BMR Research Newsletter

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Platinum group minerals from a layer in the Munni Munni Complex of the Pilbara Block

The Munni Munni Complex (Fig. 1), located 45 km south of Karratha in the west Pilbara Block (WA), has been selected for a detailed petrological–geochemical study in view of its potential for platinum group element (PGE) mineralisation. The complex, which has an Sm–Nd model age of 2800 Ma (S. Sun, BMR, personal communication 1985), represents one of the best preserved layered mafic–ultramafic intrusions in Australia. Covering an exposed area of 9 by 4 km, it is composed of a basal ultramafic zone (1850 m thick) and an overlying gabbroic zone (3630+ m thick). The ultramafic zone contains rhythmically layered dunites, lherzolites, olivine websterites, clinopyroxenites, and websterites, which grade into orthopyroxenites, norites, and chromitites near the contact with overlying gabbroic lithologies. The gabbroic zone consists of a lower uniform subzone of gabbronorites and an upper subzone of interlayered anorthositic gabbros and gabbronorites. Aeromagnetic and gravity data indicate that the complex continues for a further 16 km to the southwest, beneath the Archaean Fortescue Group sedimentary and volcanic platform cover.

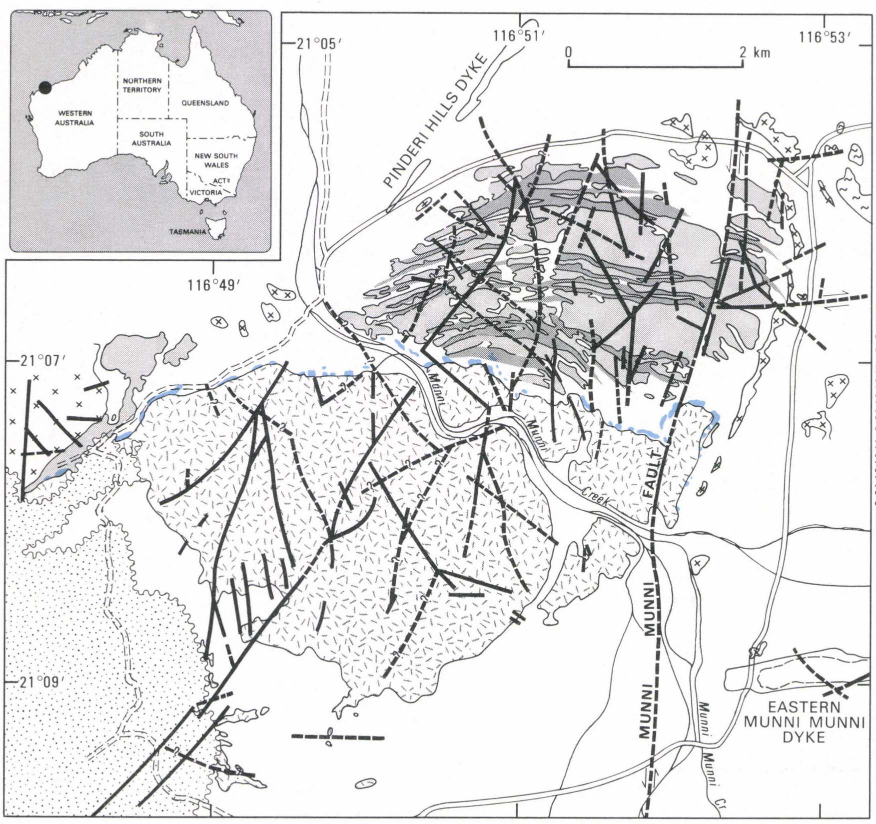
The cumulus mineral paragenesis for the complex is olivine, olivine–clinopyroxene, clinopyroxene, orthopyroxene, orthopyroxene–chromite, and plagioclase. This sequence is at variance with the major overseas PGE-hosting intrusions, in which crystallisation of orthopyroxene generally precedes that of clinopyroxene. The late crystallisation of orthopyroxene at Munni Munni is significant, since chromite mineralisation in the ultramafic and gabbroic zones is associated with the appearance of cumulus orthopyroxene at the expense of clinopyroxene.

In 1983, BMR and Hunter Resources Limited separately commenced research into the PGE potential of the Munni Munni intrusion, and in 1984 a layer of 'Merensky-style' PGE-mineralised rock was reported by Hunter Resources consultants Allan Rossiter and Dick England. Diamond drilling by the company in 1985 revealed a fairly persistent layer of PGE-enriched porphyritic plagioclase websterite at the contact between the ultramafic and gabbroic zones. PGE concentrations are as high as 2.2 ppm Pt and 3.0 ppm Pd in a 1-m-thick section of this layer. Radiochemical neutron-activation analyses (carried out at the Department of Geology in the University of Melbourne) of samples outside the mineralised layer indicate that the mineralised layer is enriched by a factor of about 10^3.

The PGE mineralisation, which is associated with elevated copper and nickel levels, may have resulted from a mixing event that involved two chemically distinct magma types. Similar mixing models have been documented by Kruger & Marsh (1982: *Nature* 298, 53–55) for the Bushveld Complex in the Republic of South Africa, and by Barnes & Naldrett (1985: *Economic Geology*, 80, 627–645) for the Stillwater Complex of Montana, USA. During magmatic differentiation of a sulphur-undersaturated magma (Munni Munni ultramafic zone rocks), the PGE concentration levels were progressively enhanced in the residual silicate melt. We infer that mixing with a more sulphur-rich tholeiitic magma (gabbroic zone rocks) resulted in rapid sulphur saturation and the scavenging of the chalcophile PGE by immiscible sulphide droplets which subsequently segregated in the porphyritic plagioclase websterite directly below the basal contact of the gabbroic zone. The mixing event has apparently been so efficient that it has depleted Pt, Pd, and Au from the lower 200 m of the gabbros. Iridium throughout both zones displays an antipathetic distribution with sulphur, and may be controlled by the early-crystallising higher-temperature phases, such as olivine and chromite.

Field evidence also supports magmatic mixing at the ultramafic–gabbroic contact:

- an unconformity occurs between the ultramafic and gabbroic zones;
- the mineralised host rock faithfully follows the basal gabbro contact;
- chromitites are present only near the contact, reflecting changing fO_2 conditions during magma mixing; and
- a variety of rock types — namely norites, orthopyroxenites, chromitites, and other hybrid types — forms lenses interfingering with the mineralised websterites. These lithologies may have crystallised from residual



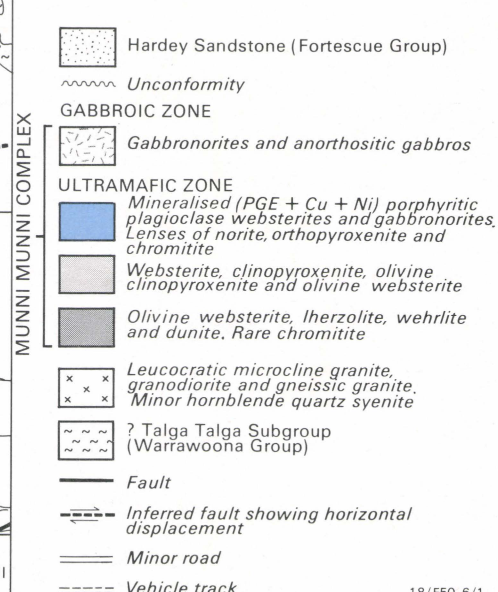


Fig. 1. Simplified geology of the Munni Munni Complex.

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Department of Resources and Energy

magma components from the main mixing cycle.

Hunter Resources Ltd has semiquantitatively determined the compositions of the Munni Munni platinum group minerals by using energy-dispersive techniques on a scanning electron microscope at the University of Melbourne. The dominant platinum group minerals include:

- cooperite (Pt>S>Pd),
- braggite or vysotskite (Pd>Pt>S>Ni),
- zoned platarsite (core: Pt>S>As>Ni>Fe), sperrylite (rim: Pt>As>Fe>S), with rarer
- moncheite (Pt>Te), and
- potarite (Hg>Pd>Au).

The platinum group minerals (Fig. 2) form small (2–30μm) grains near the margins of aggregates of actinolite, pyrrhotite, chalcopyrite, and pentlandite which are relics of sulphide liquid droplets. This relationship is typical of the Merensky Reef sulphides in the Bushveld Complex. The platarsite and sperrylite grains appear to be concentrated in silicified shear zones cross-cutting the mineralised websterite horizon, indicating possible hydrothermal remobilisation of the platinum sulpharsenides. All the Munni Munni platinum group minerals have been documented from overseas intrusions — including the Bushveld and Stillwater Complexes, the Lac des Iles and Sudbury Complexes of Ontario, and the Noril'sk intrusions of Siberia. Potarite is a rarer phase, originally reported from the Potaro River region of British Guyana. Future microprobe studies may identify additional platinum group phases in the Munni Munni Complex, and should provide information regarding their distribution and mobility in the primary magmatic and hydrothermal environments.

For further information, contact Mr Dean Hoatson at BMR, or Mr Dick England, Consultant Geologist, 10 Alrima Court, Bright, Victoria, 3741.

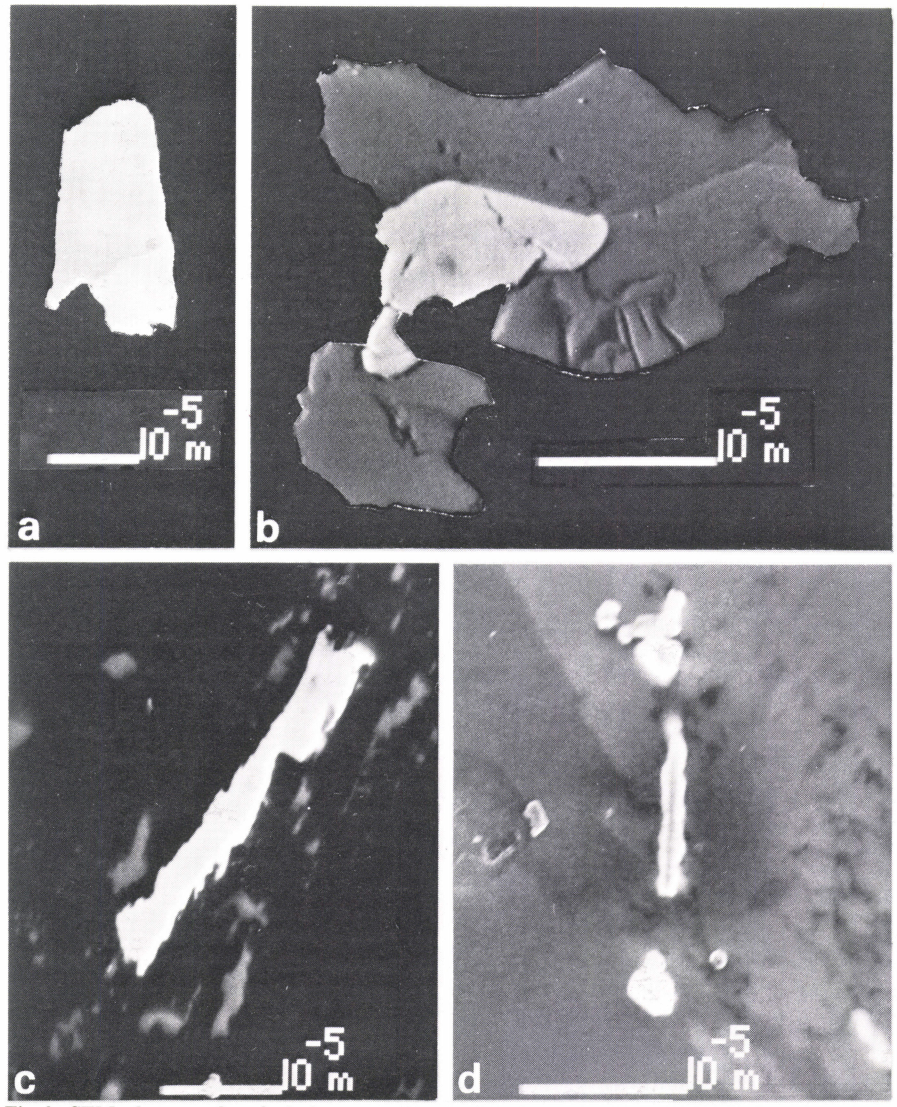


Fig 2. SEM photographs of platinum group minerals from the Munni Munni Complex: (a) a prism of braggite, and adjoining potarite in the lower right corner; (b) a prism of cooperite at the boundary of pentlandite–chalcopyrite (dark grey); (c) moncheite anhedra aligned with fine stringers of chalcopyrite; (d) cluster of zoned platarsite (core)/sperrylite (rim) anhedra in the carbonate–talc–chlorite matrix of a silicified shear zone.

Review of Baas Becking Geobiological Laboratory

The Baas Becking Geobiological Laboratory was established in 1965 — under joint sponsorship of BMR, CSIRO, and AMIRA — as a research facility in which scientists with geological and biological research skills could investigate the biological and geochemical processes associated with the formation of mineral deposits.

Initial emphasis on research was to develop an understanding of the role of biogenic factors in the formation of sulphide minerals. The objective of this research — to throw light on the mechanisms of syngenetic deposition — reflected the growing acceptance at that time that not all deposits owed their origin to hydrothermal mechanisms. Subsequent research has been broadened to include a range of mineral deposits, and studies of the formation and recovery of petroleum.

The Laboratory has now been operating for over twenty years, and the sponsoring organisations have agreed that its future directions should be reviewed in the context of (i) BMR's and CSIRO's geoscientific research roles and programs and (ii) the relevance of the Laboratory's program to the petroleum and minerals industries.

A review committee has been established to report back to the joint BMR–CSIRO Minerals (Exploration) Research Liaison Committee (MERLCO) by November 1986. The review committee comprises Dr A.D.T. Goode (BHP; Chairman), Dr P.J. Cook (BMR), Dr B.J.J. Embleton (CSIRO), Dr R.W. Henley (BMR), and Mr B.M. Thomas (Shell). Submissions have been widely sought from individuals and organisations associated with geobiological research and its findings.

Further information on the review and its terms of reference may be obtained from Mr Peter Smith (Secretary, Baas Becking Review Committee) at BMR.

BMR enhances database activity

The creation recently of the Geoscience Computing & Database Branch of the Resource Assessment Division will enable BMR to better uphold one of its primary roles — to be the primary national source of geoscience data.

The main function of the Branch will be to develop the means of making available, in a usable form, the vast amount of data generated by BMR, the exploration industry, and geoscientific institutions throughout Australia. To achieve this, an ongoing program of the Branch will be to identify and co-ordinate existing geoscience and resources databases, both within BMR and more generally within Australia, and to define immediate and future requirements.

The Branch is headed by Dr Bob Lowden, who brings to the position considerable management, geoscience, and computing skills from working with Shell International and, more recently, in the Petroleum Branch of RAD.

The Branch has two sections: Computing Operations (headed by Mr Jack Barlow) and Database Coordination & Liaison (headed by Mr Paul Shelley). A Computing Geoscience Research Unit will be established in the near future.

