BMR Research Newsletter

A twice-yearly newsletter for the exploration industry

Number 10 ISSN 0813—751X **April 1989**

In this issue:

New mapping extends Drummond Basin gold potential

This article is a brief progress report on recent mapping by BMR and the Queensland Department of Mines in the northeastern Drummond Basin and the adjoining Bulgonunna Volcanics, 100–150 km southeast of Charters Towers (Fig. 1). The work has brought to light much new geological data on what has become recognised as a major new gold province since the discovery and development of the Pajingo deposit on the northwestern edge of the basin.

As a first step in meeting the urgent need for a better understanding of the setting and controls on the gold mineralisation in this province, BMR is carrying out integrated regional and deposit-scale studies, in conjunction with the Department of Mines and various companies exploring in the area. The highly prospective Devonian–Carboniferous volcanic rocks of the Drummond Basin are more extensive than previously thought, and host all of the significant proven mineralisation.

Figures 2 and 3 (overleaf) cover the same area of the Northeast Queensland Gold Province, from the new Burdekin Dam, extending southeast to 'Conway'. The area is southeast of the historic mining towns of Charters Towers and Ravenswood; it is adjacent to several major, newly discovered, epithermal gold deposits (Pa-

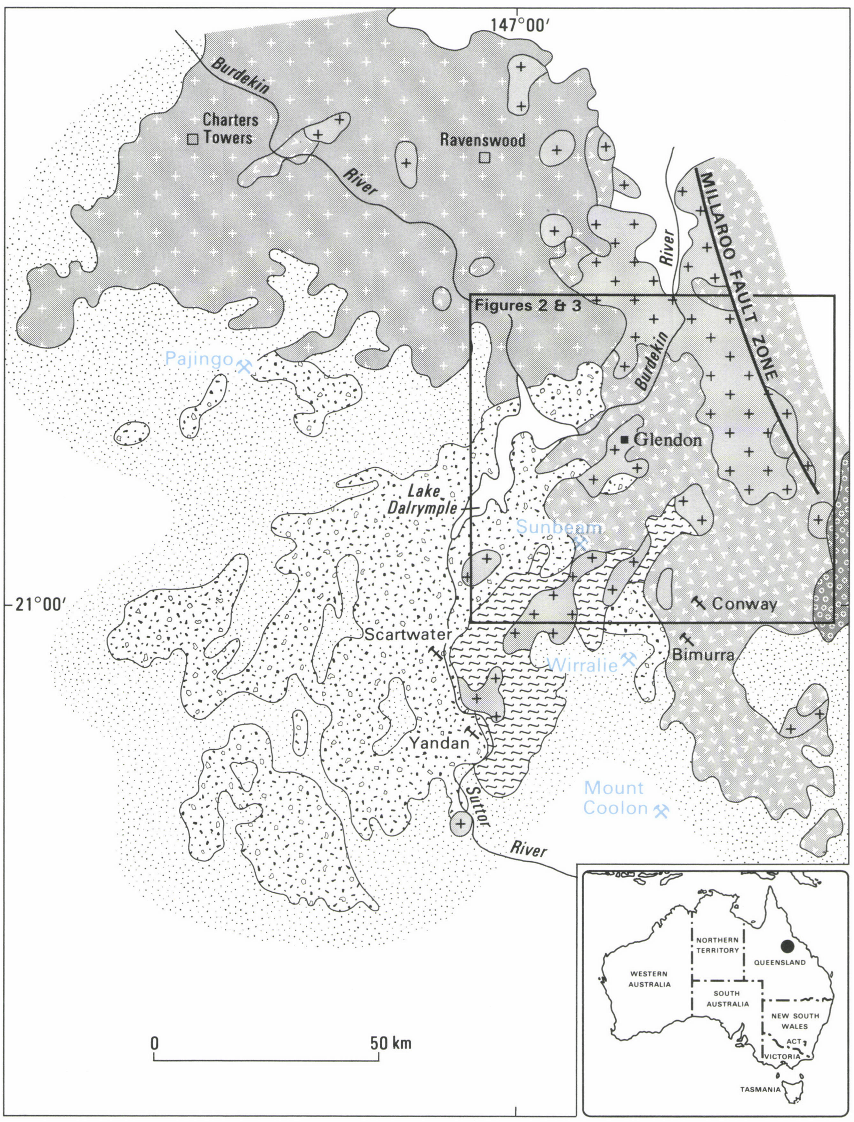

Fig. 1. Regional setting of recent BMR–Queensland Department of Mines geological mapping of the northern end of the Drummond Basin and the Bulgonunna Volcanics. Modified from *Geological Survey of Queensland, 1975: Queensland Geology, 1:2 500 000 map; Department of Mines, Brisbane*. Note that the Bulgonunna Volcanics are shown in their 'before' distribution.

Mesozoic–Cainozoic strata
Permian
Bowen Basin
Carboniferous–Permian (Coastal Range Igneous Province)
Intrusive
Extrusive (mostly Bulgonunna Volcanics)
Devonian–Carboniferous
Drummond Basin
Devonian
Anakie Inlier (Ukalunda Beds)
Cambrian – Devonian
Lolworth–Ravenswood Block
Mine
Prospect

Published by the Australian Government Publishing Service for the
Bureau of Mineral Resources, Geology and Geophysics, Canberra
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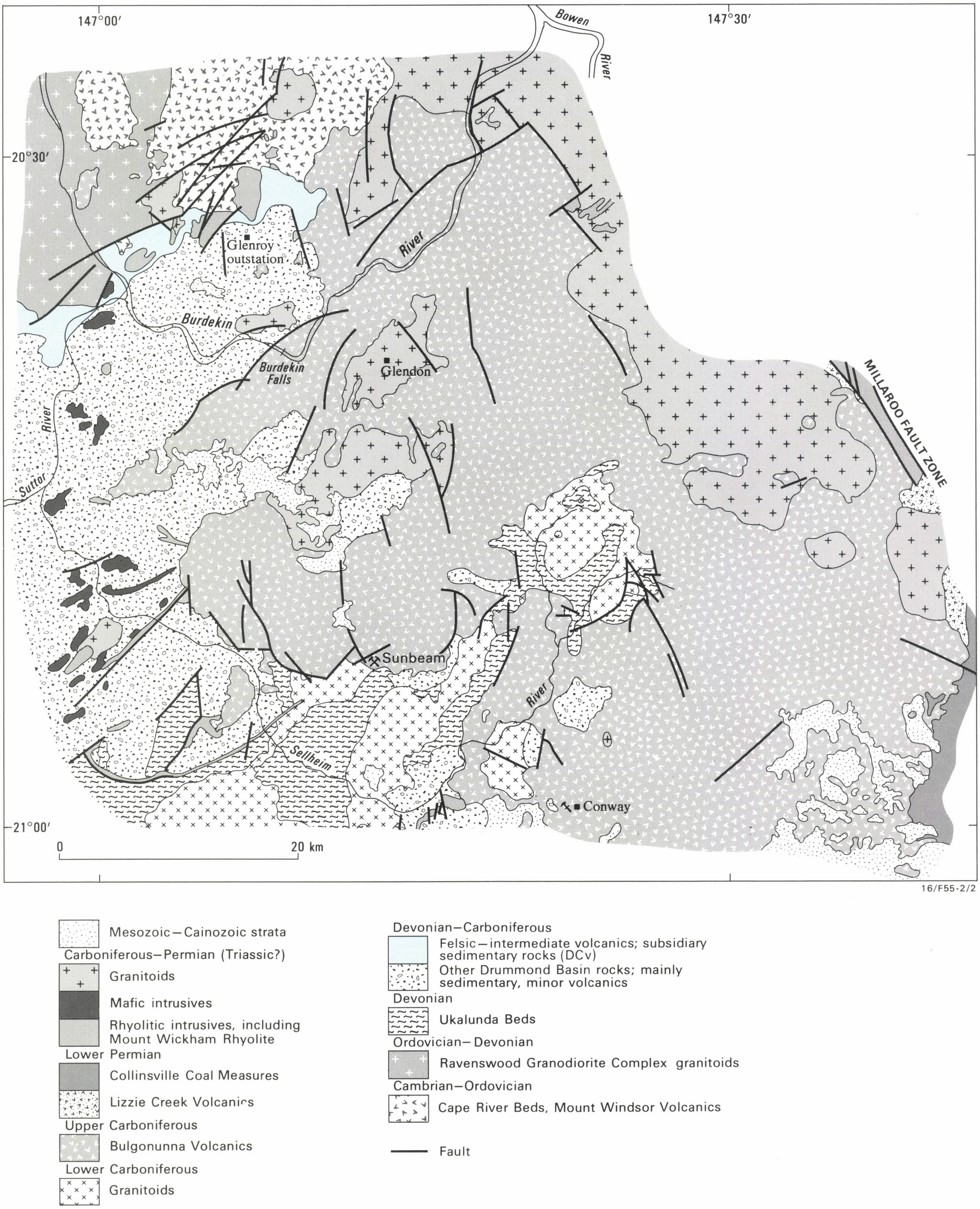


Fig. 2. Distribution of Bulgonunna Volcanics, 'DCv', and associated rocks as shown before 1988 field work. Modified mainly from CHARTERS TOWERS (SF/55-2) and BOWEN (SF/55-3) 1:250 000 scale Geological Series sheets, First Edition, 1969 and 1971 respectively.

jingo, Wirralie, Yandan), and includes numerous prospects (e.g. Bimurra, Conway, Scartwater).

The geology is dominated by Devonian and Carboniferous formations of the Drummond Basin, and Carboniferous and Permian silicic volcanics and granitoid intrusions of the Coastal Ranges Igneous Province (Henderson, R. A. *in* Henderson, R. A., & Stephenson, P. J. (Editors), 1980: THE GEOLOGY AND GEOPHYSICS OF NORTHEASTERN AUSTRALIA. *Geological Society of Australia Incorporated, Queensland Division*, 1-26). Older rocks are extensively exposed on the northern and southwestern margins of the area: Cambro-Ordovician Mount Windsor Volcanics and Cape River Beds and the Early Palaeozoic Ravenswood batholith in the north, and Ukalunda beds in the south.

Old mapping now inadequate

Until recently, knowledge of the regional geology was limited to that represented on the BOWEN (1971) and MOUNT COOLON (1968) 1:250 000 scale maps (Fig. 2). Some of the new prospects were apparently hosted by the Late Carboniferous Bulgonunna Volcanics (Cub), but the scale and accuracy of these maps are inadequate for detailed deposit studies and further exploration.

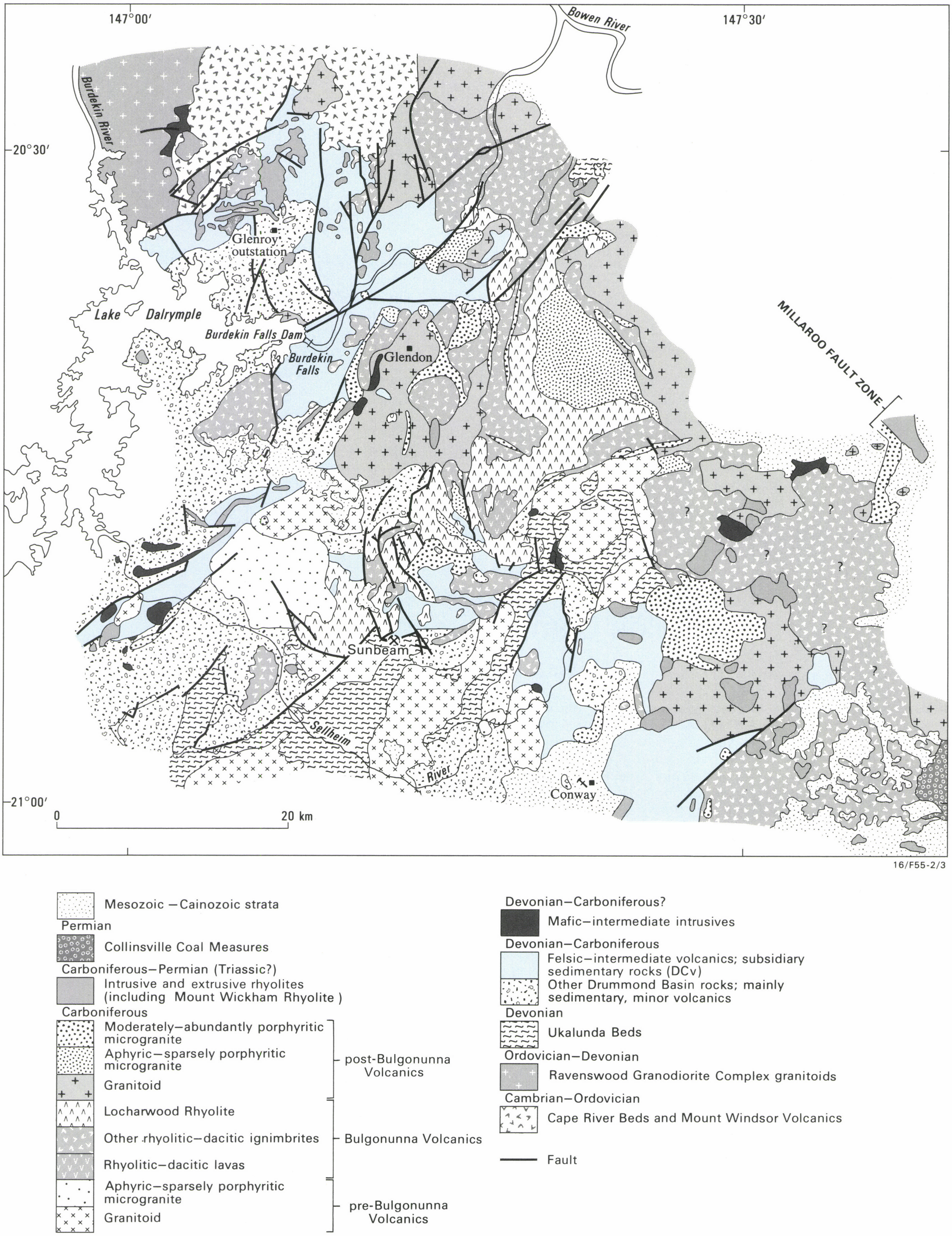


Fig. 3. Distribution of Bulgonunna Volcanics (including 'Locharwood Rhyolite'), 'DCv', and associated rocks as currently understood.

The results of the 1988 mapping are summarised in Figure 3. The area formerly assigned to the Bulgonnuna Volcanics has been substantially reduced, with the balance now assigned either to an older Devonian-Carboniferous, volcanic-rich, Drummond Basin formation (DCv) or to granitoid intrusions both older and younger than the Bulgonunna Volcanics.

The Devonian-Carboniferous volcanic unit (DCv) is overlain throughout much of the Drummond Basin by Early Carboniferous, dominantly sedimentary units, including the Scartwater, Mount Hall, and Star of Hope formations. However, in much of the mapped area it is directly overlain by Late Carboniferous volcanics and the unconformity is only locally conspicuous. Although this often makes the two volcanic units hard to distinguish, the recent mapping has shown that there are several lithological criteria by which the two units can be distinguished in the field. The Bulgonnuna Volcanics mainly comprise welded rhyolitic ignimbrites and rhyolite lavas; breccias and epiclastic lithologies are markedly subordinate. The characteristic mineralogy of the primary volcanic rocks is quartz + feldspar, and minor biotite. In contrast, the Devonian-Carboniferous volcanics consist of a compositionally and texturally wider range of volcanic and volcaniclastic lithologies, including coarse lithic breccia, ignimbrite, lava, lava breccia, conglomerate, sandstone, and mudstone. Both andesitic and rhyolitic lavas occur, and andesitic clasts are abundant in the epiclastic rocks. The characteristic mineralogy of the primary volcanic rocks is feldspar + hornblende, and only minor quartz or feldspar + pyroxene in andesitic rocks. Ignimbrite belonging to this unit is very well exposed at the Burdekin Falls Dam.

