RECORD 1982/3

ABSTRACTS

11th BMR SYMPOSIUM
CANBERRA, 4-5 MAY 1982

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Contents

* Speaker

Mineral sands - a dwindling resource?

J. Ward

In the late 1940s BMR drilled out known economic deposits of heavy-mineral sands along the east coast primarily to determine reserves of monazite and its contained thoria, then regarded to be of considerable strategic importance. On the basis of this investigation Australian reserves of heavy mineral sands in 1950 were assessed as:

rutile - 700 000 tons
zircon - 950 000 tons
ilmenite - 470 000 tons
monazite - 12 000 tons

Since then Australia has produced:

rutile - 6.4 Mt
zircon - 7.4 Mt
ilmenite - (commercial-grade) 14.9 Mt
monazite - (saleable-grade) 102 000 t

In its annual update of mineral resources, BMR estimates Australian demonstrated economic resources of mineral sands in 1981 as:

rutile - 9.5 Mt
zircon - 13.7 Mt
ilmenite - 43.6 Mt
monazite - 334 000 t

This paper traces out the history of discovery and expansion of mineral-sand resources, and clarifies the paradox of the foregoing statistics. In particular, since 1950 major additional deposits of mineral sands have been delineated on both the eastern and western seaboards, and technological breakthroughs in mining and concentrating techniques as well as increased prices for the relevant mineral commodities, have enabled mining operations to be conducted on head grades as little as one-tenth of those considered payable in the early 1950s.

Projected output from known deposits indicates that, by the turn of the century, approximately 70 percent of demonstrated economic resources of mineral sands will be depleted. However, a substantial proportion of known reserves are 'frozen' because of environmental and other considerations, and reserves actually available for mining will be depleted much earlier, particularly in the case of rutile.

Patently, known reserves of mineral sands have reached the threshold of concern and BMR has initiated a program of fundamental research into the provenance and geological controls of heavy-mineral sand deposits, and has recently undertaken a reconnaissance survey and sampling campaign on potential deposits off the east coast.

An assessment of Australian chromite resources

R. Pratt

Chromite has been mined intermittently on a small scale in Australia since 1882. However, like most of the industrialised countries, we import nearly all of our chromite, and are almost wholly dependent on imports of chromite, ferrochromium, and chromium chemicals to meet our requirements.

The known chromite deposits in Australia can be divided into three types:

(i) Podiform deposits within the Palaeozoic serpentinites in eastern Australia;

(ii) Stratiform deposits in Archaean and Lower Proterozoic mafic and ultramafic intrusives in Western Australia; and

(iii) Alluvial concentrations such as those of Tertiary age at Beaconsfield in Tasmania.

The podiform deposits are the most numerous but individual deposits are relatively small. The largest of this type known are at Princhester in Queensland. Exploitation of these deposits is dependent on the development of a suitable beneficiation process. The stratiform deposits in Western Australia are larger and are considered to have the potential for development to meet local metallurgical and chemical demand and supply overseas markets if certain mining and beneficiation problems can be overcome. Alluvial chromite was mined at Beaconsfield from 1978 to 1980 and this activity has stimulated interest in alluvial sources of chromite. Additional deposits of alluvial chromite are known at Beaconsfield and further exploration for and testing of alluvial chromite deposits would appear to be warranted.

The assessment conducted by BMR with the assistance of industry has shown that Australian chromite resources are larger than previously believed. Demonstrated resources of chromite in known deposits are large enough to be developed to meet Australia's domestic requirements. However, development of known deposits cannot be economically justified at current prices, and some technical problems need to be overcome.

Economic prospects for manganese nodules in the Southwest Pacific

N.F. Exon

Manganese nodules are present at 75 percent of 300 deep-sea stations in the Kiribati-Cook Islands region of the Southwest Pacific, which extends from 6°N to 25°S. They are most abundant and of highest metal grade (% Ni + Cu + Co) near the calcite-compensation depth, which deepens northward from 4500 m to 5500 m. Major variations in nodule concentrations and metal grades appear to be largely controlled by plankton productivity, and the deposits fall into three groups separable by latitude. The main features of these groups are tabulated below:

	Basins	Basinal sediment	Concentration (kg/m^2)		Grade (%Ni+Cu+Co)		Economic prospects
			Mean	Max.	Mean	Max.	
6°N-5°S	East Central Pacific	Siliceous ooze	8	31.6	1.73	3.55	High
5-9°S	North Penrhyn	Calcareous and zeolitic clay	1	10.7	1.32	2.10	Low
9-25°S	South Penrhyn, SW Pacific	Calcareous and zeolitic clay	13	62	1.02	2.02	Low

Nodule grades are too low in the two southern groups for these groups to have any apparent economic potential. However, the grades in parts of the poorly sampled East Central Pacific Basin are as high as those in the ore-grade fields of the Northeast Equatorial Pacific, and concentrations are moderate to high. Despite a tendency for very high grades to be associated with lower concentrations, the basin's economic potential appears to be high. More sampling is needed to confirm this potential, especially in the east and west.