BMR's scientific computing, database, and data processing activities have also been substantially enhanced with the delivery in June of a new computer system.

The system consists of a Data General MV/20000 CPU with 16 megabytes of main memory, 3.5 gigabytes of disc storage, two magnetic-tape drives, 72 terminal ports, two 8-pen digital plotters, a 600-lines-per-minute printer, and 40 VDU terminals. A high-performance Data General 7720 graphics workstation linked to the MV/20000 via an Ethernet local-area network is also included.

A Sytek Localnet 2000 broadband local-area network is being installed to allow terminal users located throughout BMR to access both the new system and the existing facilities. The number of terminals on the network is expected to increase quickly from about 80 initially, to over 200 as processing is transferred to the new system and new database applications are developed. Major software packages to be installed on the system include Data General's CEO office automation package, a statistics package, a GKS graphics package, and Data General's UNIX software.

The MV/20000 system will significantly improve BMR's computing facilities, replacing severely overloaded 16-bit minicomputer systems that have supported a wide range of general scientific processing and database management tasks over the past ten years. The Data General system will also allow in-house processing of larger tasks currently requiring extensive use of external computing services.

More details from Dr Bob Lowden at BMR.

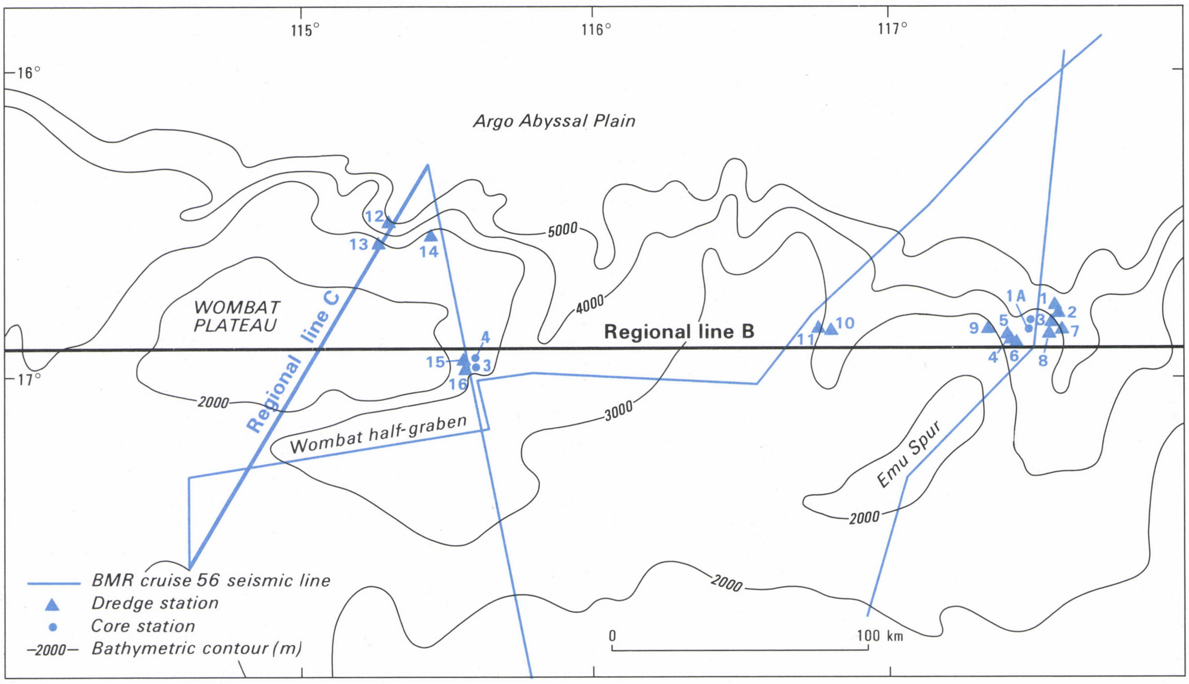
The Exmouth Plateau revisited

The Exmouth Plateau was the scene of considerable BMR work in the middle to late 1970s, and of large-scale deep-water petroleum exploration in the late 1970s and early 1980s. The BMR review phase culminated in the publication of *BMR Bulletin* 199, and 1979 field studies carried out co-operatively by BMR and the Bundesanstalt für Geowissenschaften und Rohstoffe of the Federal Republic of Germany on their research vessel *Sonne* led to further publications.

Fourteen exploration wells were drilled on the Exmouth Plateau by two consortia — the Phillips group (BP Petroleum Development Australia Pty Ltd, Australian Gulf Oil Co, MIM Investments Pty Ltd, Mobil Oil Australia Ltd, and Phillips Australian Oil Co.) and the Esso–BHP group. They resulted in several non-commercial gas finds, including the giant Scarborough gas field which is still held by Esso–BHP. The lack of oil finds in the major Exmouth Plateau structures has resulted in the cessation of exploration on the plateau. Nevertheless the plateau, which is huge, can hardly be regarded as adequately explored for the long term, and BMR undertook two research cruises over it in early 1986 in order to further evaluate its geological history and petroleum potential.

BMR's latest work consisted of four phases:

- two-ship multichannel seismic data collected on the central plateau and the southern plateau margin by BMR's RV *Rig Seismic* and Lamont–Doherty Geological Observatory's RV *Robert D. Conrad* using expanded-spread and wide-angle common-depth-point seismic profiling techniques, which provide reflection and refraction data of great value in interpreting deep sedimentary basin and crustal structure;
- regional multichannel seismic reflection data collected on the northern and western margins of the Exmouth Plateau;
- a heatflow survey of the central plateau (see article on p.10); and
- dredging and coring on the northern margin of the plateau.



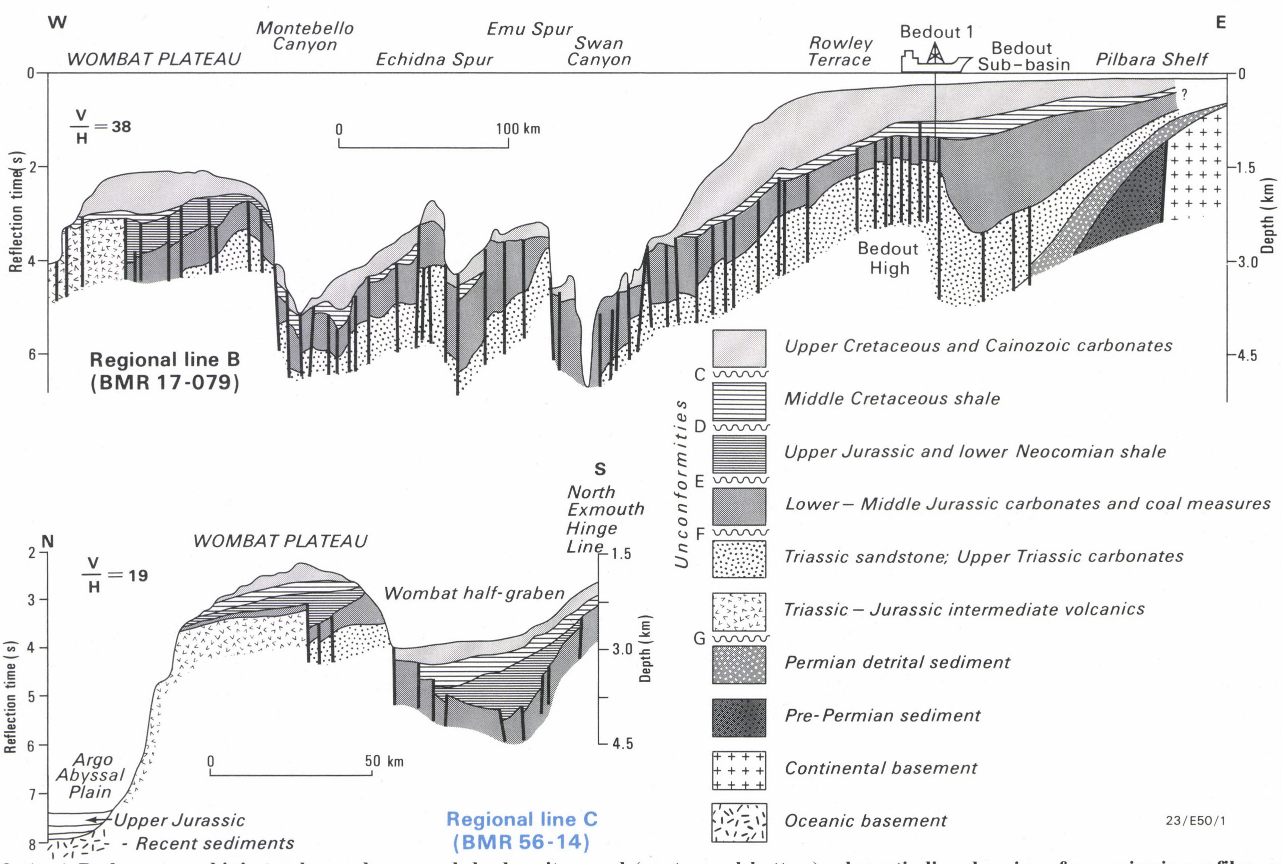


Fig 3. (*top*) **Bathymetry, ship's tracks, and core and dredge sites; and (*centre and bottom*) schematic line drawings from seismic profiles, and lithologies, northern Exmouth Plateau.**

Altogether 950 km of regional seismic lines, tied back into the high-quality commercial seismic data grid of the central Exmouth Plateau, were collected in the north. In addition 550 km of seismic reflection data were collected in five detailed survey areas, as a preliminary to sampling and to the preparation of mature Ocean Drilling Program site proposals. Sampling amounted to sixteen dredge hauls of older rocks on steep slopes and in spectacular canyons on the flanks of the Emu Spur, Echidna Spur, and Wombat Plateau, and four cores in Cainozoic sequences (Fig. 3).

The seismic and heatflow phases were clearly successful, but proper evaluation must await the completion of data processing. However, the studies on the northern margin of the plateau are more readily interpreted, and there follows a brief description of the main results.

The area studied lies in water depths of 2000–5500 m, and is bounded to the north by the Argo Abyssal Plain. In the Late Jurassic, the plateau split from another fragment of Gondwanaland, which drifted away to the northwest — leaving the oceanic crust of the abyssal plain behind. The Phanerozoic sequences of the Exmouth Plateau are up to 10 km thick, and for the northern margin are summarised in the seismic profiles and stratigraphic column (Fig. 3).

Representatives of all the Mesozoic and younger sequences shown in Figure 3 were recovered, and could be tied into the seismic stratigraphy. They included uppermost Triassic volcanics and shelf carbonates, Lower and Middle Jurassic shelf carbonates and coal measure lithologies, Lower and Middle Cretaceous shallow-marine sandstones and mudstones, Upper Cretaceous chalks and marls, and a variety of Cainozoic chalks, marls, and oozes. The presence on the northern margin of thick Jurassic coal measures, which are potential source rocks, and thick uppermost Triassic to Middle Jurassic shelf carbonates, which are potential reservoir rocks, offers encouragement for further studies of the petroleum prospectiveness of the plateau. The types of petroleum plays in the north are clearly quite different from those tested on the central plateau.

A full evaluation of the results of the Exmouth Plateau cruises is now under way; cruise reports should be published within a year, and papers on the various aspects of the cruise results will be prepared as soon as possible. Once our studies are fully integrated with the company data set, we should be able to better:

- determine the structural and stratigraphic framework of sedimentary basins and deep crust;
- relate the plateau's evolution to that of the surrounding oceanic crust beneath the abyssal plains;
- define the history of basin subsidence;
- define regional thermal history; and
- use all these factors to re-assess petroleum potential.

For further information, contact Drs Neville Exon or Paul Williamson at BMR.

Gold medal awarded to BMR

BMR cartographic designers have won the supreme accolade of the printing industry: a gold medal presented to BMR for the design of the Arltunga–Harts Range Region 1:100 000 geological map.

The map earned this distinction in the "Specialty or 'Special' Printing" category at the third National Print Awards (NPA), announced in Adelaide in March this year.

Submitted to the NPA by the printer, Mercury-Walch Ltd, the map was one of 959 entries, which were grouped into 27 categories. The gold medal awarded to BMR was one of only 22 presented by the panel of judges, comprising an independent group of professionals selected for their special qualifications and wide experience in the graphic-arts industry.

Welcome Dick Henley

New Chief Scientist, Division of Petrology & Geochemistry

BMR extends a warm welcome to Dr Dick Henley, who took up his appointment as the new Chief Scientist in the Division of Petrology & Geochemistry in May this year.

Dick is a leading authority on the genesis of mineral deposits, on processes in geothermal systems, and on the quantitative application of geochemical principles to diverse investigations — in mineral exploration, geothermal energy development, and environmental geoscience.

Born in England, and now a New Zealander, Dick gained his B.Sc. (Hons.) degree in geology (with chemistry) at the University of London in 1968, and his Ph.D. in geochemistry ('The hydrothermal chemistry of gold and the origin of Pre-Cambrian vein gold deposits') from Manchester University in 1971.

Dick lectured in applied geology and geochemistry at the University of Otago, New Zealand, between 1971 and 1975, and was Associate Professor of Economic Geology at Memorial University, St Johns, Newfoundland, between 1975 and 1977. Returning to New Zealand in 1977, he joined the Chemistry Division of the Department of Science and Industrial Research, Taupo, and was appointed Head of its Geothermal Chemistry Section, Wairakei, in 1981.

As Head of the Geothermal Chemistry Section, home of geothermal energy research, Dick led a team of scientists focusing on geothermal exploration based on geochemistry, and on the chemical problems associated with the development of geothermal energy. These studies — which complement research into the structure of hydrothermal metal deposits, and metal transport and deposition — have contributed to an appreciation of the development of epithermal precious-metal deposits.

Dick's geoscientific expertise has generated considerable demand for his professional services. He has consulted with the mineral exploration industries in New Zealand, the USA, and Canada, and for the United Nations in El Salvador. He has presented, by invitation, specialist courses in the USA and Australia, and papers at many specialist conferences in the USA, Canada, Australia, and Europe. He has been a visiting lecturer at the Geothermal Institute of the University of Auckland since 1979.

Dick's objective at BMR will be to lead the Division of Petrology & Geochemistry in developing frameworks for science-based exploration of Australia's mineral resources.

Palaeogeographic map project

Started in earnest in 1984, the palaeogeographic map project aims to produce a set of 1:10 000 000-scale Australia-wide Phanerozoic palaeogeographic maps — together with a complementary set of data maps, correlation charts, structural maps, explanatory notes, and bibliography — for each period. The project was initially scheduled to take six years to complete. However, industry – through APIRA (Australian Petroleum Industry Research Association) — realising the value of the project to exploration, has provided funds to accelerate production of the maps. It is now expected that the 10 full-time and many part-time workers on the project will produce first drafts of all maps in 1987, three years earlier than originally planned.

At present, Cambrian maps are with the printer; Ordovician, Permian, Triassic, and Jurassic maps are well advanced; and the preparation of the remainder is under way. The maps and summary stratigraphic columns are being computerised on an Intergraph system for ease of production in hard copy, for storage, and for subsequent updating and manipulation.

