitres per litre, and the sum of the hydrocarbons ethane to heptane range up to about 14 000 microlitres per litre. These relatively high values for the hydrocarbons methane to heptane suggest that hydrocarbons derived from the adjoining source rocks or from existing accumulations are migrating in the artesian groundwater.

The Division of Petrology & Geochemistry and its Research Programs

J Ferguson

Research in this Division is designed to undertake basic geochemical, petrological, and mineralogical studies of major sedimentary and igneous rock suites, of the environments of metalliferous deposits, and of the deposits themselves. It has the main carriage of multi-disciplinary studies of metallogenic provinces.

The functions of this Division include the development of the understanding of the origin, abundance, age, and distribution of Australia's metalliferous mineral resources in the context of the structure and geological history of the continent, and its various geological provinces, as a basis for exploration and assessment.

Diamond province studies: contrasts in the South Australian and West Kimberley fields

A.L. Jaques & J. Ferguson

Diamondiferous kimberlitic rocks occur in the north, east (Argyle) and west Kimberley (Ellendale) and Carnarvon Basin areas of Western Australia, and in the Orroroo area of South Australia. Diamond grades range from economic (Argyle) to subeconomic (Ellendale) to trace only. That many of the kimberlitic rocks of Western Australia differ significantly from the 'classical' kimberlites of southern Africa is shown by the contrasts between the West Kimberley and South Australian provinces.

The South Australian kimberlites are of Jurassic age (164-174 m.y.) and occur as dykes, blows, sills, and pipes intruding the Adelaidean of the Adelaide Fold Belt and Stuart Shelf. Petrographically they are hypabyssal calcite - phlogopite kimberlites and resemble the kimberlites from the Kimberley region of South Africa. No mantle nodules have been found but typical kimberlite indicator minerals (pyrope, Cr-diopside, picro-ilmenite, spinel) are common. The South Australian rocks also closely resemble the kimberlites of southern Africa in terms of their bulk chemistry.

The diamondiferous rocks of the West Kimberley, in contrast, are of Miocene age (20 m.y.) and occur intimately associated with leucite lamproite (Fitzroy Lamproites) forming a broad belt of more than 100 separate pipes, plugs, sills and rare dykes. Crater sediments occur in a number of pipes indicating little erosion since their emplacement. A feature of the pipes is the common late-stage emplacement of massive, magmatic rock in the form of a lava blister. The West Kimberley rocks show a petrographic gradation from phlogopite peridotite resembling kimberlite through olivine-rich leucite-poor lamproite to leucite lamproite. Major mineralogical differences between the West Kimberley and South Australian provinces include the gradation to leucite-bearing rocks, the presence of amphibole and glass, the absence of primary carbonate, and the rarity of garnet and the absence of picro-ilmenite from the indicator suite. Compared to the South Australian and South African kimberlites the kimberlitic rocks of the West Kimberley are richer in SiO_2, TiO_2, K_2O, and 'incompatible' elements, and poorer in CaO and CO_2. In common with the associated leucite lamproites the kimberlitic rocks have $K_2O>Al_2O_3$, and similarly high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios indicating that they form a consanguineous ultrapotassic suite.

Hydrothermal alteration in the Mount Gunson area of the Stuart Shelf and its possible relevance to copper mineralisation

J Knutson, Baas Becking Geobiological Laboratory (BMR), T H Donnelly, Baas Becking Geobiological Laboratory (CSIRO), P Eadington, CSIRO, North Ryde, D G Tonkin, CSR Limited, Adelaide

The aim of this project is to determine the depositional and post-depositional processes operative in the pre-Adelaidean rocks in the Mount Gunson area, SA, and to assess the possible signficance of these to base-metal mineralisation throughout the sequence. Geochemical, petrological, stable isotope, and fluid inclusion studies are being carried out in order to indentify the type(s) and extent of secondary alteration in these pre-Adelaidean rocks and the major processes responsible for this alteration.

The core material being studied comes from a drill hole located approximately 10 km north of Mount Gunson. The hole penetrated to a depth of 1000 m and intersected in turn, the Pandurra Formation (500 m thick), a sequence of tuffs, siltstones, basic, intermediate, and felsic volcanics and volcanic breccias (300 m), metasediments (200 m), and finally granitic breccia (10 m-bottom of drill hole).