Bulgonunna eruptive centres

In the northern part of the mapped area, the mappable stratigraphy within the Bulgonunna Volcanics becomes more complex from southwest to northeast. The total thickness of the ignimbrites increases in the same direction. Also, in the northeast the structure is complicated by faults and steep bedding; high-level granitoid intrusions (microgranites and porphyries) into the ignimbrites are common; and some ignimbrites are associated with coarse lithic breccias. Together, these features suggest that the northeastern area was originally closer to the eruptive centre(s) than are other areas of the Bulgonunna Volcanics. There is also a mappable stratigraphy within the southern part of the Bulgonunna Volcanics. One major ignimbrite in this sequence—the 'Locharwood Rhyolite' (Law, 1988; 9AGC, *GSA Abstracts* **21**, 238)—has now been identified in the north, enabling the southern and northern sequences to be correlated. The Devonian-Carboniferous volcanics are more extensive in this southern area than was previously known. The existence of a Late Carboniferous caldera there (the Bulgonunna Caldera; Law, 1988) is being reassessed in the light of the new field data.

All the intrusive rocks of the region, both older and younger than the Bulgonunna Volcanics, are I-types. The older group is dominated by zoned high-K intrusions ranging from quartz monzodiorite and quartz monzonite through adamellite to alkali-feldspar granite, and also includes tholeiitic gabbro. Some silver-gold-copper mineralisation is possibly related to mafic high-K plutons (e.g. Sunbeam mine). The younger granitoids (post-Bulgonunna Volcanics) are predominantly felsic adamellites, with subordinate granodiorite. They are similar in mineralogy, compositional range, and field character to Late Carboniferous (about 310 Ma) felsic granitoids of the Ravenswood batholith to the north. The entire range of granitoid ages and compositions outlined above is represented in a small and complicated area centred on Glendon Homestead. There are excellent exposures of xenolith trains, microgranitoid enclaves, and rafts of older granitoids and metavolcanic rocks in younger granitoids about 3 km north of the homestead, in Glendon Creek.

Although the prospects that are currently receiving attention are probably all hosted by Devonian-Carboniferous volcanics of the Drummond Basin, the Bulgonunna Volcanics and associated granitoids also need to be investigated carefully as they may be genetically related to the mineralisation. Alteration, disseminated pyrite zones, and gossans are widespread in the Bulgonunna Volcanics adjacent to high-level granitoid intrusions, to rhyolite domes that postdate the Bulgonunna Volcanics, and in the granitoid intrusions and domes themselves.

Other studies in progress for this project include regional geophysics, geochemistry, geochronology, and remote sensing, complemented by work on stable isotopes, fluid inclusions, and alteration at selected prospects. Mapping of the Bulgonunna Volcanics will be completed during the coming field season (1989), attention being given to areas where access has been difficult.

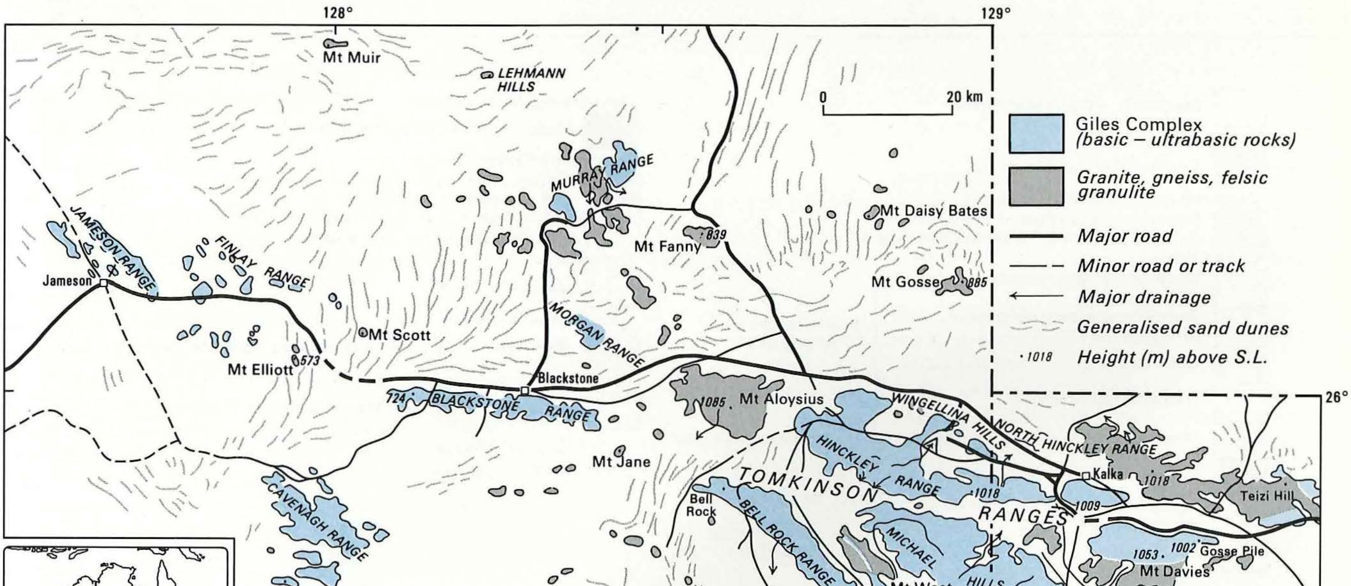
For further information, contact Dr Greg Ewers, Dr Doug Mackenzie, Dr Jocelyn McPhie, Dr Brian Oversby, or Dr Doone Wyborn at BMR (Division of Petrology & Geochemistry), or Mr Steve Law at 19 Donaldson St, Norman Park, Brisbane, 4170 (formerly c/- Department of Mines, Brisbane).

Significance of ultrabasic components of the Giles Complex, central Australia

A new investigation of the layered Giles Complex in Western Australia by BMR in 1987 and 1988, in collaboration with the University of Tasmania, the University of Melbourne, and the Geological Survey of Western Australia, has indicated a relative abundance in certain areas of ultrabasic rocks (including pyroxenite, olivine pyroxenite, peridotite, and dunite) produced by high degrees of melting of the mantle and/or extensive differentiation of gabbroic magma.

The Middle to Late Proterozoic Giles Complex, which straddles the Western Australia/ South Australia border in central Australia (Fig. 4), consists of a series of layered basic and ultrabasic intrusions and faulted segments of such intrusions emplaced within felsic granulites and intruded by granites which together form the Musgrave, Mann, Tomkinson, Blackstone, and Jameson ranges. Earlier work (Nesbitt & others, 1970: *Geological Society of South Africa, Special Publication* **1**, 547-564;

Fig. 4. Main outcrops of the Giles Complex and associated rock units in the Tomkinson Ranges and outlying terrain, WA & SA.



Daniels, 1974: *Geological Survey of Western Australia, Bulletin* **123**; Thomson, 1975: *Australian Institute of Mining & Metallurgy, Monograph* **5**, 451–460) outlined the regional setting of these intrusions and included detailed studies of the Kalka, Ewarara, Gosse Pile, and Teizi bodies in South Australia (e.g. Good & Krieg, 1967: *Journal of the Geological Society of Australia*, **14**, 185–195; Moore, 1971: *Journal of the Geological Society of Australia,* **18**, 69–80; Goode & Moore, 1975: *Contributions to Mineralogy & Petrology*, **51**, 77–97).

Layered intrusions up to 7 km thick

In the recent survey, major ultrabasic units were studied in the Murray Range, at Mount West, and at Latitude Hill. The Murray Range body consists mainly of peridotite, dunite, and olivine pyroxenite forming a succession over 2000 m thick sandwiched between gabbroic units. The thick Latitude Hill sequence is mostly pyroxenite, feldspathic pyroxenite, and melagabbro, forming over 60% of a 7000 m thick succession. The Mount West body comprises intercalated olivine pyroxenite and gabbroic units: it is over 600 m thick and may represent an ultrabasic lower part of the Bell rock gabbro. These successions are intercalated with gabbro units, including contacts where magma mixing offers potential loci for platinum-group elements and chromite mineralisation, as suggested by models based on the Bushveld Complex, Stillwater Complex, and Munni Munni Complex (Hoatson, 1984: *BMR Record* **1984/1**; Hoatson & Glaser, 1989: *BMR Resource Report* **5**; see also *BMR Research Newsletter*, **5**, 1–2).

Detailed study of the Wingellina Hills layered intrusion (Fig. 5) (C. Ballhaus & A. Y. Glikson, in preparation), which is the body underlying the Wingellina lateritic nickel deposit (Sprigg & Rochow, 1975: *Australasian Institute of Mining & Metallurgy, Monograph* **5**, 1008–1009), indicates periodic replenishment and a biomodal origin for the basic and ultrabasic magmas. In this model, late batches of olivine-rich magma are introduced into a gabbronorite-dominated magma chamber and settle gravitatively as discrete lenticular units on the floor. Magma mixing results in a hybridisation series between peridotitic and gabbroic end members. The resident basic magma was saturated in clinopyroxene and plagioclase. Major

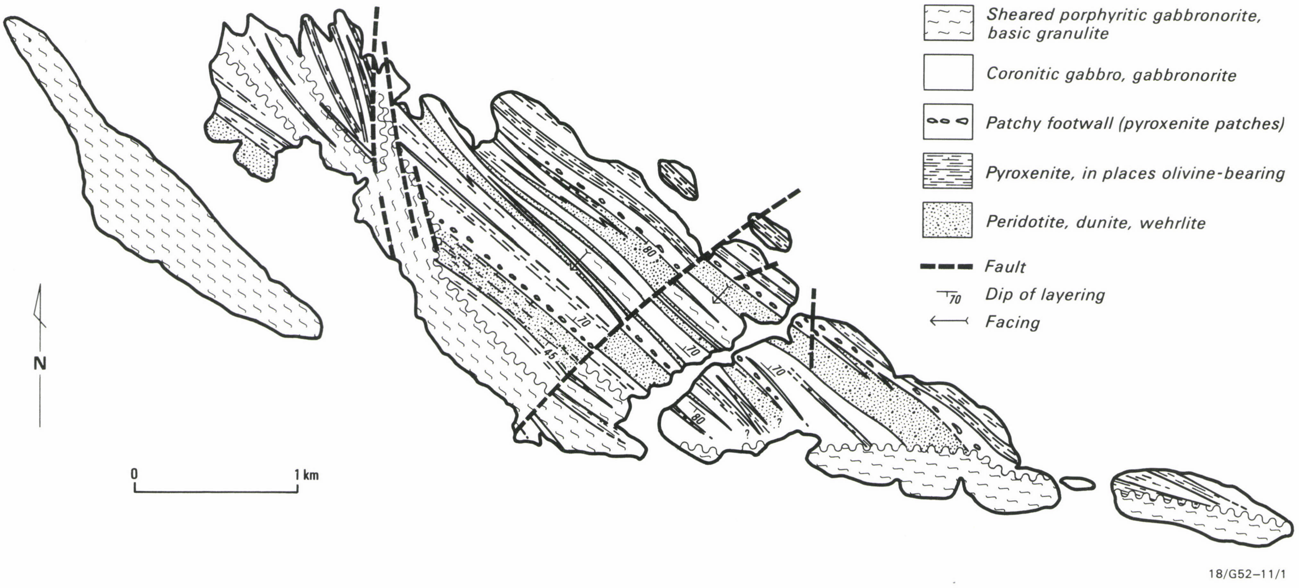


Fig. 5. Outcrop geology of the Wingellina Hills intrusion, Giles Complex, WA.

Fig. 6. LANDSAT imagery, Giles Complex, WA & SA.

ultrabasic pulses were preceded by minor pulses, as indicated by patchy basic/ultrabasic footwall zones below ultrabasic units. A bimodal derivation for the basic/ultrabasic components of the Giles Complex intrusions is consistent with the generally sharp boundaries between these components, the lenticular shape of ultrabasic units, and the lateral variations in their abundance, for example in the Michael Hills and Hinckley Range intrusions.

Mixing of ultrabasic and basic magmas may involve changes in the degree and timing of sulphur saturation and partial oxygen fugacity, potentially leading to platinum-group-metals and chromium mineralisation, respectively. However, in the Giles Complex, the emplacement of basic and ultrabasic magmas under high pressure, estimated as over 8 kb on the basis of spinel–orthopyroxene–clinopyroxene symplectites (C. Ballhaus & A. Y. Glikson, in preparation, and as observed earlier by Goode & Moore, *op. cit.*), may have resulted in the escape of volatiles to shallower crustal levels during metamorphism and cooling, involving loss of sulphur, chlorine, carbon dioxide, and other agents of metal transport and deposition. Such loss is consistent with the paucity of hydrous silicates, i.e. amphibole and mica, in the Giles Complex and also explains the paucity of sulphides, in support of earlier observations by Nesbitt & others (1970, *op cit.*).

Major lopolith

An interpretration of the Giles Complex as a series of faulted and granite-intruded relics of originally contiguous layered intrusion(s) implies primary lateral dimensions in the order of several hundred kilometres. The emplacement of such a lopolith at or near the base of the continental crust would be expected to initiate a major anatectic event; such an event seems to be reflected by the presence of widespread rapakivi and finer-grained granites that engulf and intrude the layered intrusions. In most instances the margins of the layered intrusions have been extensively recrystallised into basic granulites and intruded by hosts of felsic veins and stringers in a post-kinematic stress regime. The granites contain abundant enclaves of banded gneiss, thought to be derived from pre-Giles Complex units.

It is possible that equivalents of the Giles Complex occur extensively at depth elsewhere in central Australia. The age of this major ensialic dynamothermal event is tentatively correlated with that of 1291 ± 21 Ma old gabbro in the Fraser Complex 750 km southwest of the Tomkinson Range, determined recently by I. Fletcher & J. S. Myers (personal communication, 1988) by mineral Sm-Nd isochron.

For further information contact Dr Andrew Glikson at BMR (Division of Petrology & Geochemistry) or Dr Christian Ballhaus, Department of Geology, University of Tasmania.

Gold potential of early shear zones near Leonora, WA

The location of gold deposits in the Eastern Golfields Province of the Yilgarn Block, WA, is known to be structurally controlled, yet few regional studies have been conducted to establish the structural evolution of this very large area. Results from a current regional structural investigation of the Leonora 1:100 000 Sheet area (Fig. 7) show that the complex interaction between Archaean greenstone and granite, and the internal structure of the greenstone belt, can be described in terms of three main deformation episodes and three episodes of granitoid intrusion. The mapping is part of BMR's contribution to the Geological survey of Western Australia's initiative to produce new 1:100 000 geological maps of the Eastern Goldfields region.

Of particular relevance to mineral exploration is the implication from this study that in the Leonora Sheet area, mineralisation is related to early, dip-slip, shear zones. The major late structure in the area, the strike-slip Mount George Shear Zone, is essentially unmineralised, only one prospect having been worked on this structure in the Sheet area, whereas several mines and prospects are located on the early shear zones, including the important Sons of Gwalia deposit. This study raises the possibility of new exploration targets in the less obvious early shear zones and reopens the subject of the importance of different episodes of mineralisation in explaining the formation of vein-hosted deposits in other late strike-slip shear zones in the Eastern Goldfields.

Earliest episode

In the northwest of the area several bands of quartzite and siliceous iron formation in volcanics define the structural grain as striking approximately east-west and dipping gently to the north. These bands and the adjacent basaltic rocks have metamorphic and deformational fabrics that strike parallel or sub-parallel to this lithological layering. In the southeast, a similar relationship has been observed in a felsic volcanic sequence (e.g. at Mount Malcolm). The commonly held view that these siliceous zones are silicified and ferruginised black shale is based on the intersection of shale in drill holes beneath some of the zones. However, the clearly metamorphic quartz fabric of these rocks indicates that the silicification was earlier than, or synchronous with, metamorphism, at least in the easterly striking bands. Some of the bands have a well-defined cross-girdle quartz-optic-axis fabric, indicating that they have undergone bulk simple shear. In the northwest, the movement direction on the early cleavage is top-side-south, determined from quartz-fabric diagrams, composite cleavage ('S–C' fabrics) in basalt, and quartz-vein fibre orientations. Zones of deformation are parallel to this early fabric in the central west (e.g. Mount Ross), where movement indicators imply top-side-north displacement.