A valuable by-product of the project will be a set of up-to-date biostratigraphic zone charts for each period; these charts are being prepared by BMR and other palaeontologists. A correlation chart with a set of explanatory notes has been completed for the Cainozoic, incorporating Australian foraminiferal, nannoplankton, dinoflagellate, spore–pollen, vertebrate, and molluscan zones. Similar compilations are under way for the Silurian, Devonian, and Carboniferous. A Cretaceous biostratigraphic compilation is available from work completed earlier for IGCP Project 191. Future work will be aimed at presenting the biostratigraphy of other periods in a standardised format.

The total compilation should provide the basis for an overview of Australian biostratigraphy, highlighting those areas where correlation of Australian sequences with internationally accepted times is poorest. It should provide a focus for future multidisciplinary research involving palaeontology, magnetostratigraphy, and isotopic dating applied to improving the resolution of the time framework of the Australian Phanerozoic.

The palaeogeographic map project is supported (through APIRA) by the following companies: Aberfoyle Exploration Pty Ltd, Amoco Production Co., Ampol Exploration Ltd, BHP Co. Ltd, BP Development Australia Pty Ltd, Bridge Oil Ltd, Chevron Overseas Petroleum Inc., CRA Exploration Pty Ltd, CSR Ltd, Delhi Petroleum Pty Ltd, Esso Australia Ltd, Peko Oil Ltd, Shell Co. of Australia Ltd, and South Australian Oil and Gas Ltd.

For further information, contact Drs Peter Cook or Gerry Wilford at BMR.

Corrigendum

'Red Book'

New Australian distributor

The article 'Uranium — world perspective' (*BMR Research Newsletter* 4, p.12), disclosing the imminent release of the OECD NEA/IAEA biennial publication 'Uranium — resources, production and demand' (commonly referred to as the 'Red Book'), announced that this publication could be purchased from the Australian and New Zealand Book Co. Pty Ltd, which — however — is no longer the Australian agent for OECD publications. The new agent, from which the Red Book and all other OECD publications can be purchased, is D.A. Books (Australia) Pty Ltd, 11–13 Station St, PO Box 163, Mitcham, Victoria 3132; telephone (03)8734411.

Southwest Pacific research cruise

In May 1986 the New Zealand naval oceanographic research ship HMNZS *Tui* successfully completed a five-week research cruise in the Manihiki Plateau–Tonga Ridge region of the southwest Pacific. The cruise was part of the Tripartite II program undertaken by the Governments of Australia, New Zealand, and USA in co-operation with the Committee for the Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC).

The main objectives of the cruise were:

- to investigate the nature and distribution of seafloor manganese crusts and nodules — with particular reference to cobalt enrichment on seamount flanks; and
- to study the structure and stratigraphy of major submarine features of the region.

Sea-bottom sample and geophysical data collection was focused on three areas (Fig. 4):

- Manihiki Plateau and nearby seamounts (Suwarrow, Manihiki, Rakahanga, Pukapuka, and Nassau);
- seamounts (Machias, Capricorn, and Niue) and adjacent abyssal regions on the subducting edge of the Pacific plate; and
- Tofua Trough on the Tonga Ridge.

Sampling was by rock and pipe dredge, gravity and piston corer, and sea-bottom photography. The geophysical work included single-channel airgun seismics, gravity, magnetics, and bathymetry.

Samples were recovered from 72 of the 88 sample sites occupied in water depths of 350–5500 m. About half of the successful dredge hauls produced evidence of manganese either as crusts, coatings, or nodules. The thickest crust (15 mm) was recovered off Rakahanga.

Geophysical data acquisition amounted to 2200 km seismics, 4100 km gravity, and 5200 km magnetics; bathymetry was recorded along all geophysical lines. The high quality of the seismic data is illustrated by a segment of a section (Fig. 5) shot over DSDP site 317.

Computer processing of the geophysical data, and analysis of the samples, are currently in progress. Data interpretation is therefore still at an early stage. Some preliminary results are documented below.

The discovery that only limited deposits of manganese crusts occur on the flanks of seamounts around Manihiki Plateau and to the southwest (east of the Tonga Trench) is contrary to recent speculation (e.g., Cronan, 1984: *South Pacific Marine Geological Notes,* 3.1) that such locations are prospective for economic-grade cobalt-rich crusts.

A new Mn nodule field was discovered in abyssal depths off Nassau Island.

Coralline limestone and basic volcanics recovered from Machias and Capricorn Seamounts indicate that they are sunken atolls with a volcanic pedestal. Subsidence in the order of 700 m is attributed to the seamounts riding the descending Pacific plate into the Tonga Trench. The Capricorn Seamount summit is roughly flat-topped with a dip of about 1.7° towards the trench. The seismic data indicate that the coralline capping is 500 m thick.

The seismic data over Manihiki Plateau are superior to any previously recorded in the region. Stratigraphic and structural detail are clearly resolved in the 1.0-s-thick sedimentary section overlying Lower Cretaceous basaltic basement. Both the basement and the Cretaceous section are intersected by high-angle faults with vertical displacements of as much as 100 m. The sediments are otherwise little affected by structural deformation. Structural development is more pronounced at the plateau margins and in the Suwarrow Trough zone, where large-scale block-faulting with vertical displacements of up to 500 m is evident. In the Late Miocene a major erosion and slumping episode removed up to 250 m of section in places. A uniform blanket of Pliocene–Quaternary calcareous ooze 100 m thick covers much of the plateau surface. Severe erosion by ocean currents has led to the loss of most of the Tertiary section at the northeastern edge of the plateau. A possible active hydrothermal vent was recorded on the plateau west of Manihiki Atoll.

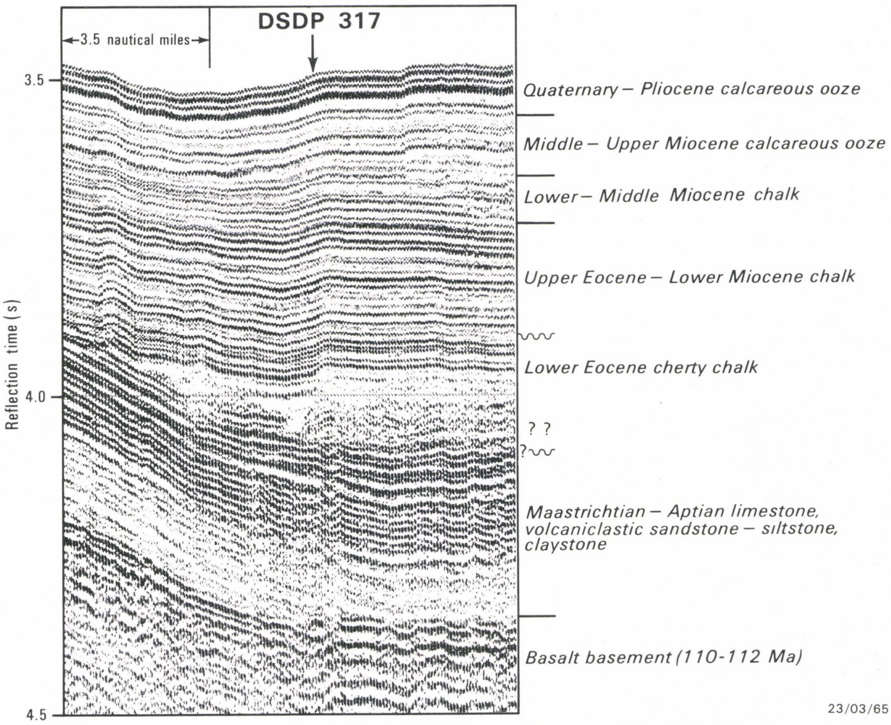


Fig. 5. Seismic section through DSDP site 317 on the Manihiki Plateau.

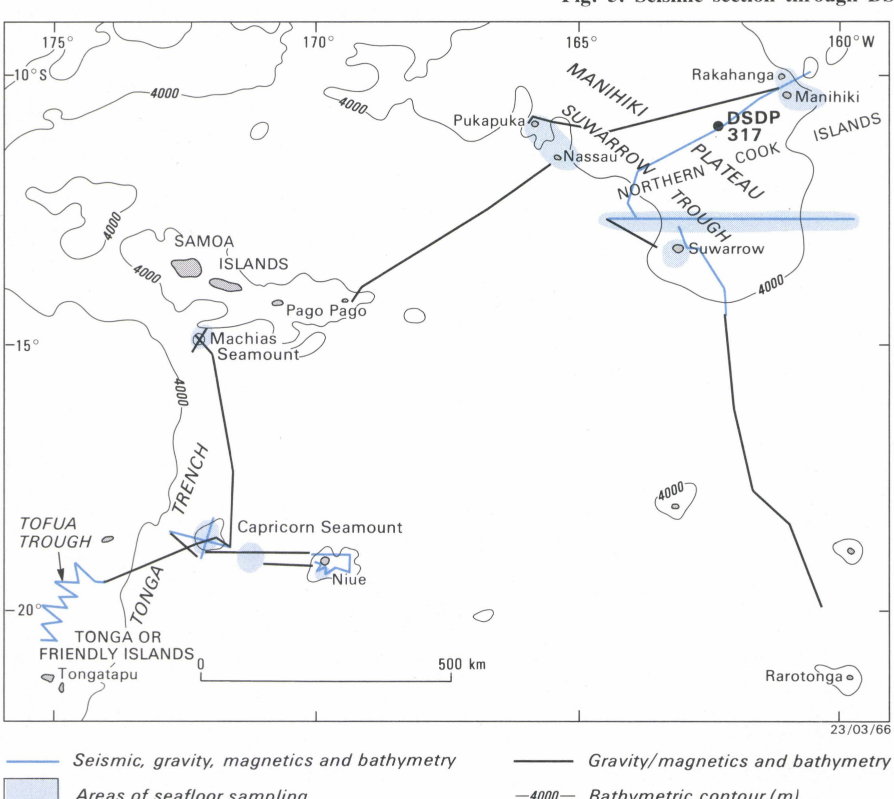


Fig. 4. Survey coverage of the cruise aboard HMNZS *Tui* in the southwest Pacific in May 1986.

Seismic data provide evidence of at least 2.0 s of well stratified sediments within the Tofua Trough. The sediments, thought to consist primarily of volcanic ash and other pyroclastic material, have been sourced by the active Pliocene–Recent Tofua Ridge volcanic chain which forms the western margin of the trough. Intrusions or buried volcanoes are apparent in the section. On the Tonga Platform, to the east of the trough, ?Pliocene–Eocene sediments lie beneath a shallow unconformity and dip gently to the west. The sedimentary section on the platform has a visible thickness of at least 1.0 s. The Tofua Trough/Tonga Platform boundary is defined by normal faults, and dips about 25° to the west.

The final cruise results and interpretations are to be published in 1987 as a special AAPG (Circum-Pacific) cruise volume.

For further information, contact Mr Peter Hill at BMR.

Murray Basin subsurface stratigraphic database

BMR has just issued a subsurface stratigraphic database for the Murray Basin. Published as *BMR Report* 262, it documents the interpreted downhole stratigraphy of 3000 boreholes drilled into the Cainozoic succession of the Murray Basin, an important groundwater basin which underlies 320 000 km² of the semi-arid zone of southeastern Australia. The use of the database is clearly not restricted to groundwater applications, and it has therefore been published for use by other workers in the basin.

Though emphasis has been placed on documenting the distribution of Cainozoic stratigraphic units, the database also contains information about the underlying pre-Cainozoic units. These include Precambrian basement and Adelaidean to Lower Carboniferous metasedimentary, sedimentary, volcanic, and granitoid rocks overlain by thin discontinuous remnants of Permian, Triassic, and Cretaceous sedimentary rocks preserved in poorly defined infrabasins. Brief summaries of both the regional geology and individual stratigraphic units are included in the *Report*.

A major objective of the borehole study has been to establish a basin-wide stratigraphic framework by documenting the regional distribution, geometry, and depositional environments of the Tertiary stratigraphic units and major aquifers of the basin. For this purpose, interpretations of borehole stratigraphy were entered into a computer database established to facilitate the preparation of subsurface maps depicting concealed geology and aquifer geometry in the Murray Basin. The database can be accessed using a number of retrieval strategies, which allow sorting and extraction of data specific to a particular map sheet, stratigraphic unit, or regional aquifer. The major data sets which were generated are tabulated in a series of microform appendices to *Report* 262, and record downhole stratigraphy in individual boreholes, as well as the distribution and thickness of stratigraphic units and aquifers. The microform appendices also contain 28 1:250 000 Sheets showing borehole localities.

Application of the database — an example

An example of automated contouring produced from the database (on an Intergraph graphics terminal; see article on p. 7) shows isopachs of the Geera Clay, an Oligo-Miocene unit consisting mainly of black clay (Fig. 6). This unit forms one of the major aquitards of the basin, and its distribution can be used to explain the occurrence of some groundwater discharge features. It was deposited in marginal-marine, interdistributary-bay, and tidal-flat environments. Palaeogeographic reconstructions of the Oligo-Miocene, based on the borehole study, indicate that these environments were flanked to the southwest by a narrow zone of restricted-marine and lagoonal environments (in which marls accumulated), bordering an extensive shallow-marine platform over which calcarenites were deposited (Fig. 7). Peat-forming swamps and deltaic and fluvial environments

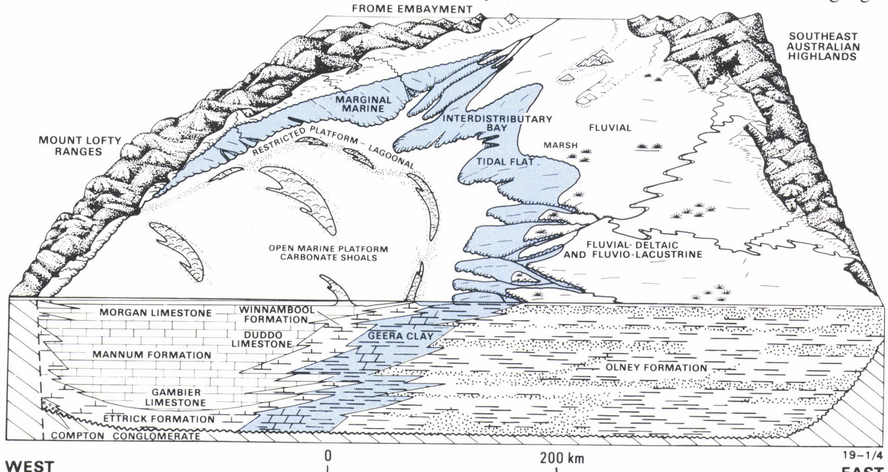


Fig. 7. Miocene palaeofacies in the Murray Basin — a diagrammatic representation derived from information in the subsurface stratigraphic database.