The use of diagenetic features for evaluating reservoir quality, Sydney Basin

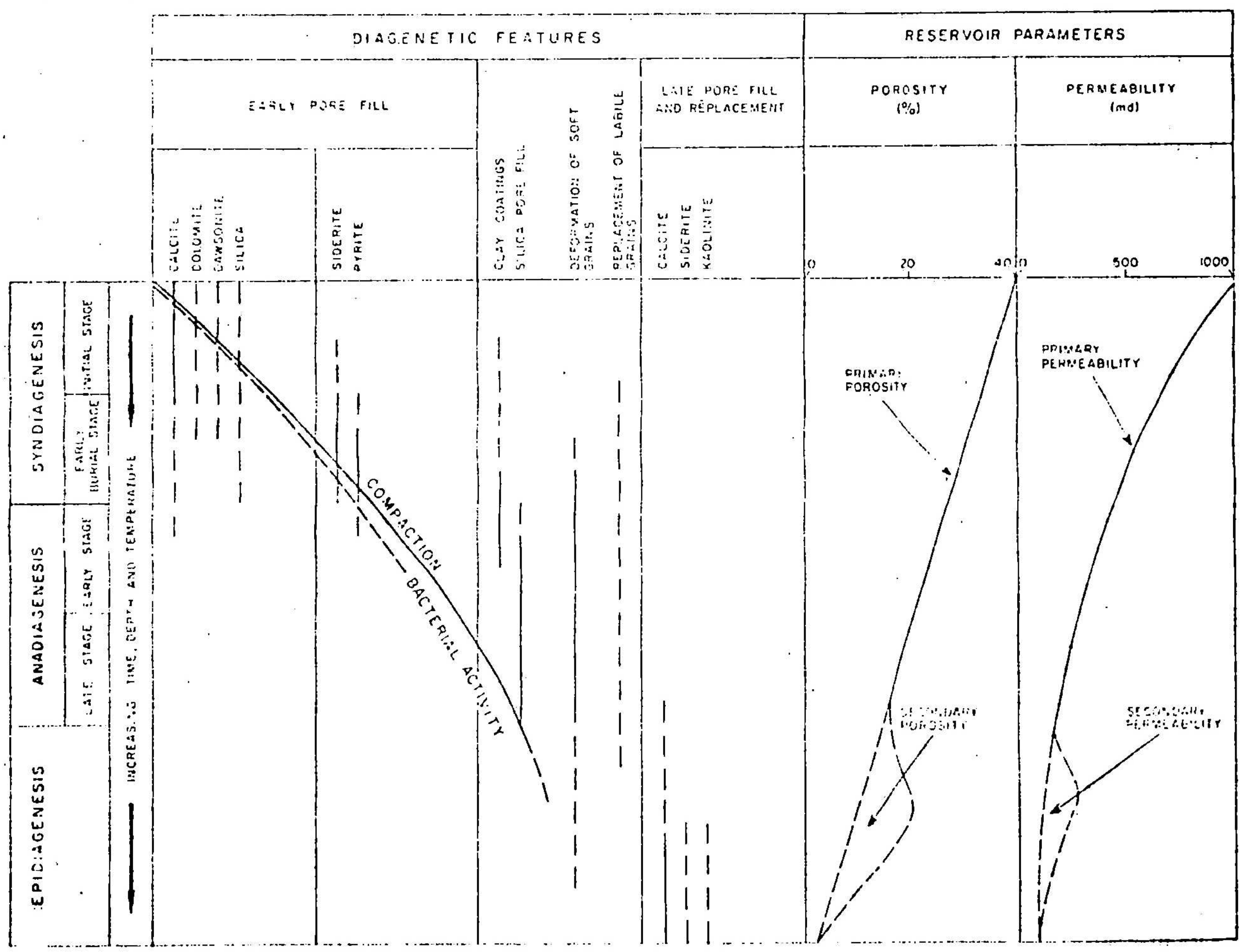
S. Ozimic

The sediments of the Permian Shoalhaven and Maitland Groups in the Sydney Basin have been subjected to at least three diagenetic phases (syndiagenesis, anadiagenesis, and epidiagenesis); and three diastrophic events (Permian Hunter-Bowen orogeny, Upper Triassic movements, and probable Tertiary epeirogenic movements).

In the arenaceous members the progressive diagenesis produced a sequence of diagenetic features (Fig. 1) that have considerably decreased the quality of the potential reservoirs, mainly by the reduction of porosity and permeability. The reduction of primary and secondary porosity as well as permeability is, therefore, attributed to the following diagenetic features that have been produced during the burial and subsequent uplift:

- early pore fill (calcite, dolomite, dawsonite, siderite, silica and pyrite),
- clay coating of detrital grains (illite),
- silica pore fill (quartz overgrowths), and
- late pore and fracture fill (carbonates and clay).