These largely easterly-trending dip-slip deformation zones host significant gold deposits (e.g. Diorite King, Jasper Hills, and King of the Hills) and are mapped as continuous with north-northwest-trending shear zones of identical structural style in the south of the map where they have been rotated to a north-northwesterly trend (Sons of Gwalia Shear Zone), and host the Sons of Gwalia, Harbour Lights, Tower Hill, and Trump gold deposits. Granite lenses were caught up in this early event and have undergone greenschist-facies recrystallisation; granite in the west of the map area is similarly deformed, and pre-dates the deformation.

Second episode

Open, upright folds ranging in scale from regional to microscopic have been identified throughout the region. They clearly fold the early, gently dipping cleavage. At Mount Malcolm in the southeast an early shear zone is also rotated on a regional scale by this event, as is early mylonitic foliation in pre-deformation granite in the west. The folds are usually open, with steeply dipping axial surfaces, and plunge gently to the north.

Third episode: strike-slip faulting

As in most regions of the Eastern Goldfields, the most obvious structural features are the northwest to north-northwest-striking strike-slip faults. In the Leonora Sheet area the main fault of this type, the Mount George Shear Zone (MGSZ), is characterised by discontinuous ridge-forming linear chert, chalcedony, and ironstone bands in a broad zone of deformation up to 0.5 m wide within external bounding faults. The structure of the breccia within the shear zone is complex. There is good evidence that some of the chert bands are allochthonous, whereas others may have formed by synmetamorphic metasomatism of shale. In addition, some chalcedonic layers were probably deposited from siliceous fluids during faulting. The MGSZ is a major geological structure separating dominantly high-magnesium basalt sequences to the west from tholeiitic basalt and felsic volcanic sequences to the east.

In the north, the early cleavage surfaces and early-metamorphosed siliceous iron formation bands are rotated against and truncated by the MGSZ. On a mesoscopic scale, chert lenses within the MGSZ in places retain an early inherited easterly orientation and are truncated by faults parallel to the external bounding faults of the MGSZ. As well as demonstrating that the MGSZ is a later event than the south-directed shear zones, the evidence of rotation of the external cleavage and lithological layering shows that the regional sense of movement on the MGSZ is sinistral. This is consistent with the mapped cleavage pattern bordering the zone, which in general becomes less intense away from the zone, particularly to the west; also, the closer to the MGSZ, the closer to the trend of the fault is the cleavage oriented.

Mineralisation and structure

Williams, Nisbet, & Etheridge *(Australian Journal of Earth Sciences,* **36,** in press) show that the Sons of Gwalia, Harbour Lights, and other gold deposits lie within the Sons of Gwalia Shear Zone and associated early structures. Gold-bearing veins at the Sons of Gwalia mine and harbour Lights pit appear to be temporally as well as spatially associated with the early deformation. In the old workings at Sons of Gwalia, high-grade ore shoots comprise abundant quartz-rich layers a few centimetres thick that are isoclinally folded with axial surfaces parallel to the foliation and axes parallel to the local stretching lineation. On the scale of the pit, higher-grade zones are elliptical in plan and also tend to plunge parallel to the stretching lineation that defines the movement on the shear zone. There is only one dominant foliation in the Sons of Gwalia pit, and a very strongly peaked distribution of lineation values. There is no evidence of overprinting by a second shearing event.

The structure is similar at Harbour Lights but is complicated by the presence of numerous competent bodies within the succession,

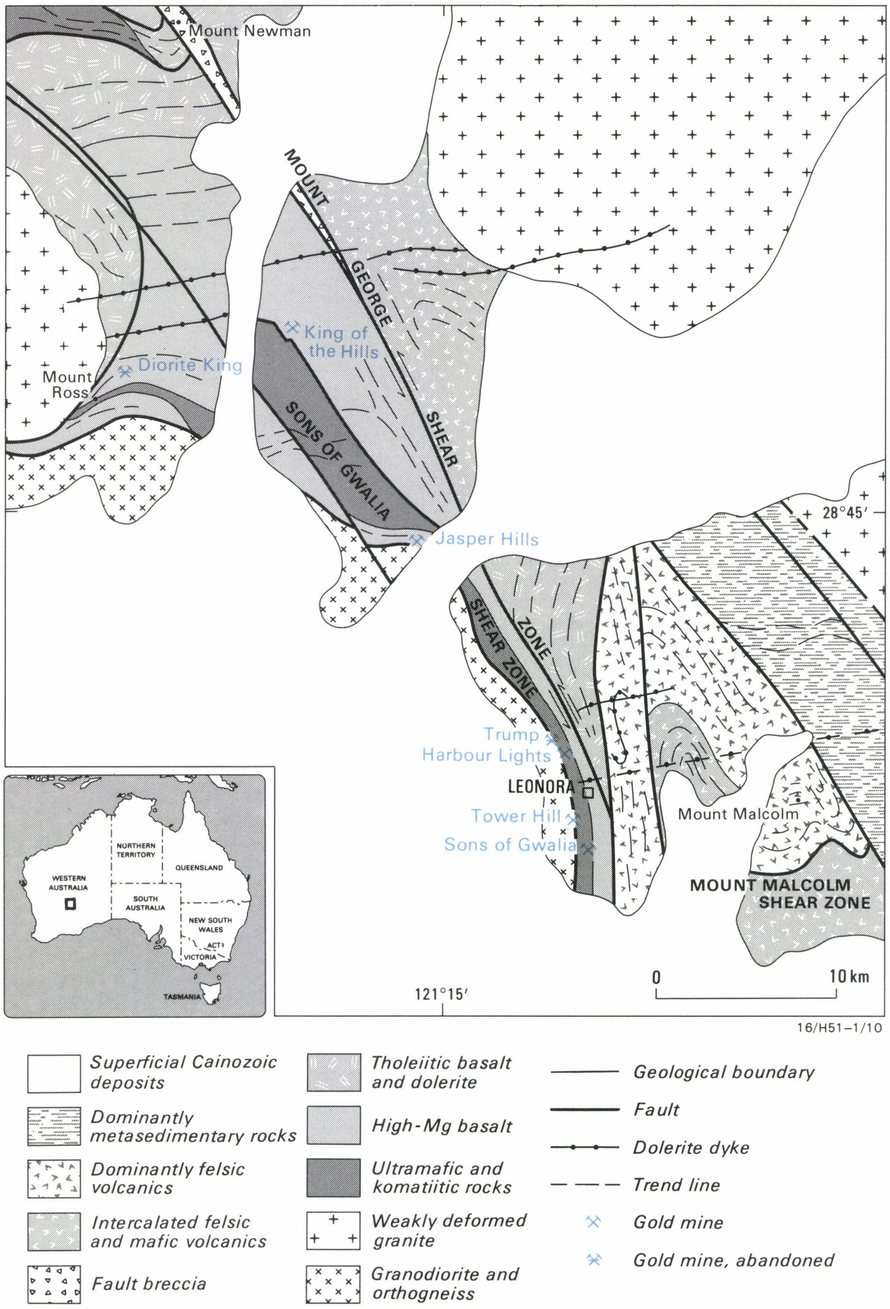


Fig. 7. Major structural elements of the Leonora 1:100 000 Sheet area, WA.

forming boudins ranging in scale from 30 m to microscopic. Many early-formed veins are preserved as quartz-carbonate boudins and isolated lenticules. The highest-grade mineralisation is in fuchsitic selvedges surrounding large boudins. The geometry of the boudins is consistent with their having formed during the early shearing event. Although several crenulation cleavage surfaces are present, they overprint the mineralisation; the latest is an upright surface correlated with the second regional deformation. Richly mineralised veins are also folded with axial surfaces parallel to the dominant shear foliation. We agree with Skwarnecki (Advances in Understanding Precambrian Ore Deposits, Vol. 2, *University of WA Geology & University Extension, Publication* **12**, 1988, p. 111) that the bulk of the Harbour Lights mineralisation is synchronous with the early deformation. As at Sons of Gwalia, there is no evidence of overprinting by structures related to the MGSZ.

It has been suggested by the gold research group of the University of Western Australia that much of the mineralisation in the Leonora area is late in the structural history and related to the MGSZ. The regional deformation history established during the current mapping does not support this view. Although at Tower Hill and Harbour Lights several undeformed or weakly deformed veins contain high gold values (and at King of the Hills late tension veins, essentially undeformed, also host high-grade ore), in all these areas the orientation of the veins is consistent with the overall sense of movement on the dominant early shear zones. We prefer an interpretation of these veins as forming late in the deformation history of the early shears, and not during late overprinting by the strike-slip event. This late-stage , continuing mineralisation and hydrothermal activity also resulted in local retrogression of the peak amphibolite metamorphic assemblage that formed during the early deformation.

Summing up, this study has provided a framework within which to place detailed structural studies of individual deposits, and has led to the conclusion that the zone of mineralisation extending from Sons of Gwalia north to King of the Hills is hosted by a regional early, dip-slip shear zone and is genetically related to that shear zone. Regional and mine-scale evidence shows that this early shear zone is folded by upright north-trending open folds. The regional strike-slip faults (e.g. MGSZ) and associated folds and cleavage overprint the early shear zones and early cleavage, and in the Leonora area are not significant hosts for mineralisation.

For further information contact Dr Peter Williams or Dr Mike Etheridge at BMR or Dr Wally Witt or Dr Cees Swager at GSWA, Kalgoorlie Office.

Kalgoorlie regolith results

Initial results from the Kalgoorlie Regolith Project (see *BMR Research Newsletter*, 6, p. 9) are now available. Data for 59 regolith terrain units covering the Kalgoorlie 1:1 000 000 Sheet area (120 °–126 °W, 28 °–32 °S) are recorded under 16 primary headings. The unit boundaries, their grouping into provinces, and major mineralisation are shown on the preliminary Regolith Terrain Map at 1:1 000 000 scale (BMR *Record* 1988/3).

Aspects of the landscape history and regolith of the Kalgoorlie region of the Yilgarn Block were published in the *BMR Journal of Australian Geology & Geophysics* (Volume 10, Number 4) in June 1988. Results include a new geomorphic chronology (extending back to the Permian) and a new model of landscape evolution.

The methodology of regolith terrain mapping and its application to mineral exploration are discussed in a paper by R. Chan recently published in *Zeitschrift für Geomorphologie* (Supplementband **68**). A paper on this topic was presented at the Second International Conference on Prospecting in Arid Terrain held in Perth in April 1988.

For details, contact Ms Roslyn Chan at BMR (Division of Petrology & Geochemistry).

Major new platinum-group metals report

GEOLOGY AND ECONOMICS OF PLATINUM-GROUP METALS IN AUSTRALIA, by D. M. Hoatson & L. M. Glaser, 1989. *BMR Resource Report* **5**, 81 pp (A4 page size), 8 tables, 16 figs, 3 appendixes. Price: $34.95. Available from: Publications Sales, BMR, GPO Box 378, Canberra, ACT 2601.

This latest BMR Resource Report, published in March, opens with a chapter on the economics of platinum-group metals, including their applications, world supply and demand, political-economic-strategic factors affecting production and marketing, and the economics of possible future production in Australia.

The chapter, 'Worldwide Geological Setting', includes a classification of deposit types, together with descriptions of the Bushveld Complex, Stillwater Complex, New Rambler mine in Wyoming, and the gold-palladium-platinum deposit at Coronation Hill, NT.

The major section, 'Geology of Platinum-Group Metals in Australia', concludes with a recommended exploration strategy and summary descriptions of all known Australian occurrences, together with a location map.

Listed in an appendix are all known layered mafic-ultramafic complexes in Australia (also with a location map). There is an extensive bibliography and an index to prospects, locations, and deposit types.

New publications on SW Pacific geology and mineral resources

Since 1982, Australia, New Zealand, and the USA have co-operated in a Tripartite Marine Geoscience Research Program involving the offshore areas of the Southwest Pacific island nations of Cook Islands, Fiji, Kiribati, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu, and Western Samoa.

Sixteen research cruises have been mounted under the auspices of CCOP/SOPAC (the regional marine geoscience body) averaging 20 days each. One set of cruises, using the USGS vessel, *S.P. Lee,* was petroleum-oriented and consisted predominantly of multichannel seismic profiling. The second set was oriented towards offshore minerals and regional tectonics and made extensive use of geological sampling as well as under-way geophysics.

The work has led to a much better understanding of the sedimentary basins of the region and their petroleum potential, and the mineral resources potential of adjacent oceanic basins (manganese nodules, cobalt-rich manganese crusts, and hydrothermal polymetallic sulphides). Basins with more than 5000 m of sediment are now known to exist offshore in Tonga, Fiji, Vanuatu, Solomon Islands, and northern Papua New Guinea, and all have petroleum prospects as frontier areas. The exciting results of the Tripartite Program have acted as a catalyst for other research in the area, so that the scientific database for the region has expanded faster than expected. All of the data from the petroleum-oriented cruises will be in the public domain and will be available in hard copy from BMR's Copy Service or as data tapes from the Marketing Manager of BMR's Division of Marine Geosciences & Petroleum Geology.

BMR scientists have been heavily involved in the work, and reports on the Tripartite Program have appeared in several issues of the *BMR Yearbook* and *BMR Research Newsletter. BMR 82* and *BMR 87* (yearbooks) contain articles with maps showing all the areas studied.

The results from the cruises are generally published in the Earth Science Series of the Circum-Pacific Council for Energy & Mineral Resources. These Circum-Pacific Council Publications are available at very reasonable prices from the AAPG Bookstore, PO Box 979, Tulsa, Oklahoma 74101-0979, USA, and in some cases from the Australian Mineral Foundation, PB 97, Glenside, SA. Two new Southwest Pacific Tripartite volumes came out in 1988—Volumes 8 and 9. The following Tripartite volumes have been published so far:

Geology and Offshore Resources of Pacific Island Arcs—Tonga Region, compiled and edited by D.W. Scholl & T.L. Vallier. 35 papers, 488 pp.

Investigations of the northern Melanesian Borderland, edited by T.M. Brocher. 10 papers, 199 pp.

Geology and Offshore Resources of Pacific Island Arcs—Central and Western Solomon Islands, edited by J.G. Vedder, K.S. Pound, & S.Q. Boundy. 25 papers, 306 pp.

Marine Geology, Geophysics, and Geochemistry of the Woodlark Basin—Solomon Islands, edited by B. Taylor & N.F. Exon. 12 papers, 363 pp.

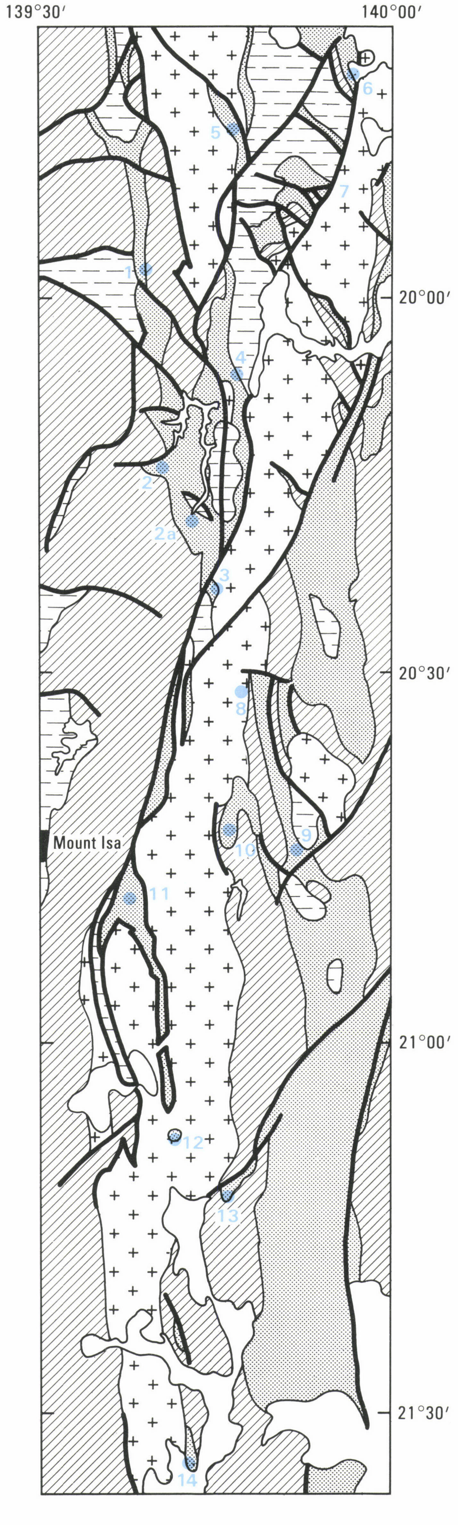
Geology and Offshore Resources of Pacific Island Arcs—Vanuatu Region, edited by H.G. Green & F.L. Wong. 23 papers, 442 pp.