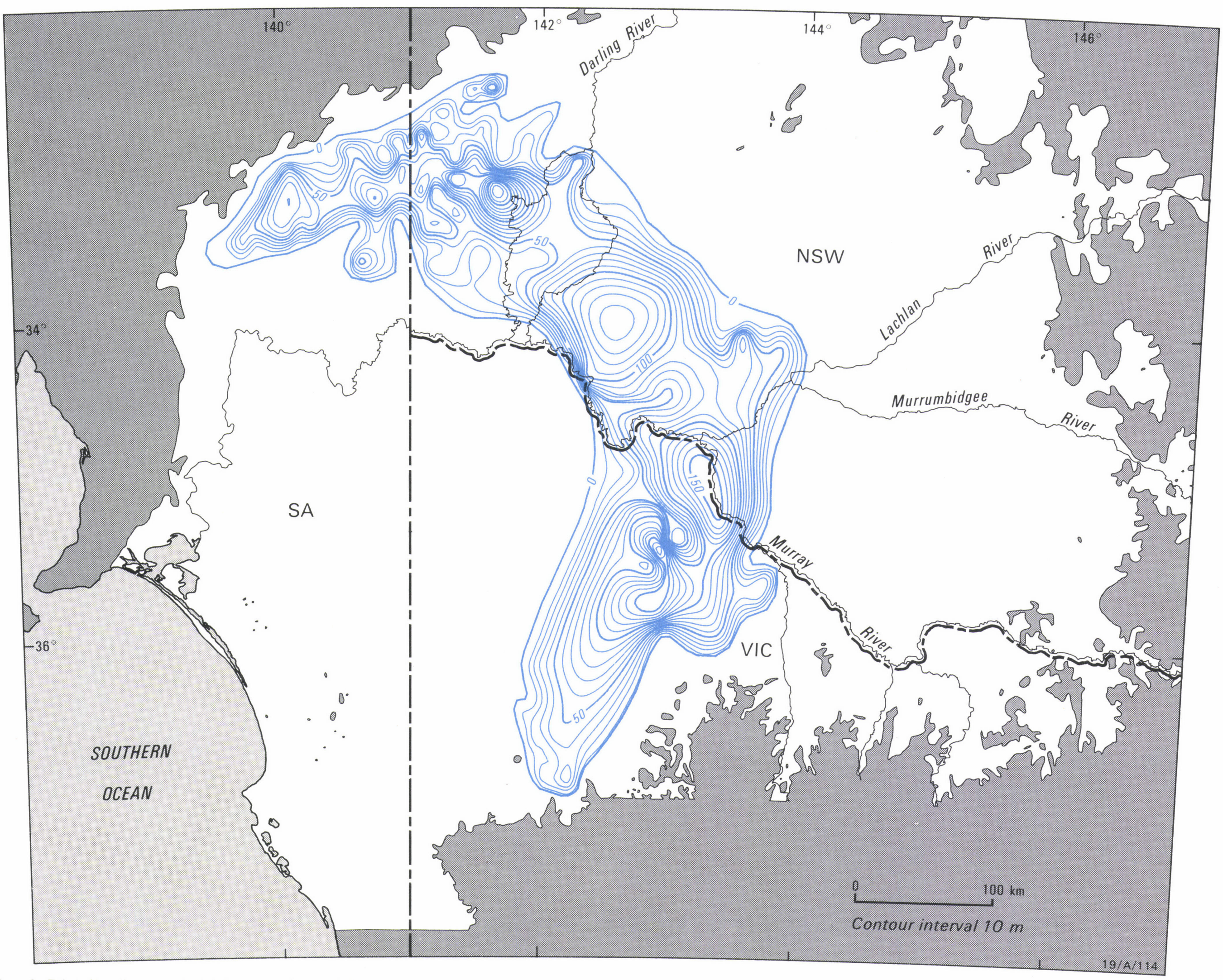


Fig. 6. Distribution and thickness of the Oligo-Miocene Geera Clay from borehole data in the Murray Basin subsurface stratigraphic database.

lay to the north and east of the arcuate zone of deposition of the Geera Clay. The Geera Clay therefore separates fluvial sands of the Olney Formation (Renmark aquifer) in the east and north from calcarenite formations to the west and south (Murray Group aquifer). Because groundwater flows towards the main depocentre of the basin in the central western part of the basin, the permeability barrier created where the Renmark aquifer is stratigraphically truncated by the Geera Clay has resulted in present-day groundwater flow disruption and upward leakage, which find surface expression in a broad band of modern groundwater discharge zones.

Report 262 has been prepared as a contribution to the Murray Basin Hyrogeological Project, a long-term study which is being undertaken by the Division of Continental Geology in conjunction with participating State geological surveys and water authorities. It can be purchased from the BMR Bookshop in Canberra, and Australian Government Publishing Service (AGPS) Bookshops in all capital cities. The price is $11.95 (plus postage — 275 g).

For further information, contact Mr Campbell Brown at BMR.

BMR's P&MR Conference

BMR's Petroleum and Minerals Review Conference will be held at the Australian Academy of Science building, Canberra, on 18–19 March 1987.

The conference is designed to provide participants with a broad overview of and outlook for the petroleum and mineral industries.

For further information, contact Mrs Evelyn Young at BMR.

Towards the integration of image processing and computer graphics in BMR

Contrasting scales and projections of various data sets (e.g., geological, geochemical, and geophysical maps, and remotely sensed images) have in the past posed difficulties in applying the data satisfactorily to planning strategies for petroleum and mineral exploration programs. Now, however, these same data sets can be merged into a digital geoscientific database in which the data are stored, processed, correlated, and interpreted in soft-copy form (i.e., on a high-resolution colour TV monitor screen). Data in this form can be quickly combined and displayed at an appropriate scale, and projected in the form of multiple-theme images. Hard copy would be produced as a multiple-theme solution to a problem, rather than as another single-theme map.

This capability has evolved as a result of the recent development of suitable computer-graphics and image-processing hardware for data capture, processing, and display. This development enables the data in microcomputer-hosted databases to be transferred directly to a mainframe-computer-hosted database, then linked with a graphics database; thus, the results of an interrogation of the mainframe-computer database can be displayed graphically, and a report of these data can be generated by selecting a graphic element. Another significant development is the ability of both computer-graphics and image-processing systems to accept — with limitations — both vector and raster data for display and processing: traditional vector-processing (computer-graphics) systems can now do simple processing of raster (image) data, and vice versa.

These developments exceed the capabilities of the Comtal colour-image-processing system that BMR bought in 1980. This system has served BMR well. It has been used in the application, processing, and display of a large variety of data types — including satellite-scanner, airborne-scanner, digital terrain, geophysical, geochemical, and geological data.

The Comtal system is currently being used almost exclusively for processing the data resulting from the US/Australia Joint Scanner Project, which acquired airborne-scanner data aboard the NASA C–130B (Hercules) aircraft carrying three state-of-the-art remote-sensing instruments (see *BMR Research Newsletter* 4, pp. 14–15). Preliminary results indicate that over the BMR target sites the instruments can greatly assist with the subdivision of volcanic units (Eastern Creek Volcanics in the Mount Isa Inlier), the differentiation of basic and ultrabasic components of igneous complexes (Munni Munni Complex in the Pilbara Block), and the detection of phosphatic rocks (Duchess, Qld). To make the most of these data, BMR needs access to a more advanced image-processing and computer-graphics facility.

The acquisition of such a new facility is already planned. Specifications of the image-processing component of the facility include a minimum of six user workstations together with a high-resolution digitiser and image writer. The heart of the computer-graphics component of the facility will be the Intergraph hardware which BMR bought in 1985 (see *BMR Research Newsletter* 3, p. 17). This hardware comprises an Intergraph workstation, digitisers, pen plotters, and graphic screens; it will be supplemented by the acquisition of four further workstations, a terminal for the review and development of software, an output colour plotter, and a matrix camera for generating slides. These devices for both applications will be distributed across two or more minicomputers linked to the BMR computer network. Purchase of the computer-graphics hardware is programmed for the present fiscal year, and the image-processing component should be in operation by the end of 1987.

The monetary value of data collected by BMR over the past 40 years is difficult to calculate but must be of the order of hundreds of millions of dollars. The new image-processing/computer-graphics facility will enable BMR users to integrate these data more efficiently and cost-effectively. When linked to the new BMR computer (see article on p.2), the new facility will provide users in BMR with even more processing 'muscle'. This will benefit a wide range of existing and future BMR projects — including basin analysis, studies of metallogenic provinces, hydrogeological studies, regolith studies, and the production of associated maps. The linking of databases with computer graphics will make the facility even more useful, because the user will be able to readily check on individual data points to establish their reliability, determine what other data are available, or add new data. A simple example of the application of this technology in BMR's hydrogeological studies in the Murray Basin is documented on p.6.

For further information, contact Messrs Bob Moore or Steve Holliday at BMR.

Woodlark Triple junction

Sonar imagery from a spreading back-arc basin

A joint study of the Woodlark triple junction by members of the Hawaii Institute of Geophysics, the BMR Divisions of Marine Geosciences & Petroleum Geology and Petrology & Geochemistry, and the ANU Department of Geology is examining the active Woodlark Basin spreading centre, and the consequences of its subduction beneath the Solomon Islands volcanic arc.

The work involves the acquisition and interpretation of side-scan-sonar imagery (part of which is shown in Fig. 8) and complementary bathymetric, seismic, magnetic, and gravity data. The data were collected in December 1985 during a research cruise by HIG's RV *Moana Wave,* on which Dr B. Taylor (Hawaii Institute of Geophysics) and Dr K.A.W. Crook (ANU) were co-chief scientists. The imagery was obtained by SeaMARC II, a state-of-the-art system that provides a real-time image of a 10-km swath across the sea-floor. Simultaneously a topographic image is produced, colour-coded according to elevation.

Preliminary analysis of the imagery (Fig. 9), in water depths of 2500–4000 m, has identified many important tectonic features related to the complex plate boundaries in the vicinity of this triple junction between the Pacific, Australian, and Solomon Sea plates. Parallel scarps related to the formation of oceanic crust at spreading centres occur both east and west of the Simbo Fracture Zone. Those to the east lie on the flanks of the Ghizo Ridge, the crest of which appears to mark part of the active spreading centre between the Australian and Solomon Sea plates. The boundary between these plates passes westwards into the Simbo Fracture Zone, which is a transform fault within a major topographic feature — the Simbo Ridge — surmounted by several small volcanic cones.

A peculiar feature of the area is the presence of major volcanic centres on spreading basalts southwest of the Pacific plate boundary, a subduction zone; the volcanics are andesites and dacites typical of island arcs, instead of the ocean-ridge basalts characteristic of spreading centres. The volcanic centres are on the island of Simbo, at the northern end of the Simbo Ridge, and the eastern end of the Ghizo Ridge (where Kana Keoki and Coleman submarine volcanoes, not shown in Fig. 8, are covered by other imagery collected during the survey). The newly discovered Coleman volcano is a perfect cone, and may be dormant. Samples from some of these volcanic centres were collected on a research cruise in 1982, in which the same institutions and scientists participated. That cruise was part of the Tripartite Marine Geoscience Program, aimed at assessing seabed resources and geological hazards in the Exclusive Economic Zones of southwest Pacific island nations.

The 1982 cruise had revealed the need for a more detailed survey of the triple-junction region, and its potential for contributing to an understanding of arc and fore-arc magmatism, the thermal and metallogenic consequences of spreading-centre subduction, and seismic and volcanic hazards. Amongst other things, the detailed survey confirmed the absence of any volcanic edifice at the site of the elusive Cook submarine volcano.

The accurate location of spreading centres and fracture zones has set the scene for camera and dredge surveys like those carried out in the Manus Basin by RV *Moana Wave* immediately after the Woodlark Basin survey. The Manus Basin study revealed the presence of hydrothermal chimneys on an active spreading centre in an overall setting not unlike that of the Woodlark Basin (Both & others, 1986: *EOS*, 67(21), 489–490). Such chimneys are likely to be present in the Woodlark Basin, and any polymetallic sulphides associated with them could prove to be long-term mineral resources.

For further information, contact Dr Neville Exon or Dr Wally Johnson at BMR.

Fig. 8. Greatly reduced side-scan-sonar imagery of the Woodlark triple junction. Highly reflective areas such as scarps and lava flows appear black, and sediment-covered areas appear pale grey.

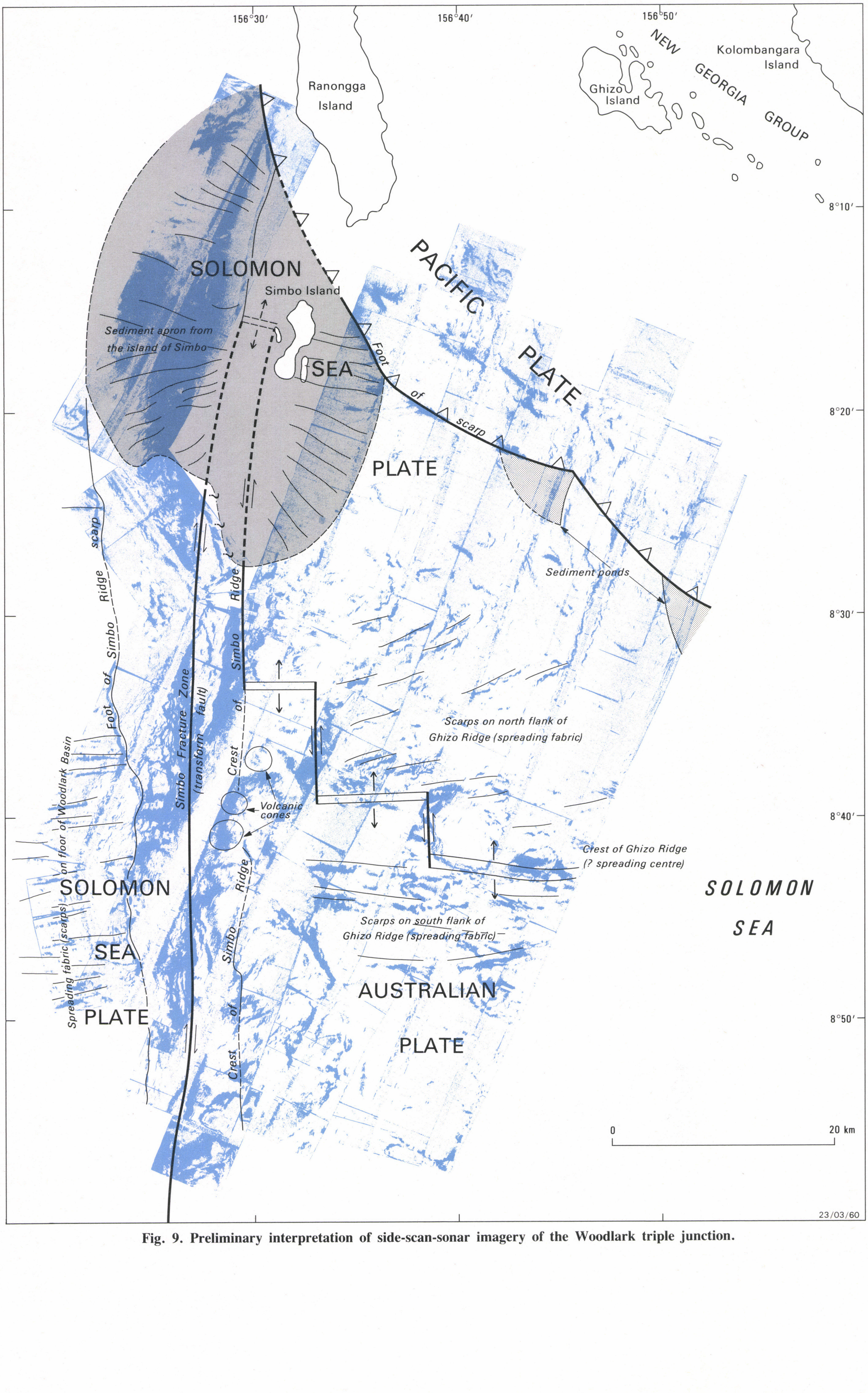


Fig. 9. Preliminary interpretation of side-scan-sonar imagery of the Woodlark triple junction.