DIAGENETIC FEATURES AND RESERVOIR PARAMETERS IN THE ARENITES OF SHOALHAVEN AND MAITLAND GROUPS



The Nabarlek uranium deposit - petrology, geochemistry, and some constraints on genesis

G.R. Ewers, John Ferguson, & T.H. Donnelly

The Nabarlek uranium deposit is located in the Alligator Rivers Uranium Field (ARUF) near the other major deposits of Jabiluka, Ranger, and Koongarra. Broad similarities and some significant differences in the features and setting of the mineralisation at Nabarlek, as compared to the other ARUF deposits, have prompted the present study. The petrology and geochemistry of the host rocks and ore zone have been investigated and, in conjunction with limited stable-isotope data, have enabled some constraints to be applied to the genesis of the Nabarlek deposit.

Mineralisation is confined to a crush zone in Early Proterozoic schists, and occurs near an unconformity with overlying Middle Proterozoic sandstone. The results indicate that uranium was transported to the site of a deposition as a uranyl complex, and that the earliest mineralisation was associated with massive chlorite and possibly carbonaceous material. This carbonaceous material has since been largely or completely oxidised by high-temperature fluids entering the ore zone. At or after 920 m.y., the orebody was extensively sericitised. This sericitisation has caused a remobilisation of uranium and appears to have reset uraninite ages to 920 m.y. The replacement of chlorite by sericite has been accompanied by the formation of hematite, and where residual uraninite is present, redox reactions involving iron and uranium are evident. Erosion of the Middle Proterozoic cover rocks in the recent past has exposed the deposit to the effects of weathering.

The influence of tectonism on petrogenetic processes in the South Alligator Valley area in Early to Middle Proterozoic time

P.G. Stuart-Smith & R.S. Needham

The South Alligator Valley area lies in a broad, major northwest-trending crustal structure which has been the locus of tectonic activity since Early Proterozoic time. Tectonism in the area has influenced sedimentation patterns, igneous activity, metamorphism, and the distribution of uranium mineralisation.

During the Early Proterozoic the area formed part of the northwest-trending South Alligator Trough, an incipient fault trough which formed the central axis of the Pine Creek Geosyncline. The Trough was the locus of several periods of mafic to felsic volcanism, and thicker sedimentation than in other areas of the geosyncline. Facies changes within the South Alligator Group across the eastern margin of the Trough indicate pene-contemporaneous faulting and partial erosion to the east. This margin continued to be a major zone of dislocation during metamorphism and deformation between 1870 and 1800 m.y. ago.

Following uplift and erosion of the Early Proterozoic metasediments between 1800 and 1760 m.y. ago, renewed igneous activity accompanied block faulting along reactivated northwest-trending Early Proterozoic faults within the Trough. Two separate sequences of felsic volcanics and fluviatile sediments were deposited in fault-bounded basins. Volcanics in the latter sequence were probably comagmatic with granite intrusion at about 1760 m.y. Faulting was active before, during, and after sedimentation.

At about 1650 m.y., Middle Proterozoic platform sedimentation of the western McArthur Basin sequence of northern Australia extended across a relatively stable, peneplaned, metamorphic basement (the Arnhem Shelf). In the South Alligator Valley area the braided alluvial sandstone of the Kombolgie Formation was deposited. Considerable subsidence related to reactivation of faults resulted in at least double the thickness of Kombolgie Formation sedimentation compared to other parts of the Arnhem Shelf.

A very long stable erosional period followed, during which the marginal faults of the Trough remained active and the Middle Proterozoic sediments were locally drag-folded. Continued faulting is evidenced by the deformation and basin development of Cretaceous and Tertiary sediments.

These long-lived faults have also been important in localising uranium mineralisation at around 800 and 500 m.y. ago in the area, by providing suitable structural sites, and contacts between the probably Middle Proterozoic volcanic source rock and host Early Proterozoic carbonaceous strata.

Design and interpretation of gamma-spectrometer and radon surveys for mapping and exploration in the Pine Creek Geosyncline

D.C. Stuart

Field and theoretical studies provide a guide to the use of gamma-spectrometry and radon surveys for mapping and exploration in the Pine Creek Geosyncline.

Regional traverses employing surface and down-hole gamma-spectrometry, and radon surveys, establish the radioelement characteristics of important stratigraphic units of the geosyncline. The results indicate that the radiometric characteristics of overburden and weathered rocks commonly reflect the radioelement concentration of fresh bedrock. Iron-rich units in the important Koolpin Formation produce a characteristic radiometric response which can be used to map the formation on a regional scale, and assist in the delineation of areas prospective for uranium mineralisation.

Detailed surface and down-hole gamma-spectrometer and radon surveys over zones of mineralisation and radiometric anomalies at Rum Jungle, and in the Alligator Rivers area, indicate the radiometric characteristics of uranium mineralisation in the geosyncline. The results suggest that uranium mineralisation is commonly accompanied by a surficial radiometric halo which gives rise to both gamma-spectrometer and radon anomalies.

Although the investigation of a strong radon anomaly without a coincident gamma-spectrometer anomaly illustrates the potential for radon methods to indicate the presence of deposits blind to gamma-spectrometry, the results show that finding the source of such anomalies will be difficult. Radon methods are also shown to be particularly useful for prospecting in areas of radioactive contamination.

Modelling indicates that important surface expressions of uranium mineralisation may not be detected by high-sensitivity, close-spaced airborne surveys. Even on the ground, high-sensitivity, close-spaced surveys are necessary to ensure detection of small but significant surface expression of bedrock radioelement concentrations.