Geology and Offshore Resources of Pacific Islands Arcs—New Ireland and Manus Region, Papua New Guinea, edited by M.S. Marlow, S.V. Dadisman, & N.F. Exon. 17 papers, 288 pp.

The volumes contain a broad spectrum of articles: onshore geology and organic geochemistry; and offshore tectonics, structure, stratigraphy, sedimentology, sediment geochemistry, gas geochemistry, palaeontology, igneous petrology, igneous geochemistry, and heat flow. Special emphasis has been placed on reviews of petroleum potential and of offshore mineral occurrences. Most volumes also contain an excellent regional synthesis chapter using all available information from both onshore and offshore.

For further information, contact Dr Neville Exon or Mr Jim Colwell at BMR (Division of Marine Geosciences & Petroleum Geology).

Sequence-stratigraphy, rifts, and tides at Mount Isa



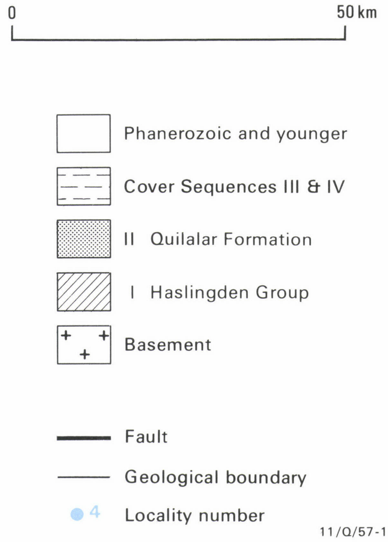


Fig. 8. Geological map of the area of detailed study of the Quilalar Formation, showing locations of measured sections.

A new field study of the Haslingden Group and Quilalar Formation, near Mount Isa in northwest Queensland, has provided a wealth of detail on the environmental setting and sedimentological evolution of these major Proterozoic units. The relatively new concept of 'sequence-stratigraphy' (Bally, 1987: *Atlas of Seismic Stratigraphy; AAPG, Studies in Geology,* 27, 1-10), has been successfully applied to the study of the Quilalar Formation, and a well-constrained model of its paleogeographical evolution is now available. These results have implications for regional stratigraphic/structural interpretations and for mineral exploration, and will be critical in later basin-evolution modelling.

The volcano-sedimentary Haslingden Group is the oldest cover sequence in the Mount Isa Orogen; it is between 1800 and 1710 Ma old and may be as much as 18 km thick. It was previously interpreted as a single-stage rift sequence. The overlying Quilalar Formation was interpreted as the succeeding sag phase of sedimentation caused by the thermal contraction of the lithosphere. The recent detailed studies of parts of this sequence by a BMR-US group (M.J. Jackson, BMR; Prof. K. Eriksson, Virginia Polytechnic; and Dr E. Simpson, Kutztown University, Pennsylvania) suggest a multiple rifting history, including periods of gentle sag sedimentation, for the Haslingden Group, and confirm a thermo-tectonic origin for the Quilalar Formation.

The Bottletree Formation locally underlies the Haslingden Group, and the Mount Guide Quartzite is the oldest formation in the Group. Although rift-related conglomeratic alluvial-fan sediments occur in the Bottletree Formation, and braided stream deposits are present in the lower part of the Mount Guide Quartzite, much of the upper Mount Guide Quartzite con-

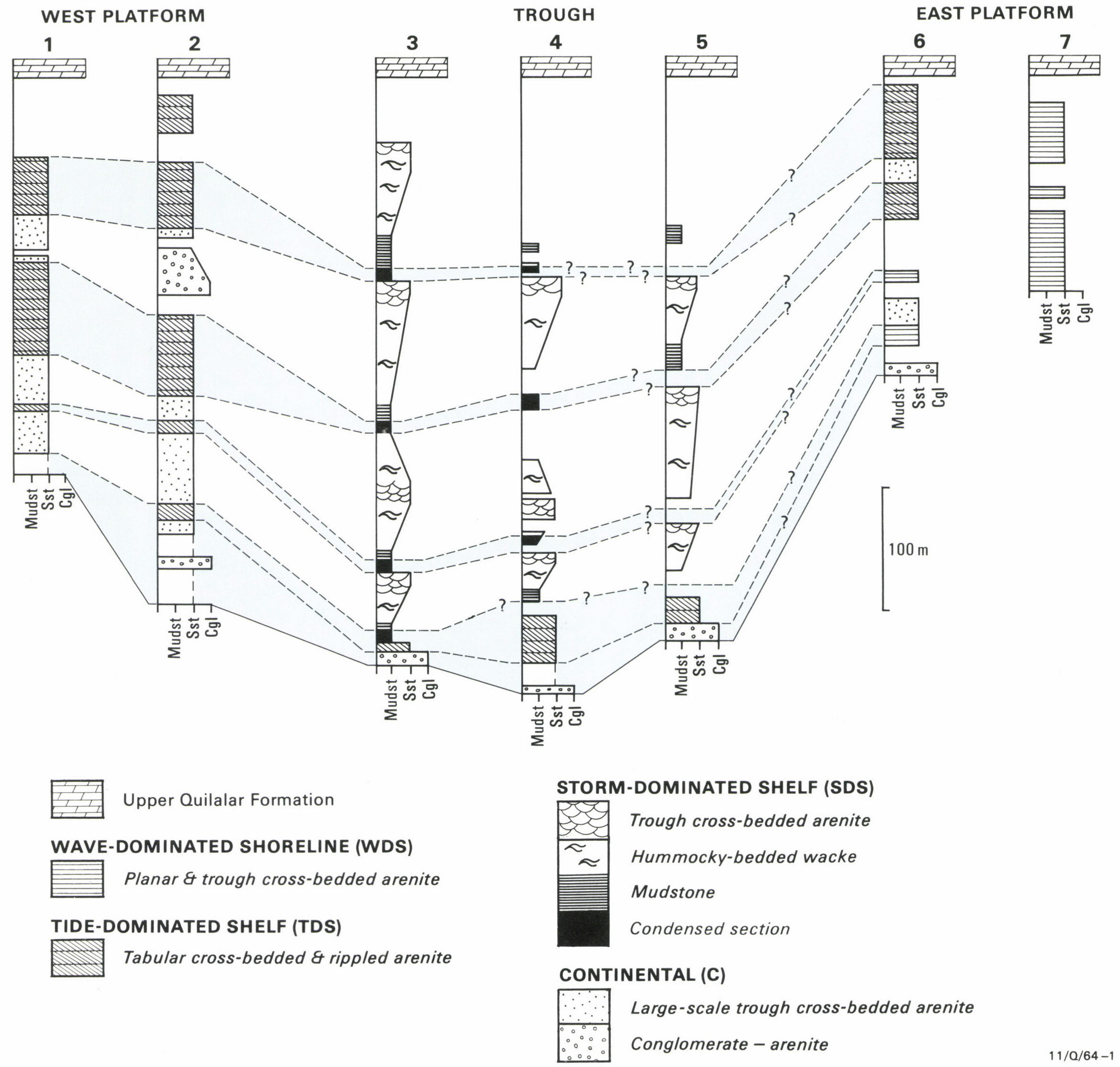


Fig. 9. Cross-section showing distribution of SDS, C, TDS, and WDS depositional systems in the Quilalar formation, in time and space; locations of measured sections are in Fig. 8. Depositional systems are associated in *transgressive systems tracts* (blue-shaded) and *highstand systems tracts* (unshaded).

sists of cyclic sequences of large-scale cross-bedded arenites that were deposited as large sand waves on an extensive tide-swept shelf.

Measurement of these cycles from excellently exposed continuous sections, 10 km east of Mount Isa, has enabled the construction of Fischer curves (see, e.g., Read & Goldhammer, 1988: *Geology,* **16**, 895–899). These are curves of cumulative cycle thickness corrected for linear subsidence, plotted against time, and provide a means for assessing the magnitude of third-order (1 to 10 Ma) fluctuations in sea level. In the Mount Guide case the Fischer curves are smooth and regular; this is considered to be more consistent with a eustatic control rather than a tectonic control, which, intuitively, could be expected to be less regular in a multiply rifted setting. Continued deposition in tide and wave-dominated shallow-shelf, tidal-flat, and shoreline environments was a major process in the overlying upper part of the Haslingden Group (4 km thick Myally Subgroup). However, there are also thin sections of fluvial, aeolian, and possibly lacustrine sediments, and there is a well developed regolith at the top. Turbiditic siltstones and mudstones and hummocky cross-bedded units in the Bortala Formation (mid Myally Subgroup) may indicate an early development of storm-affected outer shelf and deeper trough environments similar to those seen later during the deposition of the Quilalar Formation.

A facies analysis of the 300–500 m thick lower clastic part of the Quilalar Formation and its correlative, the Ballara Quartzite, in the areas shown in Figure 8, has enabled four depositional systems to be distinguished. The systems are restricted areally to north-trending marginal 'platforms' or a central 'trough' paleogeographic setting. They each consist of several facies, categorised broadly as 'storm-dominated shelf' (SDS) 'continental' (C), 'tide-dominated shelf' (TDS), and 'wave-dominated shoreline' (WDS). SDS facies are arranged in *ca* 100 m-thick progradational sequences grading from massive black shales (condensed sections) at the base, through hummocky bedded wackes, to cross-bedded quartzites at the top (Fig. 9). Shoaling from storm-dominated outer shelf to shoreface environments is indicated.

Continental facies include pebbly feldspathic sandstones and large-scale cross-bedded aeolian dune sandstones. TDS facies consist of cycles of cross-bedded and rippled quartzite, reflecting the migration of sandwaves in a subtidal regime that repeatedly shoaled to intertidal environments. These cycles, or parasequences in the Bally (1987) terminology, are identical to the upper Mount Guide Quartzite cycles mentioned above, but unfortunately outcrops are not continuous enough to allow Fischer plots to be constructed. WDS facies are preserved in 2 m thick cycles that contain megarippled surfaces, trough-cross-bedded arenites, and low-angle swash-laminated sandstones. This sequence of facies reflects flooding and wave reworking to form a ravinement surface, followed by shoaling from shoreface to beach environments.

The value of a sequence-stratigraphic approach is readily evident in Fig. 9 where the various depositional systems are shown associated in the 'systems tracts' (Bally, 1987). *Transgressive systems tracts* (blue-shaded) consist of TDS and WDS on the 'platforms' and condensed-section deposits in the 'trough', and are related to a gradual increase in the rate of sea-level rise. *Highstand systems tracts* are represented by SDS in the 'trough' and coeval C on the adjacent 'platforms', and developed during periods characterised by decreased rates of sea-level rise or fall. A conventional lithostratigraphic approach would almost certainly have resulted in a correlation between the resistant cross-bedded quartzites of the platforms (TDS) with the cross-bedded quartzites at the tops of the SDS, requiring a significantly different, and somewhat less convincing, genetic interpretation. The contrasting paleogeographies of the two systems tracts are shown in Figure 10.

The implications for mineralisation within the Quilalar Formation are twofold:

(1) the condensed-section deposits were formed in strongly reducing deep-water environments with low clastic input and

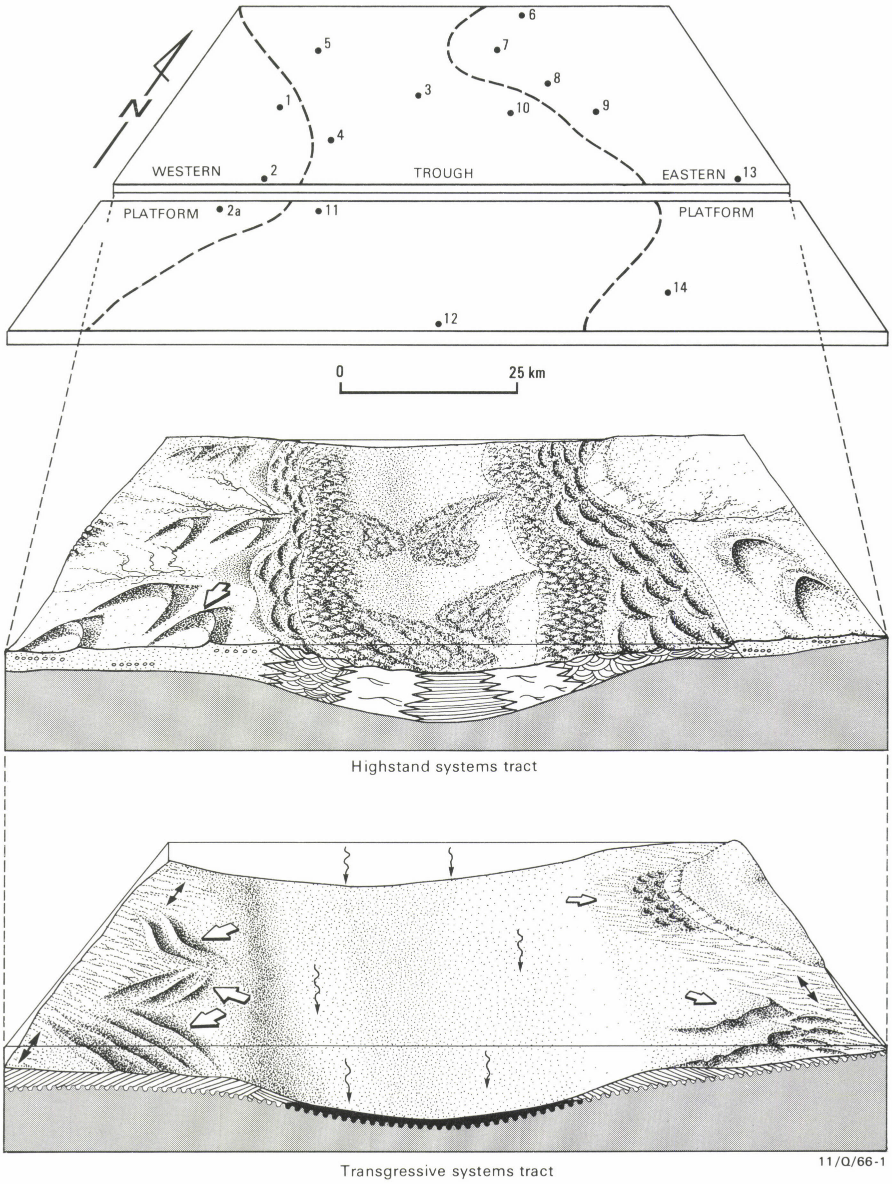


Fig. 10. Paleogeographic models on a palinspastic base (top) for a *highstand systems tract* (centre) and a *transgressive systems tract* (lower). Orientation of bedforms and paleocurrents is based on vector means from primary sedimentary structures that have been corrected for block rotation associated with late stage, strike-slip faulting.

could represent attractive hosts for base and precious metals (c.f. Telfer gold), and
(2) the continental deposits in the highstand systems tracts include reworked aggraded fluvial sediments that could host Proterozoic placer deposits.

Ken Eriksson has returned to USA following the conclusion of his sabbatical at BMR and plans to model the early evolution of the sequences at Mount Isa using the McKenzie (1987: *Earth & Planetary Science Letters*, **40**, 25–32) model as a basis. Publications on aspects of the sedimentology research are in press or in preparation, and a review of all stratigraphic and sedimentological studies done in the Mount Isa area between 1984 and 1988 is to be published in a forthcoming BMR Bulletin.

For further information, contact Mr Jim Jackson at BMR (Division of Continental Geology).

First palaeomagnetic data: Permo–Carboniferous epithermal activity in the Flinders Ranges?