Marine heatflow

A new field for Australian marine geoscience

While measurement of the quantity of heat flowing out through the ocean floor may appear to be a rather esoteric exercise, such data are actually very useful when taken in conjunction with other geological information. The two primary objectives of recording such data are to assess the thermal history of sediments and hence to refine estimates of hydrocarbon potential, and to elucidate the importance of different tectonic processes in the geological evolution of an area.

Until recently, all the heatflow data recorded from Australian waters had been acquired by foreign institutes; most of these data are from oceanic crust. In addition to these data being sparse, they were also widely scattered, permitting no more than generalised interpretations (Cull & Conley, 1983: *BMR Journal of Australian Geology & Geophysics*, 8, 328–337).

In late 1985, the Division of Marine Geosciences & Petroleum Geology purchased a state-of-the-art digital thermal gradient measuring probe. At the same time, existing equipment was assembled or modified in BMR to enable the thermal conductivity of the bottom sediments to be measured (heatflow being the product of the thermal gradient and the thermal conductivity). The deployment of RV *Rig Seismic* from Townsville to Fremantle in early 1986 provided the opportunity to thoroughly test the new equipment, and to acquire heatflow data systematically on thinned continental crust in two priority areas of the Division's program — the western Coral Sea and the Exmouth Plateau (Fig. 10). The cruise objectives were largely realised, and, as a result, the existing Australian marine heatflow database was increased by more than 40 per cent.

Examination of the data reveals that the average heatflow in both areas studied (~60 mW m^{-2}) is close to the world average. In the Queensland Trough, the data show a general correlation with the sedimentary basins of the trough: the higher values are recorded over shallow basement, and lower values are recorded at the depocentres. Data from the Exmouth Plateau show a greater range than the Queensland Trough data, and a general correlation with the gross geological structure. The heatflow along a dip-line transect appears to vary from high in the Montebello Trough (an aborted rift), to low on the eastern side of the Exmouth Plateau Arch, before rising again towards the northwest continental margin (Fig. 11). Geohistory analysis (Falvey & Deighton, 1982: *APEA Journal*, 22(1), 65–81) of the Exmouth Plateau heatflow and well data is currently under way with the aim of producing a refined estimate of the hydrocarbon potential.

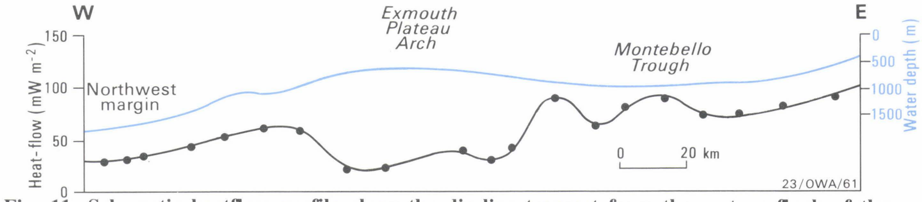


Fig. 11. Schematic heatflow profile along the dip-line transect from the eastern flank of the Montebello Trough to the northwest margin of the Exmouth Plateau.

With the expertise that has now been gained in heatflow equipment and data handling, the measurement of marine heatflow is now a routine operation on most RV *Rig Seismic* cruises. New heatflow data have recently been acquired from the north Perth Basin, and an extensive program will be undertaken (in co-operation with the Geological Survey of Japan) on the second southern margin cruise in November–December 1986.

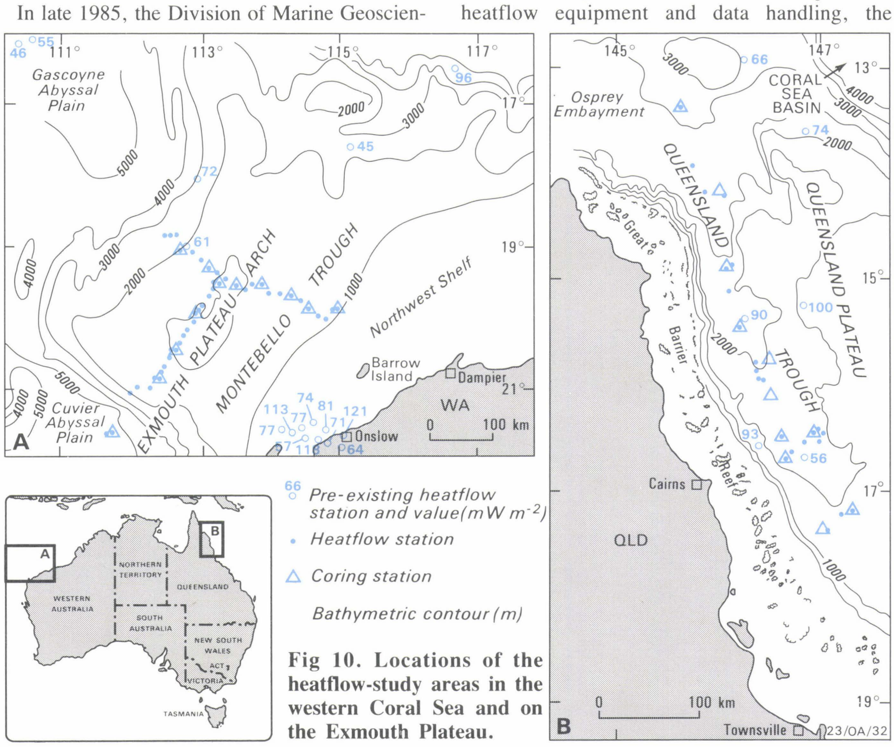


Fig 10. Locations of the heatflow-study areas in the western Coral Sea and on the Exmouth Plateau.

In addition to the routine measurement of heatflow on RV *Rig Siesmic* cruises around Australia, future research will be focused on two other pursuits — equipment research and development, and the measurement of shallow-water heatflow. Recently, BMR and Amalgamated Wireless Australia (AWA) submitted a joint proposal to NERDDC to obtain financial support for the development of a high-quality heatflow meter. The prototype heatflow meter will be capable of real-time acoustic telemetering of data to the surface and in-situ thermal conductivity measurements, and will also have a long-term measurement capability. The ultimate objective is to manufacture in Australia a heatflow system with world-wide export potential.

Studies will be applied to solving the technical and theoretical problems associated with the measurement of heatflow in shallow water (i.e., continental shelf), the prime area of industry exploration. During the Otway–Bass–Gippsland cruise of RV *Rig Seismic* planned for early 1987, we plan to carry out a variety of experiments in the measurement of shallow-water heatflow, including the use of a vibro-type probe system and continuous measurement of thermal gradient for a period up to one month.

For further information on this project, contact Dr Dong Choi, Mr Howard Stagg, or Mr Mike Swift at BMR.

Stable isotopic evidence for high rates of organic carbon accumulation in the Late Proterozoic

Carbon-isotope trends in carbonate strata can be used to identify periods characterised by high rates of accumulation of organic matter, which should correlate with good hydrocarbon source rock potential. While Proterozoic basins are traditionally viewed as too old to have sourced major oil or gas deposits, such isotopic data imply that the Late Proterozoic was a period characterised by unusually organic-rich sedimentation.

Marine carbonates commonly have $\delta\,^{13}C$ values close to 0‰, while organic carbon in sedimentary strata generally has $\delta\,^{13}C$ values 25–30‰ lower. If the carbon input to the oceans is more or less constant, variations in the proportions of it being sequestered in the carbonate and organic-carbon reservoirs will cause changes of mean $\delta\,^{13}C$ values for the oxidised and reduced carbon phases, without altering the isotopic fractionation between these phases ($\delta\,^{13}C_{carbonate} - \delta\,^{13}C_{organic} = \Delta\,^{13}C =$ 25 to 30‰. For example, increased rates of accumulation of organic matter on a global scale (higher mean organic carbon/carbonate ratios) will result in increased $\delta\,^{13}C$ values for carbonate. Also, anomalous $\delta\,^{13}C$ carbonate values may develop locally during diagenetic cementation of organic-rich sediments: unusually positive $\delta\,^{13}C$ values can be generated in zones of bacterial methanogenesis, while variably negative $\delta\,^{13}C$ values can result in near-surface zones of bacterial oxidation and sulphate reduction; in these situations, $\delta\,^{13}C$ values can be highly variable.

There have been numerous carbon-isotope studies of Phanerozoic carbonate strata, but the database for Proterozoic sequences is generally poor. However, a series of recent studies, several of which have involved staff of the Baas Becking Geobiological Laboratory, indicates that anomalously positive $\delta\,^{13}C$ carbonate values are features of Upper Proterozoic sequences.

In Riphean sequences from the north Atlantic (Svalbard and east Greenland), a combination of generally elevated $\delta\,^{13}C$ values up to 10‰ and fairly constant $\Delta\,^{13}C$ values (average 28.5‰) implies preservation of primary isotope compositions generated in a period characterised by high rates of accumulation of organic carbon on a global scale.

Vendian carbonates studied from several countries have variable proportions of high $\delta\,^{13}C$ values. With very few exceptions, the carbonates analysed from the Yangtze Gorges sections near Ichang (People's Republic of China) have δ ^{13}C values between 1 and 7‰. Associated kerogens also have variable carbon-isotope compositions, and Δ ^{13}C values range up to 37‰. These data imply that primary isotope compositions have been masked by diagenetic carbonate cements generated from ^{13}C-enriched bicarbonate in pore waters after bacterial methanogenesis. The best approximation of the δ ^{13}C values for primary carbonates in this sequence should come from the organic-poor beds. These have mean δ ^{13}C values of about 3‰ near the base and 2‰ near the top of the Vendian sequence.

The other uppermost Proterozoic sequences analysed, in Siberia and Morocco, also contain anomalously ^{13}C-enriched carbonates, though in lower relative abundance than in the Yangtze Gorges sequence.

The results of these carbon-isotope studies indicate that organic-rich sedimentation occurred on a global scale in periods of the Late Proterozoic. A corollary to the results is that unmetamorphosed basin sequences of this age could contain, or have sourced, major oil and gas deposits. The abundance of benthic microbial communities (many preserved as stromatolites), plankton diversification, absence of burrowing organisms, and rift-related tectonic settings may have been important factors contributing to the high levels of organic matter buried in Upper Proterozoic strata. Rapid negative δ ^{13}C shifts in the Proterozoic–Cambrian boundary beds may reflect decreased rates of burial of organic matter and/or greater oxidation of organic carbon. This could have resulted, at least in part, from the evolution of animals capable of effective sediment bioturbation.

For further information, contact Dr Ian Lambert, Dr Malcolm Walter, or Mr Terry Donnelly (Baas Becking Geobiological Laboratory) at BMR.

The notion and motion of the Australian lithosphere

The term 'lithosphere' originates from the Greek roots *litho* meaning rock and *sphaira* meaning sphere or ball, and was originally coined by Dana in 1896 to define the rigid and stony outer shell of the Earth. Since then, the term has been used and abused in a number of ways. One of the reasons for the abuse comes from our knowledge of the plate tectonic model and our acceptance of oceanic lithosphere as the type example of a lithospheric plate: oceanic lithosphere is created at ridge crests, transported across the ocean, and subducted at trenches. This is a simple concept, easy to visualise.

Continental lithosphere, however, is not so easily visualised. Continents are generally very old and evolved; they have upper mantle roots which can be very complicated. The refractory roots generally consist of rocks depleted by the removal upwards of silicate melts, and there is no reason to suppose that the roots correspond to the outer rigid shell of the Earth, although this is a popular misconception. Compared with oceanic lithospheric plates, the continental lithosphere is not simply thicker with a different kind of crust, and does not behave like the oceanic lithosphere in the plate tectonic model.

Continents as boundary layers

Jordan (e.g., 1981: *Philosophical Transactions of the Royal Society of London,* A301, 359–373) described continents as a chemical boundary layer (cbl), comprising the crust and the uppermost mantle depleted by the upward removal of partial melts. The depleted mantle is less dense than the surrounding undepleted mantle. Consequently, it is unable to remix with the rest of the mantle, and remains fixed to the base of the continents for millions, probably billions, of years, as evidenced by the isotopic ages of both nodules in volcanic rocks and inclusions in diamonds from kimberlitic intrusions in Precambrian regions.

The base of the cbl usually lies well below the base of the strong outer part of the Earth — Jordon's mechanical boundary layer (mbl) — which can support surface loads by flexure and is probably the closest modern-day analogue to Dana's original concept of the lithosphere. In areas of partial melting, the base of the mbl will lie above the zone of partial melting. In other areas, the thickness of the mbl will be controlled by the temperature-dependent viscosity of rocks and the geothermal gradient; mantle rocks lose their rigidity between 900 and 1300°C.

The thermal boundary layer (tbl) is the region where heat transfer occurs mainly by conduction. The mantle within the tbl does not convect, although some heat transfer no doubt results from the flux of incompatible elements from deep in the mantle.

The boundary layers all influence the formation of natural resources. The mbl controls the response of the outer part of the Earth to stresses — thus, it determines the nature of sedimentary basins. The cbl is the source of mantle-derived rocks and minerals — including diamonds — at the surface. The tbl controls mantle heat flux to the surface; heat is an important ingredient in many mineralising and tectonic processes.

The boundary layers of the Australian continent

Within the Australian continent, estimates of the depths of the three boundary layers can help to place the Australian lithosphere and upper mantle roots into a plate tectonic framework.

Seismic models provide a basis on which to build an understanding of the continental upper mantle. A low-velocity layer occupying depths of about 120 to ~190–200 km in eastern Australia has no equivalent above 250 km below the shield areas in the west. Low-velocity layers are traditionally interpreted as zones of partial melting, which reduces the shear modulus of a rock causing a lower seismic velocity. The reduction of the shear modulus has more effect on the shear-wave velocity than the compressional-wave velocity, as observed in eastern Australia. The top of the low-velocity layer, representing as it therefore probably does a drop in shear strength, may be interpreted as the base of the mbl. If so the mbl is substantially thinner under eastern Australia (<120 km) than it is under the west (at least 250 km).

The differences in seismic character between east and west correlate with differences in heat flux. Heat flow in the shield areas is generally below world average; in eastern Australia it is equal to or greater than world average. Geothermal gradients are therefore higher in the east. Nodule geothermobarometry and downward extrapolation of surface gradients in eastern Australia suggest that temperatures of 900–1300°C occur at depths between 50 and 100 km. In the shield areas, these temperatures are at least 150 km deep. Thus the tbl, like the mbl, is apparently thicker in the west than in the east.