Field and model studies of emanometer surveys indicate that ratio measurements provide a quick and effective guide to anomalous concentrations of radon. The potential advantages of high-sensitivity, down-hole gamma-spectrometer surveys are shown to be difficult to achieve owing to instrument, calibration, and geological noise problems.

Geology of the Davenport Geosyncline - preliminary results

D.H. Blake & A.J. Stewart

The Davenport Geosyncline is a relatively little known Precambrian region containing deposits of W, Au, Cu, Pb, Ag, and U. It links the Precambrian Arunta and Tennant Creek regions to the south and north, and is overlain to the east and west by flat-lying Palaeozoic sediments of the Georgina and Wiso Basin successions. A joint BMR-NTGS project, started in 1981 and planned for completion by 1985, is aimed at determining the Geocyncline's detailed stratigraphy, structure, geological history, tectonic setting, and mineral potential.

Most of the rocks exposed in the area examined so far are assigned to the Early or Middle Proterozoic Hatches Creek Group. No rocks older than this group have been identified, and the presence of the Warramunga Group in the region has not been verified - a possibility yet to be dismissed is that the Hatches Creek and Warramunga Groups are partly lateral equivalents. The Hatches Creek Group is at least 10 000 m thick and consists of resistant ridge-forming sandstone units interlayered with less resistant and commonly much weathered sedimentary and volcanic units. The sedimentary rocks are shallow-water deposits consisting largely of quartz derived from elsewhere and volcanic detritus that is probably locally derived; they also include carbonates (some containing stromatolites) and evaporites. The volcanic rocks are represented by both lavas and pyroclastics, and appear to show a complete range in composition from olivine-bearing basalt to rhyolite; however, no chemical data are available yet.

The Hatches Creek Group is subdivided at present into eighteen formations, and more generally into lower, middle, and upper parts. In the lower part the constituent formations interfinger laterally with one another, but the middle and upper parts show a general layer-cake stratigraphy. The upper part differs from the other two parts in being essentially non-volcanic. There may be a significant unconformity at the base of the middle Hatches Creek Group, where a major ridge-forming sandstone unit overlies several different volcanic and sedimentary units of the lower Hatches Creek Group.

The Group has been folded into domes and open to tight anticlines and synclines, extensively faulted, and has been regionally metamorphosed to mainly middle and upper greenschist facies. The major folds have steeply inclined arcuate axial planes and gentle to moderate plunges. Axial-plane cleavage is common, and schistose rocks are present locally. Two folding episodes can be recognised in places. Most faults postdate the folding. Primary sedimentary and volcanic textures are generally well preserved within the Group, but metamorphic greenish-brown biotite, epidote, white mica, and chlorite are widespread.

Numerous mafic and felsic sill-like bodies, metamorphosed to greenschist facies, intrude the Hatches Creek Group, especially the lower part, and may be comagmatic with extrusive volcanics of the Group. The mafic intrusions consist of gabbro and dolerite and commonly contain country rock screens. The felsic sills are predominantly granophyre. There are also some granite intrusions which appear to post-date the folding and regional metamorphism, and hence may be much younger than the Hatches Creek Group. A Rb-Sr age of 1660 m.y. and K-Ar ages of between 1540 and 1320 m.y. have been obtained previously on some of these granites.

The known metalliferous mineral deposits are mainly located in quartz veins, at least some of which (e.g., the tungsten lodes at Hatches Creek) appear to post-date folding and are possibly related to granite emplacement. However, there may be some syngenetic mineralisation, as copper and lead minerals locally occur in amygdales in basaltic lavas, and gabbro, dolerite, and granophyre commonly contain sulphide minerals.

Reassessment of the tectonic setting of the Mount Isa Inlier in the light of new field, petrographic, and geochemical data

L.A.I. Wyborn & D.H. Blake

It has been proposed recently that the Mount Isa Inlier represents a Proterozoic continental margin on the eastern side of the Australian craton. This proposal is based largely on geochemical criteria: volcanics of the Tewinga Group are reported to be comparable in chemistry to those of the Andean region, and to have K_2O/SiO_2 values which decrease eastwards; basalts in the west have been related to continental tholeiites and those to the east to ocean-floor tholeiites. Additional evidence put forward in support of the suggestion includes: (1) older Precambrian basement is known only to the west of the Inlier; (2) deep water sediments, represented by turbidites, are restricted to the easternmost part of the Inlier; and (3) a general increase in regional metamorphic grade from west to east and a predominance of folding in the east and faulting in the west (and also regional Bouguer gravity anomalies) indicate eastward crustal thinning. However, none of these criteria may be valid.

The Tewinga Group consists mainly of felsic volcanics which belong to two quite separate suites: the 1870 m.y. old Leichhardt suite, and the much younger Argylla suite, which is dated at about 1780 m.y. Andesite, the characteristic volcanic rock of the Andes, is either very rare or absent in both suites, and also elsewhere in the Mount Isa Inlier. The K_2O values of the felsic igneous rocks are somewhat variable, but do not show a general decrease eastwards. The main mafic volcanic units exposed in the Inlier are probably between about 1810 and 1760 m.y. old and are remarkably uniform in chemistry except for one part of the Eastern Creek Volcanics in the west, which is relatively enriched in incompatible elements such as Ti, P, Y, and Nb.