All rock units below the Pandurra Formation are strongly hematitised and there is ubiquitous K-feldspar metasomatism. Textural relationships indicate that there were a number of different and/or overlapping veining episodes, including at least two episodes of calcite introduction; one early in the alteration sequence and one late. The early carbonate is fine-grained and dusted with hematite and is associated with K-feldspar and secondary quartz. Coarse crystalline calcite formed very late in the metasomatic episode/s and commonly replaces feldspar, quartz and, to a lesser extent, tourmaline and fluorite. Specular hematite and minor chalcopyrite were probably introduced at the same time as this late calcite. Fine brittle fracturing of the feldspathic rocks postdates K-metasomatism as well as the main tourmaline and fluorite mineralisation, and could be associated with the later calcite mineralisation.

The extreme secondary alteration makes precise identification of the original igneous rock types difficult. Overall, the volcanic and volcaniclastic rocks are basic to intermediate in composition. Most rocks analysed are depleted in Na_2O and Sr and enriched in K_2O. Iron values vary greatly, ranging from 3.5% in a tuff to 50% in a hematite-rich rock.

Carbon isotope results indicate that calcite in vugs and veins of the feldspathic rocks overlying the calc-silicate unit is of magmatic origin. Generally there is a tendency for $\delta^{13}C$ values to become less negative away from these rocks. Preliminary sulphur isotope results also indicate that sulphides with isotopic values consistent with an origin from magmatic-hydrothermal fluids occur at the same stratigraphic levels as the magmatic $\delta^{13}C$ values.

Fluid-inclusion results suggest the presence of magmatic, mixed magmatic and connate, connate, and meteoric fluids. It may be significant that the magmatic-hydrothermal fluids occur in the same rock types in which the $\delta^{13}C$ values indicate a substantial magmatic component. Estimated salinities of these hydrothermal fluids range up to 30-35 wt % NaCl and temperatures range up to 380°C. Some of the fluid inclusions of magmatic origin are vapour-rich, suggesting that boiling has taken place.

Proterozoic and Palaeozoic extensional tectonics and mineralisation in the western Georgetown Inlier

D E Mackenzie & B S Oversby

The Proterozoic (about 1430 Ma) dominantly ignimbritic 'Croydon Volcanic Group' and a locally superimposed Permian acid-to-basic igneous suite, which includes the Bullseye Rhyolite, reflect broadly analogous tectonic regimes.

Accumulation of the 'Croydon Volcanic Group' and emplacement of related granitoids appear to have been influenced by roughly E-W-oriented extension, which followed similarly-oriented compression during the 'Jana Orogeny' (about 1470 Ma); the Permian rocks probably formed under the influence of NE-SW-oriented extension.

The northwestern part of the Croydon volcanics is interpreted as a second-order syn-volcanic subsidence structure. Gold-bearing quartz reefs and veins, commonly associated with graphite concentrations, and stanniferous greisens are spatially, and probably genetically, related to altered rhyolite dykes, extensive zones of alteration, and/or shear zones in the volcanics and associated granitoids. Some of the quartz reefs, greisens, and rhyolite dykes are in NW-trending swarms, and may have formed under the influence of the Permian extensional regime. However, the bulk of the available evidence indicates a Proterozoic age; the quartz reefs and veins were probably emplaced into fractures formed during late-stage 'settling-in' of the volcanic-granitoid pile. Extensions of known mineralisation might be expected in zones of shallow-dipping reefs or veins localised at stratigraphic discontinuities in the volcanic sequence, in zones at or near the granite-volcanics contact, and in vent-facies rocks in the northwest 'structure'.

The Permian Bullseye Rhyolite, along with possibly Permian andesite, is preserved in a group of closely-spaced, NNW-trending horsts and grabens which lie at the northwestern end of a major NW-trending composite fault zone, which includes the Robertson Fault, and on which also lie the Permian Agate Creek Volcanics. Similar rhyolitic ignimbrite crops out 15 km to the west, where it is associated with Permian andesite, and dacite, granodiorite (Awring Granodiorite), and dolerite of probably Permian age; most of these rocks are preserved in a small northwest-trending graben. The Awring Granodiorite and small roof pendants of altered Permian (?) rhyolitic ignimbrite contain late-stage hydrothermal Ag-Cu-W mineralisation. Areas along the 'Agate Creek-Bullseye' trend where small-scale block faulting and Permian igneous rocks occur, such as the Bullseye Rhyolite itself, may also be prospective for metals such as Cu, W, Sn, Ag, and Au, and this has clear implications for exploration in other areas of Permian magmatism and tensional tectonics in northeastern Queensland.

Volcanic-hosted massive sulphide deposits - the state of the art

M Solomon
(University of Tasmania, joining BMR shortly)

Among the diversity of form and composition, three prominent styles can be recognised - Cyprus-type, Kuroko-type, and Rosebery-type, the latter being particularly important in eastern Australia and eastern Canada. The quantification of potential for new finds, and the efficiency of subsequent discovery and development, are linked to our understanding of the genesis of these deposits and the reasons for their diversity.