In eastern Australia, recent alkaline volcanics originate from a refractory source, and possibly represent the partial melt in the low-velocity layer, suggesting that the mantle is being depleted in the cbl at depths of 120–200 km. Because cold depleted upper mantle has a higher seismic velocity than undepleted upper mantle, the high velocities under the shield areas suggest that mantle depletion in the west extends to greater depths than in the east. This is supported by the geochemistry of mantle nodules (originating from depths of 100–200 km) in kimberlite pipes: they are usually refractory in nature, but enriched in incompatible elements which presumably have fluxed upwards from deeper sources.

The notion and motion of the lithosphere

The variable thickness of the three boundary layers across Australia prompts the question of how the Australian continent is decoupled from the underlying mantle. Conventional wisdom would dictate that if the continent is to decouple from the underlying mantle, it would do so in eastern Australia at the base of the mbl, which must lie above or at the top of the low-velocity zone. However, the mantle within the low-velocity zone is refractory but enriched in incompatible elements from below; it is not pristine upper mantle, and nor is the mantle under the low-velocity zone. It must have underlain the continent for some time. This suggests that the continent is not moving relative to the low-velocity zone in eastern Australia; rather, the low-velocity zone is moving with the continent. The apparent great depth of depletion of the mantle under the shield areas suggests that the upper mantle to depths of several hundred kilometres is moving with the continent in the west.

The notion of a continental lithospheric slab — a mechanical boundary layer overlying a weaker substratum — decoupling from the upper mantle is not supported by the available data. Although we may define a rigid outer shell in Australia it is not uniform in thickness. Nor is it related in any sense to the plate tectonic process. Instead, the continent has a root hundreds of kilometres thick, and even though the root may be weak and soft, as indicated by the low- velocity layer in the upper mantle in southeast Australia, the continent has been carting it around the globe for many millions of years.

For further information, contact Dr Barry Drummond at BMR.

Computer modelling for gold tax inquiry

The Resource Assessment Division of BMR was requested by the Inquiry into the Taxation of Gold Mining to carry out financial computer modelling of several hypothetical gold mines.

The work entailed determining cost structures for four different models: an underground mine, a large open cut, a medium open cut, and a tailings recovery operation. From this cost structure, we determined a mine head-grade that would yield a discounted cashflow rate of return (DCFROR) of 18% for each model; assessed the effects of the changes in DCFROR caused by imposing a tax on these models; and calculated the required head-grade that would bring each model back to 18% DCFROR with an imposed tax.

Making an assumption about the distribution of gold values within the hypothetical orebodies for the three hard-rock mines enabled us to develop grade/tonnage curves, from which we could calculate the gold ore reserve at particular cut-off grades for each mine. From these curves, we estimated the minimum loss of tonnage of gold ore and gold metal for each mine when the cut-off grade was increased to maintain profitability after the imposition of the tax.

A further study considered what the effects on profitability would be for the three hard-rock mines with similar ore-grade distributions and higher mine head-grades if (1) the annual production rate were unchanged but the duration of the operation were reduced, and (2) the annual production rate were reduced but the duration of the operation were unchanged.

Additionally data supplied as submissions to the Inquiry, and made available to BMR, formed the basis of several other computations that we did to determine profitability before and after tax.

The Inquiry completed its work at the end of August, when the Chairman — Mr Gerry Gutman — gave his findings to the Federal Treasurer.

For further information, contact Mr Peter Ingham at BMR.

French expeditions to the southern Kerguelen Plateau

BMR scientists accompanied two French geoscientific cruises to the southern part of the Kerguelen Plateau (south of Heard Island) in January–March this year. The objective of these expeditions — MD47 and MD48, aboard the French supply and research ship NO *Marion Dufresne* — was to provide information essential for the selection of sites for scientific drilling of the plateau, which is scheduled to begin in December 1987. The BMR scientists were invited because most of the investigations were in waters under Australian jurisdiction.

The first cruise — under Roland Schlich, Director of the Institut de Physique du Globe, Strasbourg, and current chairman of the Indian Ocean Panel of the Ocean Drilling Program — gathered 4450 km of multichannel and 1450 km of single-channel seismic reflection, magnetic, and gravity data; the second cruise – under Lucien Leclaire, Director of the Geological Laboratory of the Museum National d'Histoire Naturelle, Paris — gathered 2700 km of single-channel seismic and magnetic data, several hundred metres of sediment cores from 16 sites, and 4–5 t of rock from eight dredge sites (Fig. 12). These included the first rock samples collected from outcrop on the southern part of the plateau. Both cruises used as a basis for their planning the multichannel seismic reflection data collected by BMR in 1985 (Ramsay & others, 1986: *BMR Report* 270).

Previous investigations had established the presence, on the eastern flank of the southern part of the plateau, of a large deep sedimentary basin (Raggatt Basin; Fig. 12; *BMR Research Newsletter* 3, p.3) with more than 2 s (two-way travel time, twtt) of sediment; had located an area of exposed basement on the western flank of the plateau (on the Banzare Bank); and had identified a boundary beyond the eastern margin of the plateau between deeper (presumably older) oceanic crust and shallower (presumably younger — Eocene) oceanic crust of the Southern Ocean.

First cruise

The first of the 1986 French cruises was designed to complement the 1985 *Rig Seismic* work. Multichannel seismic lines tied the *Rig Seismic* lines in the Raggatt Basin and extended data coverage to the south. The areal extent of the Raggatt Basin is now better defined; the basin trends south-southeastwards for about 500 km to just south of 60°S. Two sonobuoy experiments indicated that the maximum sediment thickness in the centre of the basin exceeds 3.5 km. North of the basin, the plateau has a complex faulted structure. West of the basin, the area of basement exposure on Banzare Bank was found to be more extensive than previously thought, and to have seismic velocities in the range 4.8–5.0 km s^{-1}.

The existence of a continuous fault-bounded ridge (Williams Ridge, previously Williams Seamount) on the northeastern margin of the plateau was confirmed by single-channel seismic data and bathymetry. The deep ocean basin (Labuan Basin) to the east of the southern plateau was further delineated by multichannel seismic data. The basin, a possible conjugate to the Diamantina Zone, is in faulted contact with the southern Kerguelen Plateau. Its northeastern boundary (southeast of Williams Ridge) is defined by a roughly 2 s offset in basement depth. An abyssal channel parallels the East Kerguelen Sediment Ridge at the base of the eastern flank of the southern part of the plateau.

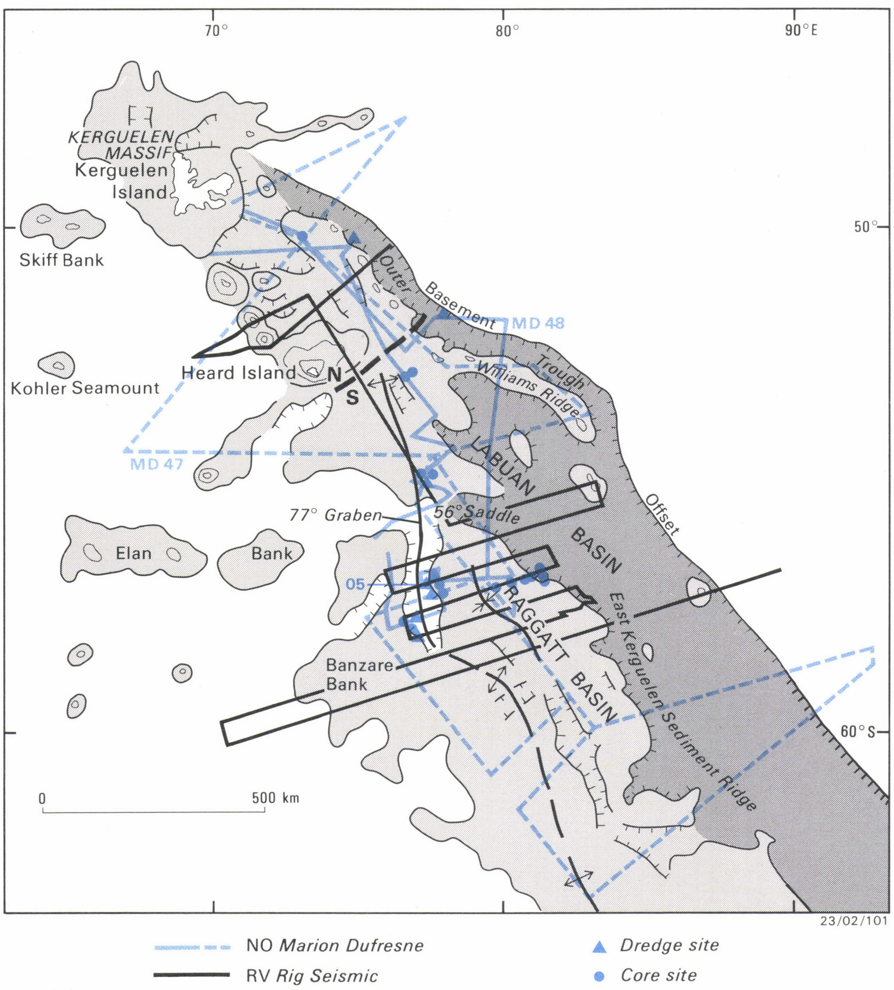


Fig. 12. Kerguelen Plateau region: ships' tracks and sample sites, and major structural elements determined from SEASAT-derived gravity data and from seismic reflection data collected by the Lamont–Doherty Geological Observatory in the 1970s and BMR in 1985. The light screen indicates elevated areas; the heavy screen indicates deep basins adjacent to the eastern flank of the plateau. The thick dashed black line is the boundary between the contrasting northern and southern parts of the plateau.

Second cruise

Previous geological investigations, mostly in the northern sector of the plateau between Heard and the Kerguelen Islands, had established the presence of Upper Cretaceous (Maastrichtian), Paleocene, and Eocene pelagic oozes — about 1 s (twtt) thick — unconformably overlain by a Neogene–Quaternary section — also about 1 s (twtt) thick — of partly volcanogenic sediment with remarkable large-scale current-bedding features. No Upper Eocene or Oligocene sediments had been cored, and no basement samples recovered.

Fig. 13. A small quantity of conglomerate was recovered with much submarine lava and lava breccia in dredge 05 from a depth of 2200 m on the eastern flank of the 77° Graben at latitude 58°S. The conglomerate comprises cobbles of lava, lava breccia, and rare chert in a partly exsolved matrix of white bioclastic limestone; the matrix includes fragments of corals and small bivalves. The conglomerate and the composition of the matrix are evidence of shallowing and partial emergence of the Kerguelen Plateau, probably in the mid-Tertiary. The photograph is of a cut face of specimen MD48DR05.07, reproduced at twice true scale.

On the second cruise, coring into the southern part of the plateau by the French team, in conjunction with BMR seismic data, established the presence of a similar geological environment. The main difference is the evidence of considerable erosion of the Neogene–Quaternary section in the south (whether entirely submarine or partly subaerial is not known), and the general thinning of this section to 0.2–0.3 s (twtt). The partial erosion of the Neogene cover enabled us to sample the Palaeogene and Upper Cretaceous strata. However, erosion was nowhere sufficient to expose the deeper sediments of the Raggatt Basin, which remain a prime target for scientific drilling.

One of the cores penetrated several metres of Quaternary foraminiferal ooze, and bottomed in a gravel horizon composed of pebbles of volcanic, granitic, and metamorphic rocks; the gravel horizon almost certainly represents ice-rafted material. Similar pebbles were collected by free-fall grab during the BMR operations in 1985 (Ramsay, Colwell, & others, 1986). Another core — in unfossiliferous, probably Paleocene sediment — encountered five successive horizons of large (90-mm diameter) spherical MnO nodules, indicators of low rates of sediment accumulation.

Dredging was concentrated on escarpments flanking an axial graben (77° Graben; Fig. 12), and two stations were sampled on the northeastern margin of the plateau. In the course of the dredging program, the graben was traced northwards, and was shown to be 500 km long.

Most of the eight dredge sites yielded altered basaltic volcanic rocks, which included massive lava, intensely amygdaloidal lava (amygdales to 2 cm), possible pillow fragments, and lava breccia with finely recrystallised calcareous matrix. Several sites disclosed evidence of shallowing in the mid-Tertiary: thus, one site yielded blocks of massive bioclastic limestone, and others a conglomerate of volcanic pebbles in a matrix of bioclastic material which includes fragments of coral, crinoid stems, echinoid spines, and benthonic foraminifera (Fig. 13); preliminary examination of the matrix in one sample (by D.J. Belford of BMR, and D.W. Haig of the University of Western Australia) indicates that it is no older than Miocene. Chert with interbedded dolomite sampled at one site may coincide with a strongly reflective horizon apparent in the BMR seismic data. Boulders of volcanics were collected from both sites on the northeastern margin, one of which yielded a 1-t boulder of phlogopite gabbro that probably originates from a subvolcanic stock: the K–Ar age of the phlogopite is 13.1 Ma (AMDEL Report G6741/86). Most sites also yielded ice-rafted exotic blocks and boulders of granite and metamorphic rocks.

Interpretation

Geological data from these and preceding cruises indicate that the basement of the plateau is at least as old as Late Cretaceous (Maastrichtian); indeed, the thick sequence of probably pre-Maastrichtian sediment in the Raggatt Basin suggests that it is older. Geological, magnetic, and sonobuoy refraction data suggest that the basement is volcanic, but do not preclude the possibility that the volcanic rocks overlie rifted continental crust. The volcanics sampled are basaltic, but have high TiO_2 (2%) and moderate K_2O, and are thus more akin to volcanic-island or off-ridge basalts than mid-ocean-ridge basalt (rock chemistry from R.C. Price, La Trobe University).

Much of the southern part of the plateau has the form of a north-northwesterly oriented elongate swell with a central axial graben, and inward-facing half-grabens on each flank — a structure such as might develop at an incipient rift. Some of the faults appear to have been intermittently active through the Cainozoic to the present day. The dredged rocks indicate shallowing, and probable emergence, of parts of the plateau in the mid-Tertiary, followed by subsidence since the Miocene.

Matters arising — 1985 and 1986 cruises

The 1985 BMR investigation of the Kerguelen Plateau was directed at determining the petroleum potential of the southern sector, which is under Australian jurisdiction; data from this cruise will be released to the public in April 1987. Data and samples from the two French cruises are being studied currently in France and Australia, and results will be released in due course by the French chief scientists. Preliminary results have been incorporated in a joint Australian–French proposal for scientific drilling under the Ocean Drilling Program; the proposed drilling will investigate the age, origin, and evolution of the plateau, and palaeo-oceanography of the Southern Ocean.

Further information on BMR Kerguelen Plateau data can be sought from project leader, Mr Jim Colwell; on the geophysical and geological cruises of the NO Marion Dufresne, *from Drs Mike Coffin and Hugh Davies respectively; and on Ocean Drilling Program plans for the region, from Mike Coffin.*

Global Geosciences Transect Project

Several initiatives for international co-operation in the geosciences were discussed in Washington, DC, in February at meetings which Professor Roye Rutland attended as a member of the Research Advisory Board of the International Union of Geological Sciences (IUGS).