Scattered outcrop and drillhole data show that granite and metamorphic rocks of probably Precambrian age, but not oceanic crustal rocks, underlie Mesozoic sediments of the Carpentaria and Eromanga Basins separating the Mount Isa Inlier from the Georgetown Inlier, which includes Precambrian rocks at least 1550 m.y. old, to the east. The turbiditic sediments in the southeasternmost part of the Mount Isa Inlier decrease in grainsize and feldspar content westwards, indicating a source to the east rather than to the west. Amphibolite-facies metamorphics occur throughout the Mount Isa Inlier and are not restricted in the west to thermal aureoles around granites. Most granites are themselves regionally metamorphosed to amphibolite facies. The main metamorphism postdates the deposition of the 1670 m.y. old Mount Isa Group, and hence is 100 to 200 m.y. younger than most of the volcanism. Folding is prevalent within the Inlier where layered metasediments predominate, in the west as well as in the east; faulting is most evident where relatively rigid units, such as large granite plutons and thick volcanic sequences, have been involved in the deformation. Regional gravity maps show that the Mount Isa Inlier is a gravity high which is flanked to the east and west by gravity lows, and they do not indicate that the crust is significantly thinner to the east than to the west.

Rather than being formed at a continental margin, the pronounced bimodal volcanic chemistry and other available evidence indicate that most of the Mount Isa Inlier may have developed in an intracratonic setting during a mainly tensional regime which lasted from about 1880 m.y. to about 1670 m.y. or possibly 1600 m.y. ago. Major deformation during a succeeding compressional regime caused tight folding and greenschist to amphibolite-facies regional metamorphism.

The origin of megapolygon-spelean limestone associations

Robert V. Burne

Probably the most complex products of early carbonate diagenesis described so far are limestones which originally formed as fenestral intertidal carbonates as part of a regressive sequence, and which have been subsequently altered to produce a lithology characterised by speleothemic cements lining decimetre-scale cavities, secondary pisoliths, 5-30 m scale megapolygons, and tepee structures. Rocks of this type have been described from the Permian of west Texas, the Triassic of Lombardy, and the Jurassic of the Atlas Mountains.

The origin of this megapolygon-spelean limestone association (MSLA) has never been satisfactorily explained, although it has been suggested that it forms under 'vadose schizohaline' conditions in a peritidal environment subject to alternate flushing by fresh meteoric waters and flooding by hypersaline waters of marine origin swept in by storm tides.

At Fisherman Bay, South Australia, saline continental groundwaters rising from a confined Tertiary carbonate aquifer form springs in the supratidal zone of a Holocene regressive marine-carbonate complex. When the carbonate-rich spring waters approach the surface CO_2 is evolved and aragonite is precipitated, to form areas of limestone which have close spatial relationship with the present-day springs. These limestones contain a variety of diagenetic features, including megapolygons, tepee structures, fenestral and cavernous textures, secondary pisoliths, and aragonitic speleothems and fibrous cements. Aragonite plates, found piled loosely on the floors of some cavities in the limestone, are considered to be deposits of floe aragonite, analogous to the floe calcite which forms on the surface of tranquil pools in some present-day caves. The close parallels between these limestones and the ancient examples of MSLA referred to above suggest that they share a common origin.

The petrifying spring at Fisherman Bay has a hydrological setting in which a series of independent conduits exist which are analogous to karst cave systems except for the fact that water-flow is directed upward, towards the piezometric surface of the confined aquifer. The hydrological conditions in adjacent conduits may differ markedly at any one time, and hence reference to vadose and phreatic hydrological zones based on the concept of a general water table is not relevant in such an area.

The ancient MSLA form extensive belts 30-300 km long, and are considered to have formed along belts of peritidal springs of saline continental groundwaters. This characteristic facies is therefore a geologically important indicator of a paralic environment adjacent to a land mass with karst-type cryptorheic drainage and where deposits of processes of surface drainage are absent.

Geochemical and isotopic studies of carbonate environments at Lake Eliza, Shark Bay, and Spencer Gulf

J. Ferguson & L. Plumb

Lake Eliza (SA), Shark Bay (WA), and Spencer Gulf (SA) are Holocene carbonate environments where marine and continental groundwaters influence a wide variety of diagenetic processes, including some implicated in the accumulation of hydrocarbons and base metals.

Concentrations of 3 to 4% organic C are preserved in fine-grained carbonate sediments in Lake Eliza, a coastal salt lake with a predominantly continental groundwater input. At Shark Bay, comparable concentrations of organic matter are associated with highly saline, marine groundwater environments in the intertidal zone.