The uraniferous quartz-hematite breccias at Mount Painter, at the northern end of the Flinders Ranges in South Australia, have gained renewed research and exploration interest because of similarities with epithermal ore deposits on the one hand and a certain mineralogical resemblance to the Olympic Dam deposit on the other. The origin of the breccias, however, has been poorly understood and their age was unknown. Preliminary results from a palaeomagnetic study now suggest that the breccias are much younger than the major Delamerian (Ordovician) magmatic and metamorphic event that affected the Mount Painter region. Their probable age is Permo-Carboniferous, although a latest Cretaceous age remains a possibility.

The geologic record of the Mount Painter Block in the Northern Flinders Ranges extends back to the Early Proterozoic. The Phanerozoic part of this record includes an association of hydrothermal-sedimentary breccias of problematic origin. A clue to the origin of these breccias may come from their age. Breccias consisting mainly of granitic and metamorphic clasts in a matrix of fine rock fragments form most of the hills and ridges of the Mount Painter area, including Mount Painter itself. They contain several bodies of diamictite and massive hematitic breccia, and a number of uranium deposits are associated with the latter. A vuggy breccia consisting mostly of medium to coarse specularitic hematite clasts in a matrix of coarsely crystalline quartz overlies the granitic and massive hematitic breccias at Mount Gee and locally has elevated gold concentrations.

Several explanations have been offered for the origin of the breccias, which have a number of similarities with the Proterozoic breccias at Olympic Dam. The vuggy quartz-hematite rocks are now interpreted as deposits of shallow-subaqueous to subaerial hot springs (i.e. sinters) but the precise mechanism of their formation, their genetic relation to the underlying granitic and massive hematite breccias (spring feeder zones?), and the age of the various units are unknown. Diamictite bodies within the granitic breccias contain well-rounded clasts of apparently exotic rock types, and have in the past been correlated with the Late Precambrian Sturtian tillite. However, the lack of metamorphic overprint by the Delamerian Orogeny, which reached amphibolite facies in the area, suggests a maximum age of Cambro-Ordovician for the entire breccia sequence. Late Ordovician or Tertiary have been suggested as possible ages.

An attempt was made in August 1988 to date the sinters and breccias palaeomagnetically. Oriented samples were collected from all rock types described above. The remanence in most samples was found to be stable and well defined. In three of the rock types the directions from different samples grouped together: these are the diamictite, one of the hematitic breccia bodies, and a local variant of the quartz-hematite sinter. The latter is a fine-grained, laminated, highly siliceous, red rock. The laminar bedding is deformed into irregular basins and domes a few metres across, and it was found that the grouping of the magnetic directions improved markedly when the deformation was removed by rotating each sample around its strike direction into a horizontal position. This has the important implication that the magnetisation predates this deformation and is, therefore, either primary or early diagenetic. Most of the hematitic breccia directions formed a similar cluster, but some were highly scattered. The diamictite was found to be uniformly magnetised throughout matrix and clasts. This implies that the entire diamictite was magnetically overprinted during or after its formation, presumably as a result of the hydrothermal activity that produced the sinters.

The three rock types give similar mean directions and all magnetisations are reversed. By far the best-defined of the means was that for the diamictite. Its pole plots close to the Permo-Carboniferous segment of the Australian polar wander path, and the reversed direction of its magnetisation is consistent with the long Kiaman period in the Permo-Carboniferous when the geomagnetic field was reversed. However, a latest Cretaceous age of magnetisation still remains a possible alternative, because of a large uncertaintly in the pole location ($\sim$10°) and because the Permo-Carboniferous and Late Cretaceous pole paths intersect near this preliminary pole.

Neither Permo-Carboniferous nor Cretaceous magmatism are known in the Flinders Ranges and surrounding areas. However, an extensive tectonic event affected central and southeastern Australia during the mid Carboniferous to Early(?) Permian, causing widespread deformation in central Australia (e.g. Shaw & others, 1984: *Australian Journal of Earth Sciences,* **31,** 457–485) and initiating the formation of sedimentary basins (e.g. Cooper Basin; Stanmore & Johnstone, 1988: *APEA Journal,* **28,** 155–166). It also heralded the late Palaeozoic glaciation (Powell & Veevers, 1987: *Nature,* **326,** 177–179) which may have deposited the diamictites at Mount Painter. The hydrothermal activity at Mount Painter may be related to a combination of regional tectonism, including uplift, and high local heat flow resulting from an elevated uranium content of the basement.

The preliminary results from this study illustrate the potential of the palaeomagnetic method for dating hydrothermal events. They also indicate the possibility of a more widespread metallogenic event in a region and during a geological period that have not been generally recognised as prospective for epithermal mineralisation.

For further information contact Dr Martin Idnurm (Division of Geophysics) or Dr Chris Heinrich (Division of Petrology & Geochemistry) at BMR.

BMR in Indonesia

The Irian Jaya Geoscientific Data Package

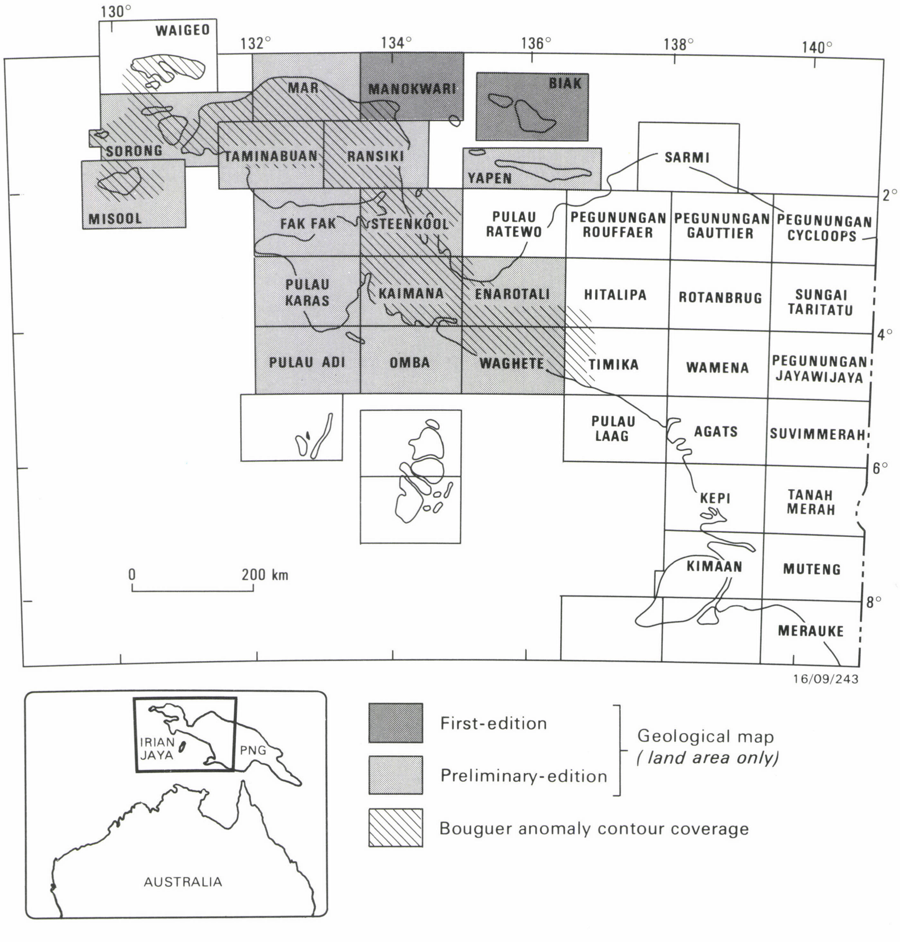
In November 1988, BMR, in conjunction with the Indonesian Geological Research & Development Centre (GRDC), issued the Irian Jaya Geoscientific Data Package. The package incorporates the results—mostly in preliminary form—of regional geological and gravity mapping (Fig. 11) and an integrated stream-sediment geochemical survey in western Irian Jaya by the Irian Jaya Geological Mapping Project (IJGMP; since renamed the Indonesia-Australia Geological Mapping Project, IAGMP), staffed by geoscientists provided by BMR and GRDC and funded by the Australian International Development Assistance Bureau (AIDAB) and the Indonesian Department of Mines & Energy.

These results are in the form of maps, reports, and contributions to geoscientific journals and the proceedings of conferences. The data package—comprising seven volumes—includes several products that had been released previously since the cessation of the fieldwork (undertaken between 1978 and 1981) and also many recently completed maps and reports.

Volume 1 contains: an introduction to the Irian Jaya Geoscientific Data Package; a 1:1 000 000 scale full-colour geological/Bouguer anomaly map of Irian Jaya; a comprehensive preliminary report on the geology of Irian Jaya, to be read in conjunction with the 1:1 000 000 map; and a catalogue and appraisal of isotopic ages determined for selected igneous and metamorphic rock samples collected during the course of project feasibility investigations (1976–77) and project fieldwork.

Volume 2 comprises ozalid print copies of 1:250 000 drainage base-maps of 13 quadrangles in western Irian Jaya: MAR, SORONG, TAMINABUAN, RANSIKI, YAPEN, MISOOL, FAK FAK, STEENKOOL, combined PULAU KARAS/PULAU ADI, KAIMANA, ENAROTALI, OMBA, and WAGHETE (Fig. 11). Two-colour, outline (preliminary-edition), 1:250 000 geological maps of the same quadrangles constitute the bulk of *Volume 3,* which also includes full-colour (first-edition) 1:250 000 geological maps and explanatory notes of the BIAK and MANOKWARI quadrangles. The grid on the drainage maps is more accurate than that on the preliminary geological maps. The co-ordinates on the preliminary geological maps are inaccurately located with respect to the topography, but the geological maps have been checked in the field and reflect the most accurate representation available of drainage, relief, and cultural detail (the inaccuracy of the grid on the geological maps did not come to light until the gravity data were about to be plotted onto the existing base-maps).

Fig. 11. 1:250 000 quadrangles in Irian Jaya covered by geological and gravity maps compiled by the Irian Jaya Geological Mapping Project.



Volume 4 is made up of two-colour, outline Bouguer anomaly maps of each of the twelve 1:250 000 quadrangles in which IJGMP acquired land-based gravity data between 1979 and 1981; WAIGEO, MAR, MANOKWARI, SORONG, TAMINABUAN (except southern one-quarter), RANSIKI, MISOOL, STEENKOOL, KAIMANA, southern and western ENAROTALI, WAGHETE, and combined western TEMBAGAPURA (TIMIKA)/ southwestern HITALIPA. These maps have been drawn on the bases with the more accurate grid. A catalogue of the gravity data in this volume complements the gravity maps.

Volumes 5 and 6 incorporate in report form the data derived from the 1:250 000 geological mapping, integrated geochemical survey, and follow-up studies. Volume 5 contains Data Records of the MAR, TAMINABUAN, and RANSIKI 1:250 000 quadrangles; a preliminary report on the geology of the Misool Archipelago; and a preprint of the explanatory note that will accompany the multicolour 1:250 000 geological/Bouguer anomaly map of the YAPEN quadrangle, which should be published later this year. Volume 6 contains Data Records of the ENAROTALI, WAGHETE, and combined STEENKOOL and KAIMANA quadrangles; and preliminary geological reports (explanatory-note draft manuscripts) of the FAK FAK, combined PULAU KARAS/PULAU ADI, and OMBA quadrangles.

Volume 7 is a collection of geoscientific papers, and contributions to the proceedings of geoscientific conferences.

The Irian Jaya Geoscientific Data Package was released officially in Jakarta in November 1988 at a special ceremony attended by representatives of the Indonesian and Australian Governments. Copies were presented to the Hon. Bill Morrison, Australia's then Ambassador to Indonesia, and to the Indonesian Minister for Mines & Energy, Ginanjar Kartasasmita, by Dr John Katili, Indonesia's Director General of Geology & Mineral Resources.

Copies of the Irian Jaya Geoscientific Data Package may be viewed in the BMR Library, Canberra. Copies of the data package may be bought at the GRDC-recommended retail price of US$5000 from BMR (attention: Copy Service) or from GRDC via Dr Rab Sukamto, Director, Geological Research & Development Centre, Jalan Diponegoro 57, Bandung, Indonesia.

An award for the Indonesia–Australia Geological Mapping Project (IAGMP)

On 7 November 1988, AIDAB announced that BMR would be the recipient of a 'highly commended' award in the AIDAB Awards for

Excellence in Overseas Development Assistance. This award was presented to BMR on 22 November at Parliament House, Canberra, by Senator The Hon. Gareth Evans, Minister for Foreign Affairs & Trade. It recognises the achievements of the IAGMP in the pursuit of its objectives—to assist Indonesia to strengthen its institutional long-term capacity to undertake systematic and comprehensive regional mapping surveys, and to produce appropriate quality maps and reports, by training Indonesian counterparts in the necessary specialist techniques; and to help establish the geoscientific framework—firstly of Irian Jaya, then of Kalimantan—as a basis for assessing mineral and petroleum potential, and for planning Earth-resource management and use.

For more details contact Messrs David Trail or Peter Pieters in Bandung at Jalan Cilaki 49 (phone 022-72103), or Messrs Geoff Bladon or John Casey at BMR.

Ocean Drilling Program (Leg 123) drills near Exmouth Plateau

During September-October 1988 the drillship *Joides Resolution* drilled two holes off northwestern Australia—one (Site 766) off the outer (western) edge of the deep-water Exmouth Plateau and the other (Site 765) in the Argo Abyssal Plain, off the northeastern edge of the plateau (Fig. 12). This was part of ODP Leg 123, and was a joint program with Leg 122. Three scientists from Australia participated in Leg 123: Dr Andrew McMinn (palynologist) from the NSW Geological Survey, Dr David Haig (palaeontologist) from the University of Western Australia, and Dr David Heggie (organic geochemist) from BMR's Marine Division.

The main objectives of the program were:

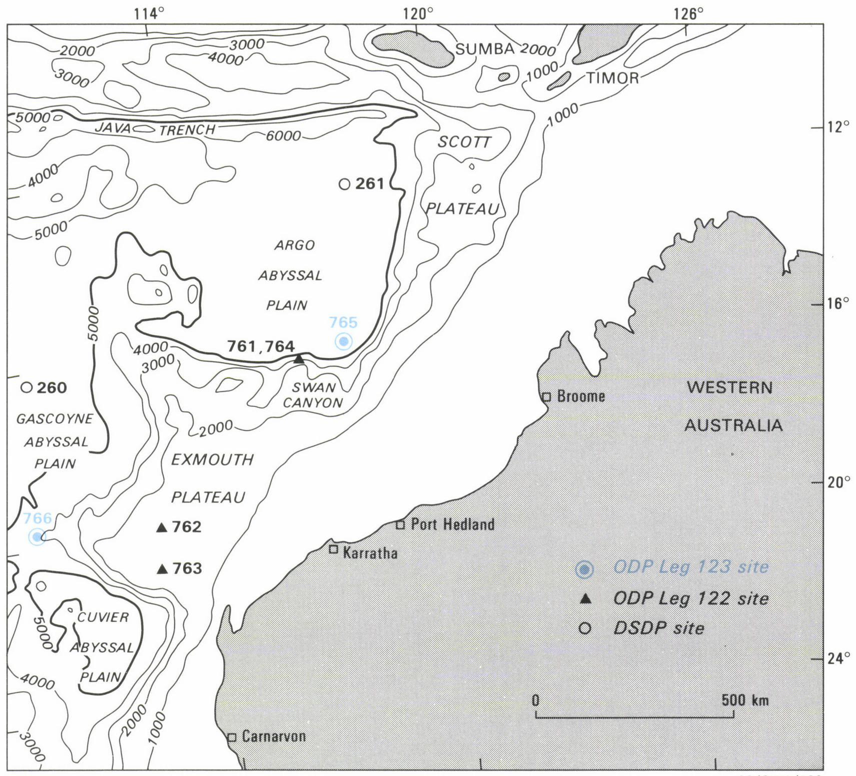
- to understand the pre-rift and syn-rift history and rift-drift transition in a passive continental margin;
- to study the Early Cretaceous to Cainozoic development of sedimentation and palaeoenvironment from a juvenile to a mature ocean;
- to evaluate the effects of basin subsidence, sediment imput, and sea-level change by studying the temporal and spatial distribution of Jurassic, Cretaceous, and Tertiary sequences;
- to investigate Middle Jurassic and mid Cretaceous anoxic sedimentation in terrigenous, shallow-water, and deep-water marine environments;
- to refine the Mesozoic geological time scale; and
- to determine the bulk chemical and physical characteristics of the oldest sediments as a key to understanding geochemical fluxes in the nearby Java Trench subduction system.