One of these initiatives — for a Global Geosciences Transect Project — follows a recent restructuring of the International Lithosphere Program for a second five-year term under its joint IUGS–IUGG (International Union of Geodesy and Geophysics) sponsorship. This initiative, arising from the successful North American Continent–Ocean Transect Program (undertaken as part of the Decade of North American Geology project sponsored by the Geological Society of America in celebration of its centennial decade, 1979–1988), proposes that an international effort be made to co-ordinate similar programs world-wide, potentially involving 200 transects.

Key features of the North American transects are that they investigate corridors up to 100 km wide, that they link together the geology of continental and oceanic crust, and that they combine all available geological and geophysical information to produce sections down to the Moho.

In the light of already completed and planned seismic reflection work, and of recent developments in terrane analysis, considerable interest is likely to be expressed in transects across the Tasmanides, which would be most closely analogous to the transects studied in North America.

The North American transects were essentially limited to Phanerozoic orogens, but the Global Geosciences Transect Project proposes that shield areas be studied as well. The project is designed to produce compilations of existing data acquired, in most cases, for other purposes. An important object is to facilitate comparison of the crust and lithosphere in various parts of the world by adopting common methods and standards of presentation.

The approach adopted for the North American program may have to be modified considerably to suit it to a study of the shield areas, where the available data are sparser, the basement rocks are commonly concealed by young platform cover, and the conceptual framework for interpreting deep structure is not established.

Nevertheless, such compilations, and the intercontinental comparison that they allow, are likely to contribute substantially to our understanding of Precambrian crustal structure and evolution, and assist in evaluating the conflicting tectonic models in relation to mineral occurrence.

The production of such transect compilations in Australia would obviously require input from all sections of the geoscience community and especially the State geological surveys. The existing Lithosphere Transect Studies of Australia Committee (LITSAC) established in relation to the Australian Continental Reflection Profiling (ACORP) program — with its subcommittees in each State — should provide a good basis for the consideration of a more comprehensive Australian program.

For further information, contact Professor Roye Rutland at BMR.

The Australian Bicentenary 1788-1988 ©

Seismic symposium

Preparations are now under way for an international seismic symposium and workshop to be held in Canberra during 1–8 July 1988. The Specialist Group on Solid-Earth Geophysics of the Geological Society of Australia, together with BMR and the Research School of Earth Sciences (ANU), are the major sponsors. This meeting is being planned to coincide with the Australian bicentenary celebrations.

Under the title 'Seismic probing of continents and their margins', the meeting will seek a better understanding of what seismic methods tell us about the geological structure of the continental crust and the processes within it, and how these results influence the search for resources. The meeting is being planned as the third in a series of related symposia, of which the first was held at Cornell University (USA) during 1984 and the second was held at Cambridge University (UK) during July this year.

BMR has a long record of seismic research into continental structures. During the 1960s, when there was still some doubt in sections of the scientific community about whether reflected energy could be recorded from deep structures, BMR recorded excellent reflections from basement thrust features on the northwestern margin of the Ngalia Basin, and from the crust–mantle boundary (Moho) under Mildura in the Murray Basin. Such early examples were used, in part, by US seismologists to support the introduction of the US COCORP project (Oliver & others, 1983: *Journal of Geophysical Research,* 88, 3329–3347), the results of which have changed many ideas about the nature of continental structures and lithospheric processes.

During the 1970s, BMR engaged in a series of seismic projects which included isolated deep reflection probes and wide-angle reflection/refraction investigations of gross crustal structure. As with research groups in other parts of the world, BMR seismologists recognised the desirability of integrating the various seismic methods to provide a fuller understanding of sedimentary basin formation and other processes in the continental lithosphere. This led, in 1980–82, to the first seismic project in the world where multimode seismic techniques were used to examine the deep structure of a major sedimentary basin — the Eromanga Basin. Extensions and improvements to the concept are now being applied internationally in the US PASSCAL program, the Canadian Lithoprobe program, the French ECORS program, and the West German DEKORP program. BMR has extended the Australian deep seismic investigations offshore as part of its 1985–88 series of regional studies of the Australian continental margin, again using multimode seismic recording.

The 1988 Canberra seismic meeting will endeavour to attract contributions from many international research projects, and the organising committee will prepare a program designed to highlight the relevance of such research to the resources of the Australasian/east Asian region.

On 22 April this year, the seismic symposium and workshop received the endorsement of the Australian Bicentennial Authority, recognising that Australian scientific achievements give cause for some form of celebration in 1988. The organising committee will be seeking the involvement of the exploration industry in the meeting by encouraging scientific participation and by sponsorship of leading overseas geoscientists to the meeting.

For further information, and circular, contact Dr Doug Finlayson or Dr Jim Leven at BMR.

Reflections of an Australian's visit to China

Rifts and resources

One way or another, the processes which result in the rifting of the Earth's crust account for a considerable proportion of the world's mineral and hydrocarbon resources. Most models of sedimentary basin evolution involve some form of rifting following a geothermal event deep within the Earth's asthenosphere. Other basins are the result of crustal deformation involving the relative movement of lithospheric plates. Many models of mineral concentration involve processes in continental rifts or at convergent plate margins driven by rifting.

Hence it was appropriate that the International Symposium on Deep Internal Processes and Continental Rifting (DIPCR) sponsored by the Inter-Union Commission on the Lithosphere (ICL) was held during September 1985 in China. There, the dangers of today's active tectonic processes in the form of major earthquakes impinge directly on the most populous country on Earth. The meeting was held in Chengdu, Sichuan Province, in southwestern China, and featured the development by the Chinese of the resources of the Panzhihua–Xichang (Panxi) Rift to the south of Chengdu (Fig. 14). The symposium was followed by a field excursion to the Panxi Rift, and Dr Doug Finlayson from BMR participated in both under the scientific agreement between the Academia Sinica and the Australian Academy of Science.

Fig. 14. Location of Sichuan Province.

Sichuan, the most populous Chinese province (approx. 100 million people) and the home of the giant panda, by any standards must be regarded as one of the world's resource-rich regions. The province's mineral and hydrocarbon resources were the focus of attention at the DIPCR symposium and field excursion. The catalogue of mineral deposits in the Panxi Rift lists Fe, Ti, V, Ni, Cu, Pb, Zn, Nb, Ta, Ce, and La as economic resources. Put these together with the associated coal and salt–gypsum deposits, the oil and gas from the Sichuan Basin (estimated in 1982 to ultimately total 3060 million bbl and 100 billion ft^3 respectively by Meyerhoff & others at the 3rd Circum-Pacific Energy and Mineral Resources Conference), and the enormous potential of the region for hydroelectric power (currently under development) — and they all contribute to a massive heavy-industrial base which could rival any elsewhere in the world.

The oil and gas resources of the Sichuan Basin have been used for some considerable time. Dr Yan Dun-Shih, Chief Geologist of the Petroleum Ministry of China, explained that there is documentary evidence of drilling for gas to a depth of more than 1000 m in the 12th century: oxen provided the power to drive a percussion rotary drill comprising bamboo pipe hardened in salt water. The earliest history of drilling in the province dates back to before 600 BC. However, the true mineral potential of the Panxi Rift has been realised only since the formation of the People's Republic.

With apologies to Dr Luo Yaonan of the Sichuan Geological Bureau's Panxi Rift research team, a grossly simplified description of the Panxi Rift reads as follows. The main part of the rift system trends north–south for 400 km on the western side of the Yangtze Platform, and has a maximum width of about 120 km, though the palaeorift was developed over a much larger area. In the mid-Proterozoic a northerly trending volcanic–plutonic magmatic arc developed on basement rocks of the Kangding Complex (migmatitic gneisses 2400–2950 Ma) on the western side of the Yangtze Platform. After the Jinning Orogeny (900–850 Ma) and a subsequent phase of rifting, the region formed a pre-Sinian craton as part of the Yangtze palaeoplate, and was stable

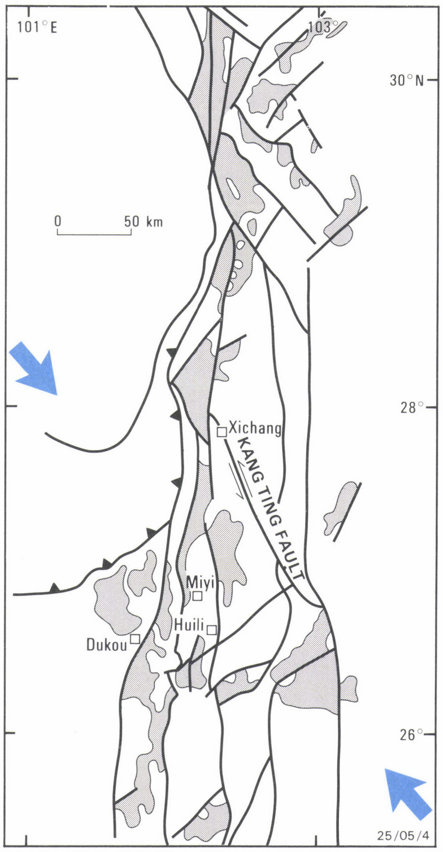


Fig 15. Pre-Sinian basement faults of the Panxi Rift zone. Exposed areas of pre-Sinian basement rocks are identified by the screen; black triangles are on the upthrust block; and the large arrows denote the direction of crustal shortening.

from the Late Sinian to the Early Palaeozoic. In the middle–late Palaeozoic, renewed rifting brought about the intrusion of ultrabasic magmas and the development of Mesozoic intracontinental deep basins. These early rifting episodes are recognised in the major basement faults of the region, many of which are active to this day.

The Panxi Rift includes a north–south-trending axial magmatic complex with Mesozoic rift basins on either side constituting a structural pattern of two grabens sandwiching a horst. Many structural features are typical of lithospheric extension, and sedimentary records indicate syngenetic faulting; tectonic reversal and the formation of fold-thrust nappes have added to the complexity of the structure of the Panxi Rift. An extensive Late Permian episode of basaltic magmatism (the Emeishan Basalts) preceded the Triassic development of rift basins, which led to the accumulation of more than 10 km of continental sediments in places. The Himalayan Orogeny caused the reactivation of basement faults and crustal shortening throughout the region. Some estimates of current movement on, for example, the Kang Ting (Hei Shuihe) Fault (Fig. 15) are put at about 6 cm y^{-1} by Molnar & Deng Qidong (1984: *Journal of Geophysical Research,* 89, 6203–6227). Zhang & others (1984: *Bulletin of the Geological Society of America,* 95, 295–312) have presented a detailed synthesis of the megatectonics of the region.

One attraction for the structural geologist is that the effects of so many of the tectonic episodes are exposed at the surface as a result of the downcutting of the enormous rivers which transect the region. To those studying sedimentary basins in Australia from seismic profiling records, the field excursion after the symposium provided a vivid, visual reminder of the scale and complexity of structures which can evolve through multiple tectonic episodes in our intracratonic basins.

The excursion — organised by staff from the Bureau of Geology and Mineral Resources of Sichuan Province — provided a graphic illustration of how basement features and sedimentary sequences form linked systems; an appreciation of these links is pertinent to a sound tectonic reconstruction of a region.Understanding the response of basement and sedimentary sequences is of fundamental importance to BMR's studies of the evolution of basins, continental margins, and marginal plateaus. These studies are currently directed at the Eromanga, Surat, Amadeus, and Clarence–Moreton Basins onshore, and the Bass, Otway, and Perth Basins and the Exmouth and Queensland Plateaus offshore.

More information on the DIPCR symposium and the Panxi Rift excursion can be obtained from Doug Finlayson at BMR.

World Ni resources

An international working group of Earth scientists has released a summary report on world resources of nickel. The report, entitled 'International Strategic Minerals Inventory summary report — nickel' ('ISMI — nickel'), was prepared as a co-operative data collection effort by Earth-science and mineral resources agencies in Australia (BMR), Canada, the Federal Republic of Germany, the Republic of South Africa, the United Kingdom, and the United States of America. ISMI reports are designed to be of benefit to policy analysts and geologists, making available non-proprietary data and characteristics of major deposits of strategic mineral commodities for policy considerations in regard to short-term, medium-term, and long-term world supply.

'ISMI — nickel' provides an overview of the supply aspects of nickel (part 1) and a summary statement of the data compiled (part 2). Part 1 discusses the distribution of deposits and districts and their geologic type; provides a breakdown of resources by economic class of country and date of discovery; and gives an analysis of world mine production by country and economic class of country. Part 1 concludes by outlining the nickel supply scenario that we face in the eighties. Part 2 tabulates such data as deposit or district location, geology, mineral production, and resources.

'ISMI — nickel' is the fourth, and most recent, in a series of reports having a similar format. 'ISMI — manganese' was released in August 1984, and 'ISMI — chromium' and 'ISMI — phosphate' were released in November 1984. Work is proceeding on similar reports for cobalt, graphite, platinum group elements, tin, titanium, tungsten, and vanadium. BMR's Resource Assessment Division has provided the data on Australian deposits and reviewed data for other countries for each of these reports. BMR's Mr Roy Towner is the chief compiler of 'ISMI – titanium'.

More details from Mr Ian McLeod at BMR.

1986 BMR Research Symposium, 13–14 November — program

The 1986 BMR Research Symposium will be held at the Australian Academy of Science building in Canberra on 13 and 14 November. A registration fee of $95, payable by 7 November, covers morning and afternoon teas, lunches, the symposium dinner after the first day's sessions, extended abstracts volume, and other conference material.

Day 1. Thursday 13 November

9.00: Registration

Morning Tea

10.15: Official opening — Senator Gareth Evans, QC, Minister for Resources and Energy, and introductory remarks from Professor Roye Rutland, Director, BMR.

10.30: Gold search: micro to macro. *R.W. Henley*

Experimental studies combined with field observations of active hydrothermal systems have provided a quantitative framework for the guidance of gold search in older terranes, and new challenges in understanding the origins of ore-forming systems as integral parts of the evolution of the Earth's crust.

11.00: Origins of Pb–Zn deposits, Canning Basin, WA. *I.B. Lambert & H. Etminan.*

Petrographic, isotopic, geochemical, fluid-inclusion, and other data have been integrated to provide information on processes involved in the genesis of Pb–Zn deposits on the Lennard Shelf, including the major Blendevale deposit. Metals were transported in hydrocarbon-bearing brines, of which numerous pulses migrated from deep basinal strata via faults and permeable beds. Sulphide was generated by biological and thermochemical reduction of sulphate.

11.30: Distribution of precious metals in Precambrian basic–ultrabasic suites. *A.Y. Glikson*

Platinum group element and gold studies of the late Archaean Munni Munni, Andover, and Soanesville mafic–ultramafic complexes of the Pilbara Block have been combined with petrological and geochemical investigations to determine the precious-metal potential of the region.

12.00: Origin of Argyle diamonds. *A.L. Jaques*

Diamonds from the rich Argyle lamproite pipe have been analysed for carbon isotopes; these data, integrated with the chemistry of mineral inclusions and the morphology of the diamonds, provide the basis for a model for the origin of the diamonds.