Continental groundwaters in peritidal areas at Shark Bay are restricted to the landward fringe of the supratidal zone. They are similar in chemical and isotopic composition ($\delta^{34}S$, +21^{o}/oo CDT; $\delta^{18}O$, -1 to +4^{o}/oo SMOW) to marine groundwaters and they do not induce major diagenetic changes in the sediments. Continental groundwaters at Spencer Gulf have a much wider range of chemical compositions and they are responsible for the precipitation of gypsum, lithification of supratidal carbonate sediments, and the generation of high concentrations of Fe_2O_3 (30 to 70%). The continental groundwaters may be identified from their sulphur, carbon, oxygen, and deuterium stable-isotope ratios, which are usually considerably lower than the corresponding marine values. Sulphur becomes incorporated into the sediments as gypsum ($\delta^{34}S$, +15^{o}/oo), and carbon and oxygen are introduced in the form of aragonite cement ($\delta^{13}C$, -4.5; $\delta^{18}O$ - 5^{o}/oo PDB) precipitated from groundwater springs.

The hydrogeochemical processes which produce high concentrations of Fe_2O_3 at Spencer Gulf are similar to those proposed for the formation of some types of low-temperature, stratiform Cu deposits, but the source rocks to not contain significant concentrations of readily available Cu, Pb, or Zn.

Australian seismic refraction results, isostasy, and altitude anomalies

Peter Wellman

Although seismic refraction surveys have been carried out over extensive areas of continental crust, the causes of variation in crustal thickness, and of variation in mean crustal velocity, are poorly understood. If the crust is in regional (3^{o} x 3^{o}) isostatic equilibrium as is suggested by many regional gravity studies, variation in crustal thickness should be caused largely by variation in surface altitude and mean crustal density.

An analysis of Australian seismic refraction results gives the following causes of crustal thickness variation. Surface altitude effects cause about 2 percent of the variation. Changes in mean crustal density cause about 38 percent. Non-planar layering and local deviations from isostatic equilibrium cause about 17 percent. The remaining 43 percent of the variation is caused by differences between geological provinces, and is thought to reflect variations in lower lithospheric density.

This study suggests that, within a geological province, 66 percent of the crustal thickness variation is caused by variations in mean crustal density. Between adjacent geological provinces 40 percent of the crustal thickness variation is caused by changes in the mean crustal density across the boundary, and 40 percent is caused by changes in the mean density of the lower lithosphere across the boundary.

BMR in Antarctica - history and achievements

R.J. Tingey

The establishment of the BMR in 1946 was closely followed by that of the Australian National Antarctic Research Expeditions (ANARE) in 1947; since then the two organisations have had a long association. A BMR geologist and a geophysicist accompanied the first ANARE to Heard and Macquarie Islands in the 1947-48 summer and BMR scientists have been members of many subsequent ANARE groups.

ANARE activities in the Australian Antarctic Territory proper did not start until 1954 when Mawson Station was established. BMR has operated a geophysical observatory there since 1955 and its Mawson-based geologists and geophysicists were, from 1954 until 1961 at least, members of exploratory parties that reconnoitred the Mawson hinterland for distances of up to 650 km. In particular, long reconnaissance journeys were made by air and by various modes of surface transport to the Prince Charles Mountains where basement metamorphic rocks and a small enclave of Permian sediments were found, and to Enderby Land where only metamorphic rocks crop out. There were also expeditions along the Antarctic coast with the expedition support ships. However, by 1961 it became evident that too much of the station geologists' time was being occupied in travelling and a change was made to helicopter-supported summer operations. At this time also a start was made on systematic 1:250 000-scale mapping near Mawson.

Reconnaissance geological work essentially finished in 1965 when ANARE provided three helicopters and a fixed-wing aircraft to support a group that included a four-man BMR geological party. The more systematic approach was further developed in 1969 when a five-year investigation started in the Prince Charles Mountains, the largest inland exposure of the East Antarctic Shield. The ANARE investigations were multidisciplinary, and supported by turbine helicopters and fixed-wing aircraft; supplies were delivered to the field area by tractor train. The main geological result of this work was the subdivision of the Precambrian basement rocks into Archaean and Proterozoic components and the development of ideas that might be applied elsewhere. Field techniques were also refined and a successful program of colour vertical air photography completed.

These techniques and ideas were then applied with considerable success in Enderby Land between 1975 and 1980. Previous reconnaissance there had revealed the existence of some very unusual high-grade metamorphics, and it was again possible to separate the Archaean and Proterozoic components of the basement metamorphic complex. BMR and university specialists also contributed structural, geochronological, geochemical, and petrological studies to the investigations (e.g. L.P. Black, this Symposium). Since the end of the Enderby Land programs, onshore field programs have been confined, by a lack of resources and a new emphasis on marine work, to limited operations near the permanent ANARE Stations.

The BMR Antarctic geophysical effort can be divided into observatory operations and regional surveys. Since the mid-1950s BMR has operated a magnetic and seismic observatory at Mawson, a site well placed for monitoring man-made as well as natural earth tremors. An observatory was also operated for a few years at Wilkes Station and readings are made for BMR at Casey and David Stations. The station geophysicists have been involved in field programs of third-order magnetic observations and gravity surveys in conjunction with the geological mapping programs. Regional surveys have included early seismic and gravity programs for ice thickness measurement, gravity work to determine crustal structure, and reconnaissance aeromagnetic surveys in conjunction with airborne radar ice-thickness profiling. In recent years marine geophysical surveys have started, the first component being magnetometer observations from the ANARE supply ships in order to upgrade information on the seafloor spreading processes involved in the isolation of Antarctica from the other Gondwanaland fragments. This was followed in the recent summer by a program in which marine seismic data were additionally gathered. Samples of the seismic data are on display at this Symposium.