Hole 765 was drilled in 5714 m of water at the southeastern corner of the Argo Abyssal Plain, about 50 km from the Exmouth Plateau. The drilling recovered 930 m of sediment and 270 m of Cretaceous basement. Hole 765 is the deepest cased hole in the world's oceans and was a major engineering achievement. Detailed microfossil stratigraphy of the brown-red silty claystone and volcanic ash layers overlying the fresh volcanic flows dates the basement as latest Berriasian-Valanginian (Early Cretaceous, about 140 Ma). This major result suggests that the age of opening of the Argo Abyssal Plain may have to be revised upward by 20 Ma, from Late Jurassic to Early Cretaceous. Calcareous turbidites, 10 cm to 5 m thick and alternating with hemipelagic (i.e. partly terrigenous) claystones, dominate the Mesozoic-Cenozoic sedimentation at this site. TOC (total organic carbon) contents of Mesozoic sediments were <1 wt% and shipboard pyrolysis studies indicate the organic matter to be Type III and therefore probably derived from the nearby continental margin and moved to this site with the turbidites.

Site 766 was drilled in 4 km of water at the western edge of the Exmouth Plateau, at the base of the continental margin. Drilling recovered 450 m of sediment overlying a 70 m sequence of sediments intruded by sills and a dyke. Microfossil stratigraphy of the oldest sediments recovered indicates an age of latest Valanginian (Early Cretaceous, about 134 Ma). Overlying the basal (Early Cretaceous) deep-water deltaic green and black sands and siltstones is 250 m of mid-Cretaceous to Cenozoic pelagic ooze containing some chalk and chert. TOC content of the Early Cretaceous sediments is generally about 1 wt% but is as high as 1.6 wt% in the Valanginian sediments. Rock-Eval pyrolysis again indicates the organic matter to be Type III. Biomarker geochemical analyses will be carried out at BMR to determine the environment of deposition.

Further information can be obtained from Dr David Heggie at BMR (Division of Marine Geosciences & Petroleum Geology); Dr Andrew McMinn, NSW Geological Survey; or Dr David Haig at the University of Western Australia.

Fig. 12. Ocean drill sites off northwestern Australia.



Under-way geochemical exploration for offshore petroleum

BMR's division of Marine Geosciences & Petroleum Geology has recently entered into a joint research program with Transglobal Exploration & Geoscience, of Leucadia, California, to study hydrocarbon gas seeps from the sea floor. Shipboard geochemical equipment to enable continuous under-way analysis of light hydrocarbons and carbon dioxide in sea water has been installed aboard BMR's research vessel *Rig Seismic* and complements existing sediment sampling and geochemical analytical systems.

The molecular and isotopic compositions of hydrocarbons in sea water (and sediments) may provide important clues to the presence of oil or gas fields and the maturity or type of source rocks (i.e. whether gas or oil prone) from which gas seeps are derived. The under-way geochemical system will be integrated with other marine remote sensing techniques that gather data simultaneously, including side-scan sonar, 3 and 12 kHz echo-sounders, and high-resolution seismic. BMR conducted the first program of this type in southeastern Australia in February-March 1989 and will do similar work later on the North West Shelf. Contributions and expressions of interest from industry to the program are invited.

Towed 'fish'

The shipboard equipment comprises three major sub-systems: deck hardware, laboratory gas-stripping and analytical equipment, and a PC-driven data acquisition unit. The deck hardware includes a fully integrated system comprising winch, A-frame, 400 m hollow cable and a towed submersible 'fish' designed to 'fly' just above the sea bed. The fish continually pumps sea water up the cable and into the geochemical laboratory where gases are stripped from the sea water. The gases are pumped to three chromatographs, each fitted with dual detectors collecting a variety of data including: total hydrocarbons and carbon dioxide every 30 seconds, C_1-C_4 hydrocarbons every two minutes, and C_5-C_6 and C_{6+} hydrocarbons every ten minutes. These data are integrated into the shipboard navigation system and the results (gas concentrations and molecular compositions) are displayed both graphically and numerically for rapid interpretation. Also, samples can be collected at sea for later isotopic analysis in the shore laboratory.

The program may lead to the development of new technology for locating gas seeps, and for the analysis of sea water from which gas has been extracted—analyses that will provide constraints on regional oceanography and background for the interpretation of hydrocarbon anomalies. The geochemical data will be integrated with side-scan sonar, echo-sounder, and high-resolution seismic data to develop information on the seafloor morphologic expression of gas seeps and on migration pathways and trapping mechanisms of shallow hydrocarbons. A direct contribution to petroleum exploration will be the production of maps showing light-hydrocarbon distribution in petroleum-prospective areas, on both a local and regional scale.

For further information, contact Dr David Heggie or Dr Geoffrey O'Brien at BMR's Division of Marine Geosciences & Petroleum Geology.

Offshore mineral studies at BMR

Offshore minerals studied by BMR over the years include heavy-mineral sands, phosphate, manganese nodules, and manganese crusts. In the 1960s and 1970s a considerable marine geological program was aimed at mapping the Australian continental shelf as part of an overall Phosphate Program. This showed that economic phosphate deposits were unlikely to be present at the surface, although scientifically interesting Recent phosphorites were discovered on the northern NSW Shelf.

The marine geological program also defined the east Australian shelf as prospective for heavy-mineral sands. A major cooperative cruise with the German Geological Survey in 1980, using RV *Sonne,* showed there are concentrations of zircon and rutile in thick sand wedges south of headlands along the coast *(Geologisches Jahrbüch,* Reihe D, Heft **56**). No potentially economic deposits were discovered, although limited exploration by mining companies has continued since then off southern Queensland and northern New South Wales.

In the 1960s and 1970s BMR also undertook a series of cruises to assess deep-sea manganese nodule and crust resources in the offshore Australian region. These were carried out largely from Royal Australian Navy vessels, frequently in cooperation with Dr L.A. Frakes of Monash University. The results were published in various BMR outlets, and summarised by Dr H.A. Jones *(Australian Mineral Industry Quarterly,* **33**(1), 1980). Manganese nodules and crusts are very common south and southwest of Australia. The most interesting, from a commercial perspective, cover an area of at least 1 million km^2 southwest of Australia. However, nodule grades are substantially lower than those of the Clarion–Clipperton Fracture Zone deposits of the eastern Pacific.

BMR's Division of Marine Geosciences & Petroleum Geology obtained RV *Rig Seismic* in 1984, for a Continental Margin Program with the emphasis heavily on studies of geological framework and petroleum potential. Only one cruise has been designed as an offshore mineral study—a geochemical research cruise off northern NSW in 1987 which found evidence for a new mechanism of marine phosphorite formation *(BMR Research Newsletter,* 7). However, a number of *Rig Seismic* cruises have recovered manganese nodules and crusts from the continental slope, and these have been investigated in conjunction with Mr Barrie Bolton of Adelaide University.

The general consensus is that deep-sea mining of manganese nodules, in which the main interest is in cobalt, nickel, and copper, is not economically viable at present (e.g. P.D. Ingham in *BMR Record* **1986/3**). Nevertheless, several countries are continuing active economic assessment programs, and at least one country (USSR) is considering having a mining vessel built. In 1987, the General Committee of the Preparatory Commission for the International Sea-Bed Authority and the International Tribunal for the Law of the Sea, in conjunction with several international consortia involving companies from countries that are not signatories to the Convention of the Law of the Sea, came to an agreement which divided all the prospective manganese nodule areas of the Clarion–Clipperton Fracture Zone among the interested parties.

In recent years there has been considerable interest in cobalt-rich manganese crusts, which commonly occur in water depths of 100–2500 m on seamounts and island slopes in the Pacific and elsewhere. These crusts may be 10 centimetres or more thick, and the most prospective of them contain about 2% Co. The USA has carried out a major program of assessing the distribution and economic potential of these crusts within the Exclusive Economic Zone on its Pacific coast and along the Hawaiian chain. Work so far has suggested that the most prospective deposits are in tropical waters.

Dredging of the Australian continental slope in cooperation with the German Geological Survey from RV *Sonne,* and from BMR's RV *Rig Seismic,* has shown that there are manganese crusts 10–20 cm thick on the Dampier Ridge (east of Sydney), Lord Howe Rise, South Tasman Rise (south of Tasmania), west Tasmanian margin, Scott Plateau, and Exmouth Plateau. It is probable that such crusts and associated manganese indules are sporadically present on current-swept outcrops in deep water right around the Australian margin and Australia's offshore territories.

In general, the concentrations of cobalt in Australian crusts are in the range 0.3–0.5%, and hence of no economic interest. However, a recent paper by B.R. Bolton, N.F. Exon, J. Ostwald, & H.R. Kudrass *(Marine Geology,* **84**, 53–80) showed that not only are crusts common and thick on the South Tasman Rise, but also that cobalt enrichment reaches 1% in one area. This non-tropical occurrence of cobalt-rich crusts is scientifically unusual and economically interesting, and clearly merits further investigation.

For further information contact Dr Neville Exon at BMR (Division of Marine Geosciences & Petroleum Geology).

Bathymetric maps: Offshore Resource Framework Map Series

The first bathymetric maps of the deeper waters of the Australian continental margin will be published later this year as a joint initiative by BMR, the Bureau of Rural Resources, and the Hydrographic Office, Department of Defence. The maps will be at 1:1 million scale and will cover the Australian Adjacent Offsore Area (legal continental shelf).

The prime purpose of the map series is to provide a planning base for research and survey operations in geoscience, fisheries, and oceanography. Specifically, the maps will support the extension of trawling and of petroleum exploration into deeper waters.

Bathymetric contours will be generated and compiled on BMR's Intergraph computer graphics system from digital depth data provided by the Marine division of BMR and by the Hydrographic Office.

Preliminary compilation of data for the first of the maps, covering the Great Australian Bight, has revealed a number of previously unknown, major submarine canyons.

For further information on this new map series contact Dr Hugh Davies at BMR (Division of Marine Geosciences & Petroleum Geology).

Zeolites and potassium minerals in central Australian salt lakes

The industrial mineral potential of salt lakes in central Australia has been highlighted by recent BMR work on the hydrogeology of the Amadeus Basin. The salt lakes studied contain hypersaline brines, some of which are rich in potassium and magnesium; efflorescent minerals such as sylvite (KCl) and thenardite (Na_2SO_4) have been identified in salt crusts; and zeolite minerals occur in deposits beneath the salt lakes.

BMR's regional hydrogeological study of the Amadeus Basin has delineated a 500 km-long groundwater discharge zone marked by a chain of salt lakes. Owing to chemical changes in the groundwater flow system and a high evaporation rate, hypersaline brines have evolved in the lakes. The largest of these salt lakes is Lake Amadeus (120 km long).

The smaller salt lakes, in the eastern part of the chain east of Curtin Springs, are chemically highly differentiated. They contain brines locally with more then 300 g/L salt (i.e. 30% salt, or 8 times the salinity of sea water). Potassium is concentrated in these brines (7 g/L or 3% of the salt), and so is magnesium (12 g/L or 5% of the salt). The brines could possibly be 'farmed' by a series of evaporating pans to recover potassium and magnesium minerals. Other potential applications of the salt lake brines are as feedstock for solar ponds, and as a medium for cultivating commercially valuable microorganisms such as *Dunaliella* and *Spirulina,* used as a source of beta carotene and high-protein feed.

Efflorescent salt crusts and near-surface playa deposits contain a wide variety of sodium, magnesium, and potassium sulphates and chlorides, and their composite salts.

Zeolites are contained in a dolomite bed intersected in two drillholes at a depth of 10 m beneath Spring Lake, a small lake east of Curtin Springs. This is evidently a palaeohydrological deposit representing former lake conditions. Zeolites are hydrous aluminosilicates with natural filtration and other properties that make them useful for a wide range of industrial applications. They are not produced commercially in Australia at present but substantial quantities of zeolites, mainly synthetic, are imported.

These discoveries suggest the need for further investigation of the resource potential of the saline groundwaters with which Australia is richly endowed, and which are regarded as a serious problem in other contexts.

For further information, contact Mr Gerry Jacobson at BMR; Ms Gresley Wakelin-King at the Northern Territory Geological Survey, Alice Springs, NT; or Dr Aro Arakel at the Queensland University of Technology, Brisbane.

New facts on old phosphates: Middle Cambrian, Georgina Basin

Despite the recognition of major phosphate resources in the Georgina Basin in far northwest Queensland (Fig. 13) in 1966, phosphate rock is still one of Australia's mineral imports. Therefore there is a need both to better understand our existing resources of phosphate and to extrapolate that understanding to the search for new resources. With this in mind scientists from BMR together with a number of other Australian and overseas scientists carried out a short-term multidisciplinary Phosphate Research Project (PHOSREP) in the period 1986–88. Middle Cambrian, Neogene, and contemporary phosphorites were compared and contrasted. In this article, observations are concentrated on the Middle Cambrian phosphatic sediments of the eastern Georgina Basin; some work on contemporary phosphorites was reported in *BMR Research Newsletter* 7 (1987), 4–5.

As a result of the recognition of hiatus and disconformity surfaces in the Middle Cambrian of the Georgina Basin, it is now possible to distinguish three intervals of phosphate deposition, in contrast to previous interpretations which inferred that all of the deposits were formed within the Beetle Creek Formation and were the same age (Templetonian; Fig. 14). This has important implications for future phosphate exploration in the Basin. Furthermore, we can now recognise the repetition of some lithofacies mosaics in each of the sediment packages concerned. Thus, the Beetle Creek Formation at its type locality on May Downs is now regarded as older than what has been called Beetle Creek Formation in the Burke River Structural Belt. Correlatives of the older Beetle Creek Formation *(sensu stricto)* include the Thorntonia Limestone, Wonarah beds, and Burton beds, and of the younger 'Beetle Creek Formation', the Inca Formation. Revised lithostratigraphic correlations are shown in Figs. 14 & 15. As phosphate deposition is now known to have occurred over a much broader time scale, rocks previously considered unprospective for phosphate need to be reassessed.

The earliest phosphogenic episode was during the Ordian–early Templetonian; these phosphorites are part of a stratigraphic sequence that unconformably overlies Proterozoic basement and is itself capped by a subaerial disconformity surface of basin-wide extent—the Bronco Stromatolith Bed (Southgate, 1986: *Queensland Government Mining Journal,* October 1986, 407–411). The phosphorite deposits at Lawn Hill, Riversleigh, Lady Annie, D. Tree, Yelvertoft, and Wonarah–Alexandria were all deposited in this sequence. These deposits occur in a complex facies mosaic that includes the Thorntonia Limestone, Beetle Creek Formation, Burton beds, and Wonarah beds; the mosaic is related to gradual transgression over an irregular palaeotopography. Four types of shallowing-upward cycle, each culminating in emergence, are recognised in the peritidal and sub-basinal portions of this Ordian sequence. Depositional features include phosphatic hardgrounds, stromatolites, phoscrete profiles, and desiccated mudstone and fenestral phosphorites.

There is some evidence from the southern part of the Basin that the Ordian phosphogenesis was related to anomalous geochemistry generated by oceanic anoxia. The lower Hay River Formation was deposited in a sulphate- and molybdenum-depleted, but phosphorus-enriched, environment, which is also characterised by positive $\delta^{13}C$ values enriched over the accepted Middle Cambrian values, and fluctuating carbonate $\delta^{18}O$ values (Donnelly & others, 1988: *Sedimentology,* **35,** 549–570).

A second phosphogenic event was during the late Templetonian—early Floran, at Duchess and Ardmore. These phosphorites are associated with a simpler facies mosaic that includes the younger 'Beetle Creek Formation' and Inca Formation. This sequence of sedimentation was related to subsidence of the Mount Isa Block.