12.30: Lunch

1.30 : Australian Geomagnetic Reference Field: the attractions of an Australian model in the field. *C.E. Barton*

The International Geomagnetic Reference Field is a poor representation of the magnetic field over Australia. Development of an Australian Geomagnetic Reference Field helps to overcome this difficulty, and serves as the basis for production of magnetic anomaly maps and as a model of the field for mapping and navigation.

2.00: Basement morphology in the Murray Basin: the key to tectonic evolution and understanding groundwater flow. *D.H. Tucker & others*

Recent detailed geophysics has revealed subtle pre-Tertiary basement features not recognised in regional data. These features are thought to control groundwater flow in the basin. The relationship between the main tectonic framework of the basin and the recently revealed fine structure will be discussed.

2.30: Basement faults in the southern Adavale Basin, and the structuring of the overlying Eromanga sequence. *J. Leven*

Basement faults in the southern Adavale Basin are interpreted to have formed during two periods of Devonian/Carboniferous compression. The geometry of these basement structures has been the controlling influence in subsequent episodes of deformation, and sediments of the Eromanga sequence were structured during the Tertiary Winton event by relatively minor reactivation of these basement structures.

3.00: Afternoon tea

3.30: The NASA/Australia remote-sensing experiment. *C.J. Simpson*

Preliminary results from this unique, international project will be presented, together with discussion of the potential application of advanced remote sensing to petroleum and mineral exploration, regolith research, and specific geological problems.

4.00: Applications of regolith studies. *C.D. Ollier*

The BMR regolith program prepared experimental maps of the regolith at various scales, which will be exhibited. Mapping and associated work brought out new concepts in geomorphic history and the formation of some regolith materials, which could be very significant in mineral exploration.

4.30: Facies model for Australian exploration: passive margin/reef association. *P.J. Davies*

The region off northeast Australia contains the Great Barrier Reef, the largest epicontinental reef system on Earth, and the Queensland Plateau, the largest marginal plateau of the Australian continental margin. Understanding their origin is important because they constitute a modern analogue of a sedimentological and structural association — reef/adjacent rift trough/marginal plateau — which has been common throughout the geological record (e.g., in the Devonian of the Canning Basin) and in places around the world has formed significant petroleum provinces. Aspects of the evolution of this unique region will be examined, and a quantitative model of reef growth defined within the tectonic and sedimentologic framework of a passive rifted margin.

5.00: Close

7.00 for 7.30: Symposium dinner

Day 2. Friday 14 November

9.00: Oil prospectivity of the Middle Proterozoic of northern Australia. *M.J. Jackson*

The McArthur Basin contains several organic-rich formations, one of which contains the world's oldest live oil. Aspects of the sedimentology, maturation history, and reservoir potential of this sequence will be described, and their relevance to the potential of adjacent basins assessed.

9.30: Petroleum source rocks: Proterozoic to Tertiary, non-marine to marine. *T.G. Powell*

Potential petroleum source rocks can be deposited in a variety of depositional environments. Environmental controls on source rock quality and type will be illustrated for both marine and non-marine potential source rocks from the McArthur, Eromanga, Clarence–Moreton, Cooper, and Gippsland Basins. The relevance of those controls to the evolution of petroleum potential will be discussed.

10.10: Improving the clarity of seismic records. *P.L. McFadden*

The Nth-root stack is an easily applied filter that can, under a wide range of circumstances, produce a striking increase in the contrast between signal and background noise. BMR scientists have been successfully applying the technique to land and marine seismic reflection data, resulting in improved clarity in the seismic records and greatly assisting interpretation.

10.30: Morning tea

11.30: New seismic results from the central Australian region, and their implications for basin evolution. *C. Wright, B.R. Goleby, & C.D.N. Collins.*

Prominent deep structures that may have influenced the development of the Ngalia and Amadeus Basins have been mapped by seismic methods. Careful imaging of these basement features is assisting in understanding the deformational history of the central Australian region, and in evaluating models for basin evolution and petroleum migration.

11.30: The Amadeus Basin: a new perspective. *J.F. Lindsay & others*

An integrated three-year BMR project has attempted to develop a new three-dimensional perspective of the basin through a detailed analysis of sedimentary sequences and the development of a refined biostratigraphy. The results suggest that the basin has had a complex evolution , the understanding of which helps place constraints on the region's hydrocarbon and water resources potential. The more significant results of this project will be discussed.

12.10: Australia's potential for further petroleum discoveries. *D.J. Forman*

Australia's petroleum resources have been recently reassessed using a new method called the trap-by-trap creaming method, which takes account of both past experience and our knowledge of Australia's sedimentary basins. Original features include the determination of a richness factor for each area and the determination of a distribution for the areas of, as yet undrilled, petroleum prospects in each trap type. The new assessment forms the basis for technical advice to Government on the prospectiveness of Australia.

12.40: Lunch

1.40: Exmouth Plateau thermal geohistory: implications for further exploration. *M.G. Swift, D.A. Falvey, T. Graham, & H.M.J. Stagg*

The 14 exploration wells drilled on the Exmouth Plateau proved uniformly disappointing. Acquisition of an extensive set of heatflow data on the plateau by BMR in early 1986 is allowing a re-evaluation of the plateau's thermal and maturation history. These studies are throwing light on the poor exploration returns to date, and suggesting future avenues of exploration.

2.10: New clues to petroleum habitats of the offshore Otway Basin. *P.E. Williamson*

New seismic data collected from *RV Rig Seismic* have been combined with industry well and seismic data and with geohistory analyses to assess the likely habitats of petroleum in this, the westernmost of the Bass Strait basins. These latest results clearly indicate good potential for hydrocarbon discoveries.

2.40: South Tasman Rise: an Otway fragment? *J.B. Willcox*

Recent studies have identified a large pull-apart basin and several small transtensional basins flanking the Palaeozoic core of the South Tasman Rise. The studies suggest that the rise was once adjacent to the Otway Basin, and moved as part of the Antarctic plate until the Late Eocene. This paper examines the tectonics of the area, and the implications for basin maturity and hydrocarbon potential.

3.10: Afternoon tea

3.40: Future directions of BMR. *R.W.R. Rutland*

4.10: Future directions of BMR. *Industry comment and discussion*

5.00: Close, and presentation of Harold Raggatt Award

Enquiries should be directed to Mrs Evelyn Young at BMR.

1st Asia/Pacific Mining Conference and Exhibition

The First Asia/Pacific Mining Conference and Exhibition will be held in Bangkok on 4–7 November 1987. The event is sponsored by the ASEAN Federation of Mining Associations and is endorsed by BMR.

The theme of the Conference is 'Minerals and the economic development of the Asia/Pacific region'.

For further information, write to:
The Secretariat
The ASEAN Federation of Mining Associations
2151 Pasong Tamo
Makati
Metro Manila, PHILIPPINES.

Hydrocarbon fluid inclusions

(continued from back page)

calcite, dolomite, sphalerite, and barite contain pure hydrocarbon inclusions and/or aqueous inclusions with variable hydrocarbon contents; in contrast, post-mineralisation calcite and barite do not appear to contain hydrocarbon inclusions. Therefore, hydrocarbons must have constituted a significant component of the mineralising fluids in this region. Attempts are being made currently to characterise the hydrocarbons in more detail, and to compare them with oil from the Blina field in the northern part of the basin. Isotopic compositions of the carbonate cements are also being studied, and these indicate influx of basinal brines from several different source beds and areas of organic degradation. The major thrust of this research project in the coming year will be on carbonates well removed from known mineralisation. These studies should yield a reasonably detailed picture linking hydrocarbon generation and migration, permeabilities, and fluid migration paths.

For further information, contact Drs Hashem Etminan, Roger Summons, or Ian Lambert (Baas Becking Geobiological Laboratory) at BMR.

Hydrocarbon fluid inclusions and timing of oil migration

Information of importance in oil exploration can be obtained from studies of hydrocarbon-bearing inclusions in diagenetic cements using a range of analytical techniques.

Small amounts of parent fluids are commonly trapped within growing crystals, and studies of these primary inclusions provide information on temperatures and compositions of the fluids involved. In addition, the features of later fluids can be studied in secondary inclusions which form, for example, during the healing of microfractures. Though most inclusions are aqueous, any hydrocarbons present during the precipitation of diagenetic cements will also be trapped. Therefore, information on the timing of oil generation, rock permeabilities, and paths of migration can be obtained from a combination of fluid-inclusion and petrographic studies of the sequences of formation of cement minerals. The relative times of entrapment of hydrocarbons (which can range from methane to bitumens) can be documented simply by identifying primary and secondary hydrocarbon-bearing inclusions within sequences of transparent diagenetic minerals. A combination of this relative approach with burial history analysis from geological data can provide a chronostratigraphic timescale for petroleum migration during burial diagenesis. The isotopic compositions of cements can yield additional information on sources of diagenetic fluids and the extent of organic degradation processes.

Techniques

Hydrocarbons can be detected in fluid inclusions by a range of complementary techniques (Fig. 16). Most liquid hydrocarbons fluoresce under long-wave ultra-violet (UV) light; therefore UV microscopy is a rapid technique for the preliminary recognition of the presence of hydrocarbons in inclusions. The behaviour of included fluids after they have been solidified on a microscope freezing stage (microthermometry) can be used to detect (i) hydrocarbons as immiscible phases or dissolved in low concentrations in aqueous inclusions, because they form waxy phases during melting of the ice; and (ii) methane (with CO_2), which depresses the triple-point temperature of CO_2–56.6°C) and increases the temperatures of melting of gas hydrates (clathrates). The recently developed laser Raman microprobe offers a powerful technique for the in-situ identification of gases and liquefied gases in inclusions (e.g., CO_2,N_2, CH_4,C_2H_6,C_3H_8), and for the detection of heavy aliphatic and aromatic hydrocarbons, by measuring the molecular vibration energy spectra (Dhamelincourt & others, 1979: *Bulletin Minéralogique*, 102, 600–610; Etminan, 1985: *BMR Record* 1985/33, 21–23) Further in-situ characterisation of hydrocarbons can be obtained by infra-red (IR) microprobe, which couples an IR microscope with a Fourier transform–IR spectrometer (Herres, 1985: *Chimia*, 39(2–3), 64–67); this technique has excellent sensitivity (picogram range), visible control of the measured sample area, and both reflectance and transmittance measurements in the one system.

The above techniques are non-destructive. More detailed characterisation of organic compounds can be made by gas chromatography (GC) and gas chromatography — mass spectrometry (GCMS), which are destructive techniques that require liberation of the fluids by heating (decrepitation) with or without crushing; their use is warranted only where a particular problem requires accurate characterisation of organic components.

In BMR, heating–freezing stages, and long-wave UV microscopy are being used routinely in studies of hydrocarbon inclusions. Preliminary experiments on the application of GC and GCMS are under way, and a multichannel laser Raman microprobe is currently being installed. Further assessment of the IR microprobe will be carried out in the near future when Hashem Etminan visits Europe in early 1987.

The techniques can be used only on samples with medium to coarsely crystalline diagenetic cements. Five-to-ten-centimetre lengths of quarter-core should be adequate for cutting the polished sections required for the non-destructive analyses, but samples two to three times larger would be required for fluid extraction.

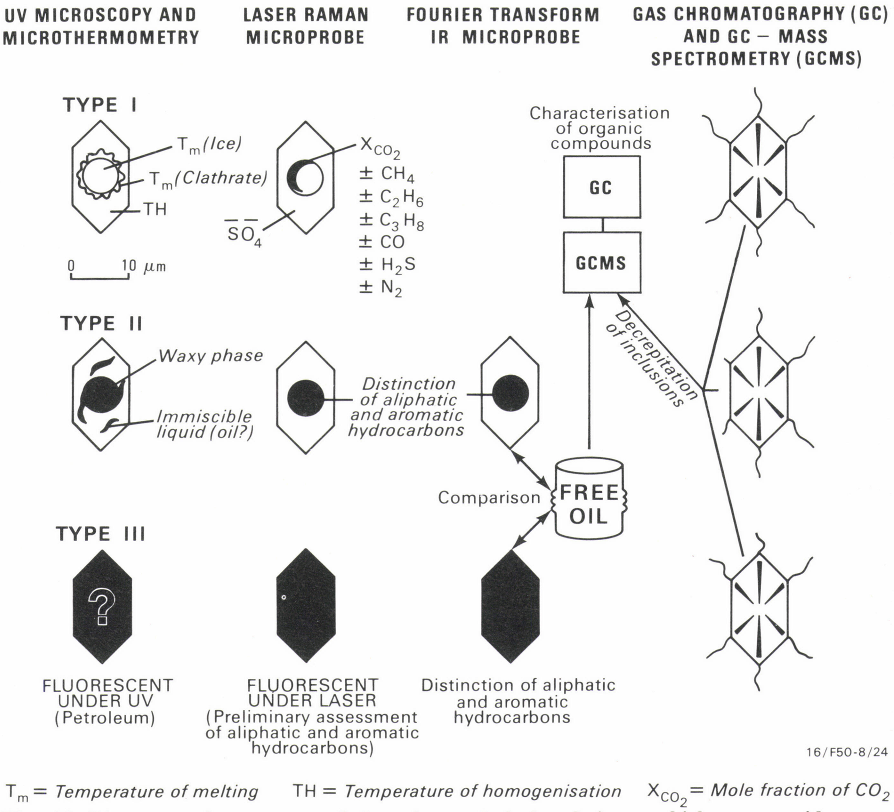


Fig. 16. Diagrammatic summary of the microanalytical techniques which can provide complementary information on the composition of hydrocarbons in different types of fluid inclusions (I — gas-rich; II — brine-rich; III — liquid hydrocarbon).

Examples

The presence of hydrocarbon inclusions in diagenetic cements has been recognised for some time, but their potential importance to oil exploration has been acknowledged only in recent years. From differences in UV fluorescence of primary and secondary hydrocarbon-bearing inclusions, Burruss (1981: in Hollister & Crawford (Editors) — Short course in fluid inclusions, *Mineralogical Association of Canada*, 138–156) reported three generations of hydrocarbons associated with different vein-filling cements and microfacturing in the Carboniferous Fayetteville Formation of Arkansas. By combining studies of relative ages of hydrocarbon inclusions with analyses of burial history from geological data, he was able to provide a chronostratigraphic timescale for hydrocarbon migration from source rocks in Mesozoic platform carbonates buried beneath the Oman fore-deep.

Fluid-inclusion research in the Baas Becking Geobiological Laboratory is presently focusing on the carbonate complexes of the Canning Basin (WA), which contain hydrocarbon inclusions in medium to coarsely crystalline burial diagenetic cements in areas of Pb–Zn mineralisation (Etminan & others, 1984: *in* Purcell (Editor) — The Canning Basin, WA, *Geological Society of Australia/Petroleum Exploration Society of Australia;* Etminan & Lambert, 1986: Abstracts, Eighth Australian Geological Convention, *Geological Society of Australia*, 66). Primary inclusions in

(continued on p.15)

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