A feature of BMR involvement in Antarctica and of Antarctic research in general is international co-operation; this probably stems from the International Geophysical Year experience in 1957. For example, in 1965 a BMR geophysicist joined a Soviet party in the Prince Charles Mountains area, and in 1973 Dr E. Truswell took part in the Antarctic Leg (28) of the Deep Sea Drilling Project. More recently Mr D. Wyborn joined a West German expedition to north Victoria Land in 1980, and a larger Australian contingent joined a US exercise in the same area this last summer.

Geochronology of high-grade polymetamorphic rocks - an Antarctic example

L.P. Black

Isotopic systematics define a long and involved geologic history for the cratonic rocks of the Napier Complex, Enderby Land. This history was dominated by high-grade metamorphism and three major phases of deformation in the late Archaean. The first of these (D_1) was widespread and pervasive, producing isoclinal folding, boudinage, transposed layering, and the varied development of an LS tectonite fabric. The second deformation (D_2) occurred under similar (medium granulite facies) conditions. It was more localised and produced asymmetric tight to isoclinal folds with inclined axial planes showing a consistent vergence and asymmetry but no penetrative fabric. Upright open to tight folds of varied style and intensity and with horizontal to shallow plunges were produced during upper amphibolite to granulite facies metamorphism at D_3. Except for the southwestern part of the Napier Complex, no more than weak upright penetrative schistosity was developed at this time. These tectonothermal events were intense enough to cause widespread resetting of both U-Pb zircon and Rb-Sr systems. Varied development of their effects at different localities, however, has allowed the derivation of a chronology.

Initial acid igneous crustal formation at 3700-3800 m.y. establishes these rocks as remnants of the earth's oldest preserved crust. However, it was considerably later, at about 3050 m.y. after significant enrichment in ^{207}Pb (over ^{206}Pb) and ^{87}Sr, that the rocks were first subjected to major tectonism (D_1). The less intense D_2 event is more difficult to define, but probably occurred at about 2900 m.y. A small but significant age spread from about 2450 to 2500 m.y. is obtained for D_3. This might indicate either an extended event or the retention of small inherited Pb components in zircon at some locations. In the latter case, the youngest part of the range would be the most realistic age estimate for D_3. Granitoid emplacement was roughly synchronous with at least D_1 and D_3. Two geochemically distinct suites of tholeiite dykes were emplaced at about 2350 $\pm$ 48 m.y., shortly after the effective cratonisation of the Napier Complex. Another suite of tholeiite dykes was emplaced at 1190 $\pm$ 200 m.y. There is little evidence of geological activity in the Napier Complex during major tectonism in the adjacent Rayner Complex at about 1000 m.y. However, most zircon populations appear to have lost small amounts of Pb at that time. Minor pegmatites were emplaced in the Casey Bay area at about 520 m.y. The youngest age obtained, for a small alkaline dyke, is 482 $\pm$ 3 m.y.

Completentary results are obtained for both U-Pb zircon and Rb-Sr systems at most sites. In common with observations made by the author on lower-grade rocks, Rb-Sr total-rock data have been found to date the development of penetrative schistosity, and thus to correlate more directly with deformation than with the thermal component of metamorphism.

Basement geology of northern Victoria Land, and some possible relations with southeastern Australia

Doone Wyborn

Northern Victoria Land geology is dominated by a thick monotonous sequence of Late Precambrian to possible Early Cambrian quartz-rich greywackes, the Robertson Bay Group, which was deposited on both sides of a meridional volcanic belt, the Glasgow Volcanics and their clastic apron, the Sledgers Group. The chemistry of the greywackes shows some systematic changes from east to west. In the east, remote from the volcanic belt, the sediments are low in Na_2O and probably represent second-cycle sediments derived from earlier sedimentary sequences to the south; closer to the volcanic belt they increase in Na_2O, and particularly Cr, reflecting a detrital input from the volcanic belt. To the west of the volcanic belt the rocks are higher in Na_2O and also Sr, but low in Cr. Here they probably represent first-cycle sediments derived from a granitic hinterland.

The northern Victoria Land rocks were deformed and metamorphosed in the Early Ordovician, during the Ross Orogeny, at the time when large quantities of quartz-rich detritus began to be deposited in the Lachlan Fold Belt of southeastern Australia. Palaeocurrent directions in the Ordovician greywackes of the Lachlan Fold Belt and chemical comparison of these rocks with Robertson Bay Group sediments strongly suggest that the Ordovician greywackes in Australia have been largely recycled from the Robertson Bay Group in Antarctica. During the Ross Orogeny the Robertson Bay Group, west of the Glasgow Volcanic belt, partially melted to produce S-type granites. These granites are higher in Na_2O than Lachlan Fold Belt S-type granites since their source sediments were high in Na_2O. The chemistry of S-type granites in the Lachlan Fold Belt is what one would expect if they had been derived from sediments chemically similar to the eastern strata of the Robertson Bay Group, and the chemical data thus suggest that such strata underlie the Lachlan Fold Belt and were the source of its S-type granites.