Detailed petrographic examination of mudstone phosphorites from the Duchess deposit both in the weathered mine pits and from fresh drill core from Rogers Ridge has shown structures that are interpreted as phosphatised remnants of solitary and colonial unicells and sheaths that once formed part of a larger microbial mat community (Soudry & Southgate, 1989: *Journal of Sedimentary Petrology).* Identical structures are found in many of the phosphate peloids in the deposits. As the thinly bedded and laminated mudstone phosphorites are laterally discontinuous and partly eroded, it suggests that the microbial mats not only assisted in the fixation of phosphate in the sediments but following their erosion they became an important source of phosphate particles.

Drilling in the Rogers Ridge area, near the Duchess phosphate deposit, has also clarified the stratigraphic significance of concretions that straddle the boundary between the younger Beetle Creek and Inca formations. They appear to represent a sediment-bypass surface with evidence of transgression and locally condensed sequence. This transgression marks the onset of the third phase of phosphogenesis in the eastern Georgina Basin.

A major rise in relative sea level during the late Floran and early Undillan eventually drowned the platform and terminated phosphate deposition. In the Thorntonia–Yelvertoft area, black shales, concretionary limestones,

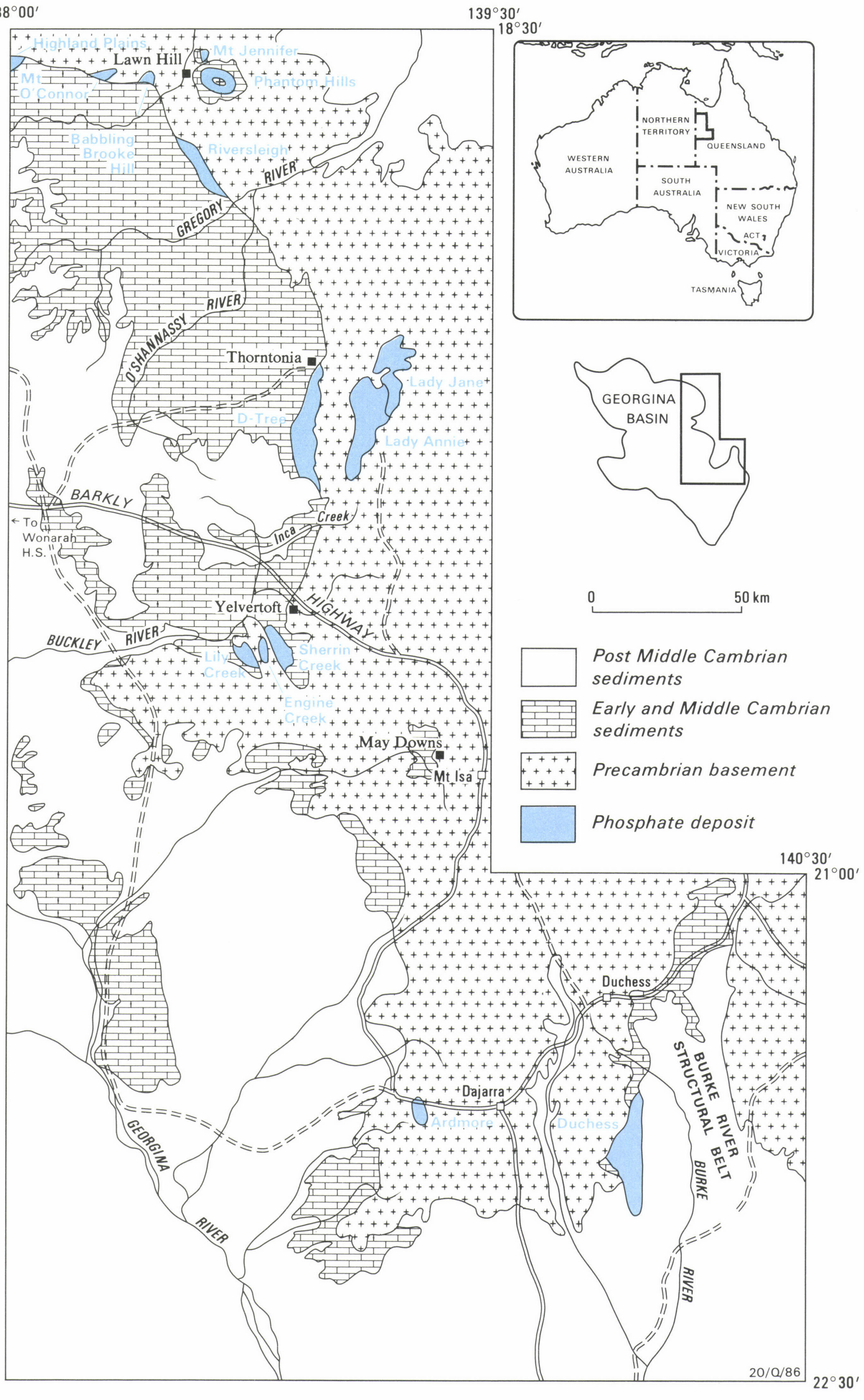


Fig. 13. The northwest Queensland phosphogenic province.

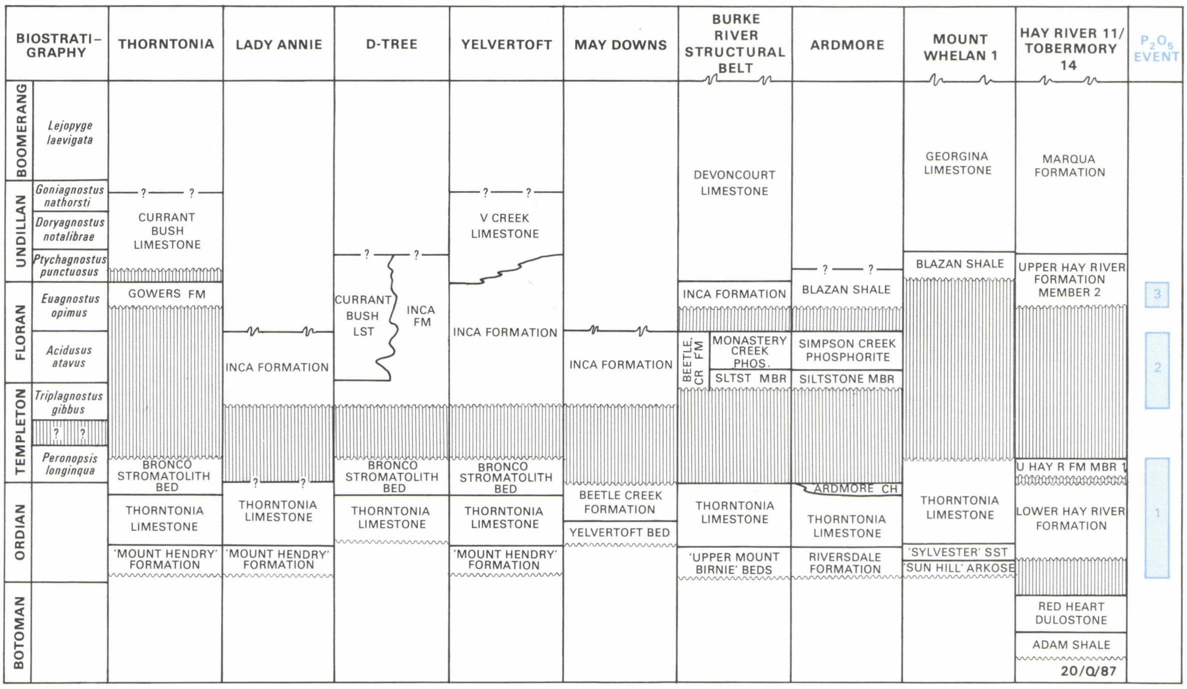


Fig. 14. Correlation of Middle Cambrian phosphogenic events, Georgina Basin.

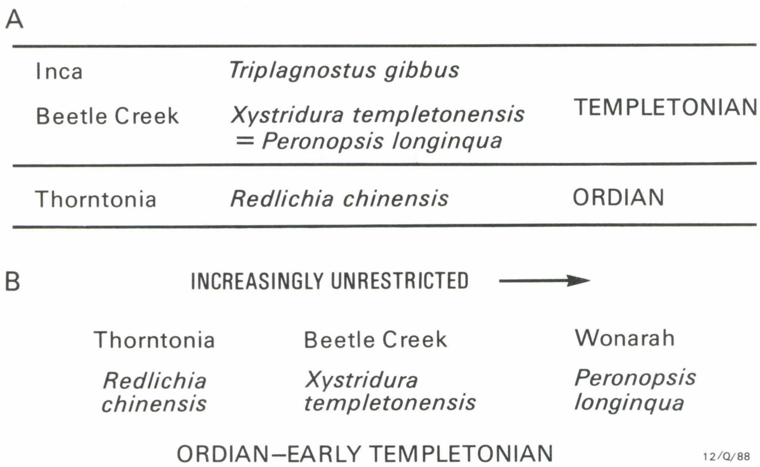


Fig. 15. Biostratigraphic interpretations, first phosphogenic episode: A—traditional bio/ lithostratigraphic scheme; B—as interpreted as lateral biofacies.

ribbon limestones, and parted limestones of *Euagnostus opimus* age disconformably overlie the karst surface developed on Ordian sediments. Peritidal phosphatic carbonates and phosphorites (Gowers Formation) were deposited around palaeohighs during the early stages of this transgression.

It is becoming evident that the Middle Cambrian phosphate deposits of the Georgina Basin were formed under conditions that can be documented in greater detail in younger deposits (e.g. Neogene of southeastern USA). In common, their distribution was controlled by bathymetry, proximity to appropriate upwelling oceanographic systems, basement subsidence rates, and eustatic sea-level change.

For further information, contact Dr John Shergold, Dr Peter Southgate, or Dr Peter Cook at BMR (Division of Continental Geology).

Radioactive tenterhooks

From April to October 1988 BMR's airborne geophysical group was ready with a contingency plan to search anywhere in Australia for radioactive debris from the Soviet nuclear-powered satellite, Cosmos 1900, that was threatening to re-enter the Earth's atmosphere out of control. In the end, fortunately, the search was not needed and the plan was stood down when the satellite was boosted into high orbit on 1 October.

Previous experience in planning for the re-entry of Cosmos 1402 in 1983 stood the airborne group in good stead. That satellite had re-entered the atmosphere over the north Atlantic, but a re-entry over continental Australia could have involved Australian authorities in an operation similar to that mounted by the Canadians in 1978, when, at a cost of several million dollars, they searched for and located radioactive debris from Cosmos 954 scattered over a remote part of northwest Canada.

In April 1988 Soviet authorities announced that radio contact had been lost with Cosmos 1900. Although they could not boost the satellite into a higher orbit via ground control, they expected this to be done by the craft's automatic inbuilt systems.

Australia's Natural Disasters Organisation, as in 1983, determined that contingency plans would have to be made to cover the unlikely event that radioactive debris would fall on Australia.

BMR met its obligation to the plan by arranging to have on standby, immediately prior to satellite re-entry, three fixed-wing aircraft (BMR's own Aero Commander plus two aircraft on contract survey) and a helicopter, for deployment anywhere in Australia within two hours. Each aircraft was equipped with a 256-channel gamma-ray spectrometer.

BMR ferried its Aero Commander back from survey in the Canning Basin in northwestern Australia to its base in Canberra. Both contract aircraft, one based near Alice Springs and the other near Perth, were to stop survey work during the standby period, to ensure rapid deployment. The helicopter was to be on standby at Nowra for deployment in a Hercules aircraft.

In the event of radioactive debris impact, the first task (to take about one week, flying 12 hours/day/aircraft) would be to search for radioactive debris near population centres and to locate the more highly radioactive debris in the more remote areas. The next step would be to define the radioactive debris 'footprint'. This would involve covering an area of 1000 by 50 km in about three weeks. Definition of the debris footprint would be followed by a more detailed aerial search involving additionally a number of RAAF helicopters equipped with gamma-ray spectrometers.

Recent publications, maps, and data releases

In the period 1 September 1988–1 March 1989 BMR released the following publications and data:

Publications

Bulletins

224—Geology of the Alligator Rivers Uranium Field, NT

Reports
284—Australian seismological report, 1984
Australian Mineral Industry Annual Review for 1986
Australian Mineral Industry Annual Review for 1987
Australian Mineral Industry Quarterly **40, No. 4**
Petroleum Exploration & Development Titles Map & Key **(July 1988)**
Petroleum Newsletter **101**
BMR Program Summary 1988–89
Geological Map Commentaries (1:100 000 scale): Cloncurry, Qld
BMR Earth Science Atlas of Australia, Map and Commentary: Land and Sea-Bottom Relief
Continental Margins Program Folio
1—Bass Basin
Records released on Open File
1988/12 (Groundwater **13**)—Hydrogeology and groundwater resources of Nauru Island, Central Pacific Ocean
1988/35—North Perth Basin Workshop
1988/36—Research cruise proposal: organic carbon cycling and Quaternary phosphorite formation, east Australian continental margin.
1988/37 (Groundwater **15**)—Palynological analysis, BMR Piangil West 1 Borehole, Murray Basin
1988/39—Reoccupation of the Heard Island magnetic station
1988/41—Submission to the Review of Marine Science & Technology
1988/42—Extended Abstracts, BMR Research Symposium, Canberra 8–10 November 1988: Palaeogeography, Sea Level & Climate: Implications
1988/43 (Groundwater **16**)—Murray Basin 88: Geology, Groundwater & Salinity Management. Conference Summary Report.
1988/44—Surficial geology, an Australian database, and their application to landscape evolution in the southern highlands of southeastern Australia
1988/45—Geochemical data analysis system (GDA) reference manual
1988/46—Amadeus Basin refraction survey, 1988: Operational Report
1988/49—Static corrections for land seismic processing
1988/50—SEAPUP update version 5.1: a computer program for estimating discovery & production of crude oil from undiscovered accumulations
1988/51—The distribution of Cadoux aftershocks: additional results from temporary stations near Cadoux, 1983
1989/1—Deep structure of the Gippsland and Bass basins (Project 9131.12): Operational Report for Cruise 1 (Survey 82)
1989/4—Research cruise proposal: light hydrocarbon geochemistry of the Otway, Stansbury, and Gippsland basins, and Torquay Sub-basin, southeastern Australia (Project 9131.20).

Release of data

Airborne geophysical maps
1:250 000—maps of 84 Sheet areas, showing either magnetic properties, magnetic contours or profiles, radiometric contours or profiles, or flight-line systems (all States)
1:100 000—magnetic, radiometric, and flight-line data for one Sheet area (King Island, Tas.).

Digital data
Digital-point-located airborne magnetic or radiometric data from 92 1:250 000 Sheet areas.

BMR publications, maps and data releases, and how to obtain them

BMR Publications and maps are listed in *Publications of the Bureau of Mineral Resources, Geology and Geophysics (Part I: Publications other than maps; Part II: Maps),* which is available free of charge from: **BMR Publication Sales, GPO Box 378, Canberra, ACT 2601 (phone 062-499519).** A *Quarterly List of Publications* showing current releases of all publications and other data is also available free of charge from BMR Publication Sales, together with detailed information on prices and postage costs. **All publications can be bought at the Publication Sales counter, BMR building, cnr Constitution Avenue and Anzac Parade, Parkes, ACT. Further information on the availability of preliminary data may be obtained from the Information Section, phone 062-499620.** Please note that orders for publications must be accompanied by payment in advance. Cheques, postal orders, etc., should be made payable to: Collector of Public Moneys (BMR). Payment from overseas should be made by bank draft or international money order in Australian currency.

The full results of most surveys and other research projects are published in two monograph series: *Bulletins* and *Reports.* Another major publication outlet for BMR's research results is the quarterly *BMR Journal of Australian Geology & Geophysics.*

The *BMR Yearbook,* covering the 12 months to 30 June, summarises the progress of all projects and lists all papers (incl. external) and monographs published in the period covered. The *Australian Mineral Industry Annual Review* covers mineral commodities, from 'Abrasives' to 'Zirconium', under the headings: production, consumption, treatment, trade, prices, new developments, exploration, resources, and world review. The *Australian Mineral Industry Quarterly* contains mineral statistics and prices, and an annual table of mineral resources. Covered so far in the *Resource Reports* series: uranium resources of Australia; coal in Antarctica; gold databases for WA, Qld, and NSW; and the geology and economics of platinum-group metals in Australia. *Australian Petroleum Accumulations Reports* so far cover the Amadeus, Bass, Adavale, and Gippsland basins.