Genetic problems fall under three headings: (a) growth on the sea floor; (b) the formation of subsurface stockwork zones; and (c) the generation of the ore solutions.

Part (a) for Cyprus and Kuroko types, based on field and laboratory studies and the discovery of chalcopyrite chimneys on the East Pacific Rise, involves the growth of a sulphide mound at temperatures $< 400^{o}C$ by fall-out from escape plumes and the incorporation of collapsed chimneys. In contrast, Rosebery-type orebodies grow by precipitation from saline solutions that reverse buoyancy and collect in basins. Major-element and $\delta^{18}O$ values around some deposits indicate that hydrothermal flow continues long after accumulation of the hanging wall.

Part (b) involves partial sealing of the subsurface flow channel as a result of thermal and chemical disequilibrium between rising ore fluid and country rock. Re-equilibration of the convective circulation in response to the decreased permeability results in fluid pressures that commonly exceed the tensile strength of the rock, forming stockwork pipes in which quartz precipitation follows the attendant pressure fluctuation.

The current model for Part (c) involves convective circulation of sea-water ($\pm$ magmatic water) driven by magmatic heating. For the Cyprus-type deposits the heater is a wedge-like basaltic magma chamber beneath a spreading ridge, for Kuroko deposits it is a small plug-like felsic pluton, and for Rosebery it is a shallow, extensive felsic sill. Suspected heater-deposit relationships have only been observed in two localities - Tasmania (in the Murchison Gorge) and Canada. Theoretical and experimental modelling of idealised fluid flow patterns allows prediction of the mineralogy throughout the circulation cells, and preliminary field studies in Tasmania indicate potential for (and the difficulties involved in) mapping flow paths.

East Australian stratabound sulphides: comparative studies

F M Vokes
(Consultant to BMR: University of Trondheim, Norway)

Studies are in progress aimed at comparing the base metal-bearing stratabound sulphide deposits of two of the world's major Early Palaeozoic mobile belts, the Caledonides of the North Atlantic Region and the Australian Tasmanides.

As a result of the IGCP Project No 60, 'Correlation of Caledonian Stratabound Sulphides', considerable advances have been made in Scandinavia in recent years in understanding the palaeo-tectonic/geographical and stratigraphic/lithological environments of formation of these deposits, as well as their chemical characteristics, their morphology and structure, and their response to metamorphism and deformation.

Geological age, host-rock lithology, and stratigraphic/tectonic position permit a number of types or groups of generally stratabound (sometimes stratiform) sulphide ores to be distinguished within the Late Precambrian and Early Palaeozoic sequences of the Norwegian Caledonides, the two main classes being: A. Mainly disseminated deposits of galena with minor sphalerite (± fluorite and barite) in Late Precambrian and Early Cambrian sandstones. These deposits belong to the class of 'lead-in-arenite' ores which occur in a belt extending from southwest Norway along the Caledonian Front Zone through central and northern Sweden to the northernmost county of Norway. Such ores are only economically important in Sweden, where the Laisvall mine is one of Europe's major lead producers. Equivalents of this type of stratabound ore do not seem to have been recognised so far in the Tasmanides. B. Massive, semi-massive, and disseminated, polymetallic (Cu + Zn + Fe ± Pb) sulphide deposits in volcanic and mixed sedimentary-volcanic sequences of dominantly Early-Middle Ordovician age in the allochthonous metamorphic sequences of the central Caledonides. Economically these have been the most important sulphide deposits of Norway and currently account for the country's total production of Cu, Zn, and Pb concentrates. Among these classical 'volcanogenic' deposits the following distinct types have been recognised: (a) Cu-Zn deposits associated with metabasaltic volcanites of ocean floor affinities ('Cyprus type'); (b) Zn-Cu deposits associated with mixed mafic and felsic volcanites related to island-arc formation.

In addition, a rather distinctive, if numerically minor, group of Zn-Pb-Cu ores occurs in a high-metamorphic nappe in the northern Caledonides. Their lithological associations indicate that their environment of deposition was dominantly sedimentary, perhaps with some felsic volcanic intercalations. Metabasic rocks (with a relatively high TiO_2 content) are quantitatively minor and occur well into the foot-wall country of the ores. These, and the metasedimentary lithology, indicate an intracratonic environment.

Comparisons between this last group and geochemically similar Australian deposits (Rosebery, Woodlawn, Captains Flat) are being made with a view to arriving at a better understanding of the highly metamorphosed and deformed Norwegian examples.

On a global scale, similarities may be recognised to the Canadian New Brunswick deposits and to the Tertiary Japanese Kuroko-type ores.