The large-format looseleaf *BMR Earth Science Atlas of Australia* by now contains 17 maps of Australia, mainly at 1:10 000 000 scale, on various earth-science themes. In similar large format, the first volume (Cambrian) of a major new publication series, the *Palaeogeographic Atlas of Australia,* is now available.

Preliminary results, results of limited interest, and some other manuscripts are published in the *Record* series. Records are produced in limited numbers; photocopies can be bought through the BMR Copy Service. Those available for reference at Open File Centres are listed in the *Quarterly List of Publications.*

BMR has published a large number of 1:250 000 scale geological maps, with 'Explanatory Notes' booklets, covering quadrangles mainly in northern Australia. More detailed, 1:100 000 scale geological maps and accompanying commentary booklets are also available for certain areas. Many smaller-scale geological maps covering various regions have also been published, often in conjunction iwth geological Bulletins. BMR also publishes stream-sediment geochemistry, radiometric, gravity (new series), total-magnetic-field (TMF), and TMF pixel maps at various scales. The results of most regional geophyscal and marine surveys are made available as preliminary maps and sections. **A brochure illustrating the extent of coverage of Australia by surveys by BMR and the State mines departments can be obtained from: Information Section, Bureau of Mineral Resources, GPO Box 378, Canberra, ACT 2601, phone (062) 499620.**

Please note that subscriptions for the *Australian Mineral Industry Annual Review,* the *Australian Mineral Industry Quarterly,* and the *BMR Journal of Australian Geology & Geophysics* are handled by the Australian Government Publishing Service. Cheques should be made payable to AGPS. Payments from overseas should be by bank draft in Australian currency. Enquiries re subscriptions should be directed to: Assistant Director, Sales & Distribution, AGPS—(062) 954411. Subscription orders should be addressed to: Mail Order Sales, Australian Government Publishing Service (AGPS), GPO Box 84, Canberra ACT 2601.

BMR Copy Service

Photoscale geological compilation sheets and other recent survey results are released as dyelines and transparencies through the BMR Copy Service. Some other documents, including Records, are also released through the Copy Service. Lists of releases are available from Information Section, BMR—address above. Orders should be sent to Copy Service, Bureau of Mineral Resources, GPO Box 378, Canberra, ACT 2601 or phone (062) 451374, fax (062) 472728.

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This number of the *BMR Newsletter* was edited by A.G.L. Paine and word-processed by P. Nambiar; the figures were drawn by staff of the BMR Cartography Section.

The purpose of the *BMR Research Newsletter* is to provide the exploration industry with early information on the progress of BMR research and on the availability of new data relevant to exploration and to resource assessment; to provide commentaries on relevant research developments worldwide; and to encourage close liaison between the exploration industry and BMR. Readers' comments and suggestions—addressed to the Director—are welcome. Requests to be placed on the mailing list should be addressed to: Information Section, Bureau of Mineral Resources, GPO Box 378, Canberra, ACT 2601.

B89/20356 Cat. No. 89 0366 8 Printed by Union Offset Co. Pty Ltd

News briefs

Hydrogeology of the Murray-Darling Basin

As a result of recommendations from the BMR Advisory Council, groundwater studies within the Murray-Darling Basin have been consolidated into one project.

The prime objective of the new **Murray-Darling Basin Groundwater Project** is to develop a database enabling technical advice to be provided on groundwater processes in the Basin. This will be viewed in the light of climatic change and environmental damage being caused by land salinisation and deteriorating river-water quality. BMR, through the Murray-Darling Basin Commission's Groundwater Working Group, is coordinating efforts in the relevant States to synthesise data on a regional, basin-wide scale.

Work is under way to compile and publish a series of 1:250 000 scale hydrogeological maps covering the Murray Basin (i.e. the geological entity), and a series of reconnaissance geological and hydrogeological maps at 1:1 000 000 scale covering the Darling River Basin. These maps will be one of the tangible products emanating from the large geological and hydrogeological databas now being compiled.

A proposal to produce a basin-wide numerical model that will simulate groundwater flow and salt movement in the Murray Basin is currently before the Murray-Darling Basin Commission.

R.V. *Rig Seismic*

BMR's reseach vessel, *Rig Seismic,* carried out a 30-day geochemical program in the Gippsland, Bass, Otway, and Stansbury basins in February and early March. The program involved phases of both seabed sediment sampling and continuous sampling of the water column for traces of hydrocarbon gases (see article on p. 12). Where present, such traces are frequently associated with microseeps from hydrocarbon accumulations at depth. In other parts of the world the under-way 'direct detection' technique is used to rank seismically defined plays and, in frontier basins, to provide an indicator of hydrocarbon source and maturity at depth. The recent trial was the first use of the under-way direct detection technique in the Continental Margins Program and its first systematic trial over a range of known but undeveloped fields in Australia. The data indicate positive results in the vicinity of a number of Gippsland Basin fields.

Eromanga-Brisbane Geoscience Transect

A compilation of all geophysical and geological data along a transect across southern Queensland, from west of Quilpie to the coast, is being prepared in BMR. The compilation draws together most of the data and many of the tectonic models for the region, which is an important producer of oil, natural gas, and coal. Similar studies are being undertaken elsewhere in the world and the data are being prepared to an agreed international format in the International Lithosphere Program's Geoscience Transects Project.

Geological and geophysical map compilations at 1:1 000 000 scale, together with the accompanying notes, should be available in the second half of 1989.

AWAGS experiment

Detailed preparations have started for the joint Flinders University—BMR Australia-wide Array of Geomagnetic Stations (AWAGS) Experiment. A continent-wide array of 50 three-axis fluxgage magnetometers will be deployed over Australia towards the end of 1989 and will record fluctuations of the geomagnetic field at one-minute intervals for about four months. This will give the first ever comprehensive picture of diurnal variations and magnetic disturbance patterns as they migrate across the continent.

The results will permit detailed analysis of the time-dependent field corrections that must be applied to aeromagnetic data. They will also provide a scientific basis for developing base-station strategies for land, marine, and airborne magnetic surveys within the Australian region.

Mineral industry publications

Australian Mineral Industry Quarterly Vol. 40 No. 4 was released in January and Vol. 41 No. 1 in April. The *Quarterly* contains summary and detailed production and trade statistics and prices for a range of mineral commodities.

At the beginning of March, BMR's Mineral Commodities Branch issued its series of Preliminary Annual Summaries for 1988 for aluminium, black coal, copper, fertiliser minerals, gemstones, gold, iron, lead, manganese, mineral sands, nickel, platinum-group metals, tin, uranium, and zinc. Each contains estimates of production, trade, and prices for 1988, reviews major developments, and gives a forecast of production for 1989.

The Branch issued an Information Sheet in March, containing its estimates of Australia's identified resources of minerals and fuels as at 31 December 1988. This continues an annual series begun in 1975. An Information Sheet specifically for uranium, which also sets out resources in other countries, was also issued in March.

Recent graphics contract boosted

A contract with Intergraph Corporation Pty Ltd for the supply of interactive graphic workstations to BMR's Cartography Section has been amended to include the supply and maintenance of additional equipment that will help produce final maps for the BMR Palaeogeographic Atlas. The existing system will be augmented by the addition of two stand-alone high-performance 'Interview' and 'Interact' workstations.

Additions will include increased disk memory, system memory, an Optronics 5040 scanner-photo plotter, and a comprehensive range of software to support BMR's cartographic services and products. Total value is $850,000. Delivery, installation, acceptance testing, and training are due to commence in April 1989.

These facilities will enable efficiency gains in map production that are essential, for example, to meet the timetable for the Hydrogeology Program in the Murray Basin. They are a step towards making geoscience maps available in digital format for use by exploration companies and in integrating and presenting geoscience data more effectively.

McArthur Basin study

International petroleum companies have shown considerable interest in BMR's rcently completed study of the petroleum potential of the Middle Proterozoic of the McArthur Basin, NT. BMR staff have been asked to participate in oil company and joint industry-academic seminars on Precambrian oil, which is now receiving serious attention at an economic target. Commercial petroleum reserves occur in Precambrian rocks in Oman and the Soviet Union.

Seismic monitoring

Monitoring of earthquakes and nuclear explosions continues at BMR's Australian Seismological Centre (ASC). Approximately 100 seismic events per day are recorded by the ASC's network of seismographs. Four underground nuclear explosions were detected in December—two in eastern Kazakhstan, one in Novaya Zemlym, and one in Nevada.

Following the 22 January 1988 earthquakes at Tennant Creek, NT, aftershocks continued through December 1988 and January 1989. Magnitude ML 4 earthquakes also occurred near West Wyalong, NSW, and in the Gulf of Carpentaria.

ASC is participating in an international seismic experiment to gather data for testing algorithms to be used at International Data Centres.

ODP Leg 121—Paleomagnetism

A BMR palaeomagnetist was a member of the scientific team on ODP Leg 121 (May-June 1988) which studied the evolution of the Broken Ridge Kerguelen-Heard Island Plateau, the evolution of the Kerguelen hotspot as traced in the Ninetyeast Ridge, and the fast northward movement of the Indo-Australian Plate during the Cretaceous and Tertiary.

The leg was highly successful and provided important basic information for studies by BMR's Marine Division on the evolution of the Kerguelen Plateau and the active northern margin of the Plate. At the post-cruise meeting (9–13 January 1989) the initial proceedings of Leg 121 were finalised for publication (scheduled for December 1989).

Remote sensing of hydrocarbon seepages

Research by BMR's Remote Sensing Group, using data from the NASA aircraft 7-channel scanner, flown over the Palm Valley gas field, NT, has revealed an anomalous zone of altered sandstones. This is interpreted as a result of natural seepage of hydrocarbon gases. Results of a limited soil-gas survey have confirmed that the anomalous zone corresponds to higher than background values of natural hydrocarbon gases.

The anomalous zone can be detected on Landsat TM data but is not apparent on MSS data on conventional aerial photography. Details of the investigation, believed to be the first successful remote sensing detection of hydrocarbon seepage effects in Australia, were reported at the APEA conference in Hobart in April.

Ore genesis research

Chemical controls on metal ore grades—an essential part of exploration models for economic ore deposits—are now being investigated in BMR using a new approach adapted from chemical engineering. The first application is on hydrothermal tin-tungsten deposits, where ore fluid compositions are being analysed semi-quantitatively by a new heavy-ion analytical facility (HIAF) proton-microscope technique. The work is being carried out in collaboration with CSIRO's Division of Exploration Geoscience.

Salinities from the laser Raman microprobe

BMR's laser Raman microprobe has been used to analyse non-destructively the solids, liquids, and gases in fluid inclusions from the Alligator Rivers Uranium Field, NT. A new technique has been developed to allow the rapid determination of fluid salinity at room temperature and without reference to binary salt-water phase diagrams. The microprobe studies have discovered evidence for the tapping of discrete high and low salinity fluids and provide important information on possible mechanisms of ore deposition. This will contribute to the understanding of the location of the deposits and to exploration models.

South Alligator Valley Conservation Zone

A geological map of the South Alligator Valley mineral field at 1:75 000 scale and covering most of the Conservation Zone has recently been released (see below).

An assessment is currently being made (in collaboration with the National Resource Information Centre) of the capacity of Geographic Information Systems to accommodate an extensive database of geological, geophysical, and remotely sensed data for the resource assessment program to be undertaken in the Zone.

New Alligator Rivers region geological Bulletin; new map of the South Alligator Valley, NT

Two major publications documenting the results of joint BMR and Northern Territory Geological Survey mapping in the Kakadu region have recently been released: a Bulletin describes the geology of the Alligator Rivers Uranium Field (containing the Ranger, Jabiluka, Koongarra, and Nabarlek deposits), and a 1:75 000 scale map shows the geology and mineralisation of the South Alligator Valley Mineral Field (containing the Coronation Hill gold–platinum–palladium deposit and numerous small, abandoned uranium mines). Both are available from: Publication Sales, BMR, GPO Box 378, Canberra ACT 2601.

GEOLOGY OF THE ALLIGATOR RIVERS URANIUM FIELD, NORTHERN TERRITORY, by R.S. Needham, 1988. *Bureau of Mineral Resources, Australia, Bulletin* **224**, 96 pp, 8 tables, 32 figs., 30 plates, 4 microfiche appendixes. Price: $20.95.

This Bulletin covers the northeastern part of the Pine Creek Geosyncline east of the South Alligator River and emphasises the setting and host rocks of the major uranium deposits of the region. All of the region is covered by Kakadu National Park or Arnhem Land Aboriginal Land. Mining and exploration in the park are limited to the Jabiluka, Ranger, and Koongarra mineral-lease excisions, and elsewhere are subject to the agreement of the Northern Lands Council.

A 1:250 000 scale map to accompany the Bulletin is in preparation; a preliminary uncoloured version is currently available from BMR Publications Sales.

GEOLOGY AND MINERALISATION OF THE SOUTH ALLIGATOR VALLEY MINERAL FIELD, NORTHERN TERRITORY, by R.S. Needham, 1988. *Bureau of Mineral Resources, Australia, 1:75 000 scale special map.* Price: $18.00, plus $1.20 sales tax where applicable.

This map combines information from four previously published 1:100 000 scale maps (Mundogie, Jim Jim, Ranford Hill, Stow) to cover the area of gold, uranium, and platinum-group mineralisation in the headwaters of the South Alligator River between Kombolgie Creek and Sleisbeck. It covers the southeastern half of the South Alligator Conservation Zone and is centred on the Coronation Hill gold–platinum–palladium deposit. The map includes a tabulation of data for 59 mineral deposits and prospects, plans and sections of selected deposits, and interpreted solid geology of the El Sherana–Coronation Hill area.

Canning Basin seismic survey

As part of a major new study of the Canning Basin, WA (see *BMR Research Newsletter* No. 8, April 1988, p. 12), BMR's seismic crew completed field operations in October 1988. A total of 650 km of 12-fold CDP data were acquired along three lines. Processing is well under way, with one line nearly completed and 'stacks' of the remainder being produced. Data quality appears to vary from fair to excellent. Coincident gravity and aeromagnetic data recorded along the line are also being processed.

Recent workshop on the geochemistry of basinal brines

Over 60 participants with backgrounds in ore deposits, oil, and groundwater attended a one-day workshop at BMR on 6 April 1989 on the geochemistry of basinal brines. The workshop was presented by Dr Yousif Kharaka, of the USGS, who visited BMR from 3–14 April to collaborate in the BMR project, *Hydrology of Oil and Metal Bearing Brines in the Canning Basin.*

Participants included representatives from industry, CSIRO, and tertiary institutions.

Understanding the origin and chemical evolution of basinal brines has important economic benefits, particularly to the oil and mineral exploration industries.

Waters for analysis need to be uncontaminated, and unstable characteristics such as pH, Eh, alkalinities, H_2S, etc. need to be measured in the field and processed by filtration, acidification, and addition of $HgCl_2$ as bactericide. Dr Kharaka urged participants to use geochemical codes for data analysis. He described in detail the code SOLMINEQ 88 (Kharaka & others 1988: *USGS Water Resources Investigation Report* **88-4227**), that can be used for speciation-saturation as well as mixing, boiling, ion exchange, and adsorption and dissolution precipitations. He recommended the use of speciation-saturation and mass transfer codes like SOLMINEQ 88 for improved data analysis.

Dr Kharaka described some results of his recent research. Data from several US basins show the water to be meteoric, connate, or bittern (residual liquor after evaporation of sea water beyond halite saturation) in origin, commonly a mixture. Salinities range from 5000 to 350 000 mg/L and are either Na-Cl or Na-Ca-Cl type. Some brines contain concentrations of reactive organic species (hydrocarbons) up to 10 000 mg/L. Brines from the Central Mississippi Salt Dome Basin are very high in Zn (250 mg/L), Pb (70 mg/L), and other metals, and are similar to ore-forming solutions in the Missisippi Valley type ore deposits.