Assuming that similar weathering conditions prevailed during the sediment recycling phases, the Na_2O content can provide a measure of the number of sedimentary cycles through which a given sediment has passed. Likewise the Na_2O content of S-type granites can give the same information. S-type granites produced in the Ross Orogeny with 3% Na_2O are derived from first-cycle sediments, most southeastern Australian S-types with 2-2.5% Na_2O are derived from second-cycle sediments, and rare southeastern Australian S-types derived from the Ordovician greywackes such as the Cooma Granite, with 1-1.5% Na_2O, are derived from third-cycle sediments.

East Antarctica - where are the Phanerozoic sedimentary basins?

E.M. Truswell

In the wide span of the East Antarctic coastline which extends from the Amery Ice Shelf at 70°E longitude to Cape Adare at 170°E, geophysical evidence has to date suggested the presence of Phanerozoic sedimentary basins at only three points on the continental shelf. At Prydz Bay, at the mouth of the rift structure now filled by the Lambert Glacier, aeromagnetic data have been used to suggest the presence there of up to 5 km of sediments. The age of these is unknown, but Cretaceous and early Tertiary sequences are suspected. Further east, radio echo-sounding delineation of subglacial topography has suggested that the extensive Wilkes Basin of the continental interior reaches the East Antarctic coast in the vicinity of the Ninnis Glacier and Cook Ice Shelf. The area drained by the Mertz Glacier may represent a separate sedimentary basin. The recent reported discovery of in-situ continental siltstones of Cretaceous age offshore from the Ninnis Glacier supports the concept of sedimentary basins in the area.

In a current study, the distribution of recycled palynomorphs in recent muds around Antarctica has been used as a broad guide to the position of hidden sedimentary sequences on the continental shelf. In three areas concentrations of recycled microfossils are sufficiently great to suggest the presence nearby of eroding sedimentary sequences. Near the western edge of the Shackleton Ice Shelf the presence of Early to Late Permian, Late Jurassic to mid-Cretaceous, and Late Cretaceous to early Tertiary sedimentary sequences is suspected. Near the outer edge of the continental shelf and slope to the east of Cape Carr there are indications of Early Cretaceous and Late Cretaceous to early Tertiary clastic sediments. The same age span is suggested for sequences near the western side of the Mertz Glacier Tongue.

On a reconstructed Australia-Antarctica, the sedimentary sequence predicted for the Shackleton Ice Shelf area probably faced the open Indian Ocean, at least since the northward retreat of India in the Cretaceous. Cretaceous sequences predicted for the other localities occur at points on the Antarctic coast where they would be expected on the basis of most reconstructions. The area east of Cape Carr has as its conjugate coast part of the Great Australian Bight Basin; that off the Mertz Glacier, the area west of the Otway Basin. At both these areas on the southern Australian margin thick Cretaceous rift valley sequences occur.

Geochemistry of Archaean komatiite-tholeiite suites: petrogenetic implications and early mantle evolution

A.Y. Glikson

Major and trace-element distribution patterns observed in Archaean volcanic suites, when coupled with precise geochronological and stratigraphic controls, allow an insight into the geochemical evolution of the early mantle, possible mantle heterogeneities, petrogenetic processes and the nature of the crustal environments in which the volcanic rocks were emplaced. The documentation of Archaean geochemical data in the Pilbara and Yilgarn Blocks and the Barberton Mountain Land in the Kaapvaal Craton, Transvaal, allow a meaningful discussion of these questions. Recent U-Pb zircon and Sm-Nd whole-rock isotopic studies of Archaean volcanic rocks in these terrains furnish precise primary igneous ages for these units, rendering temporal comparisons of the geochemical data possible.

The aim of this paper is to examine the geochemistry of ultramafic-mafic volcanic suites from the Pilbara, Yilgarn, and Kaapvaal shields with reference to the following questions: (1) Comparisons between critical element ratios in the Archaean lavas, modern volcanic suites, and chondrites; (2) possible existence of geochemical variations with time; (3) possible existence of lateral (geographic) geochemical variations; (4) implications to petrogenesis of the komatiite-tholeiite suite; (5) implications to composition and geochemical evolution of the early mantle, mantle-crust, and mantle-core fractionation.

Consistent trace-element anomalies are shown by associated TB (tholeiitic basalt), HMB (high-Mg basalts), and PK (peridotitic komatiites), e.g. (1) high Ni and Cr in Yilgarn mafic-ultramafic rocks and low Ni and Cr in Pilbara mafic-ultramafic volcanics; (2) high Ti and other high-field-strength (HFS) ions in associated TB, HMB, and PK in the lower Warrawoona Group (Pilbara) and in the Sandspruit Formation (Barberton). Long-term and cyclic short-term depletion in HFS and siderophile elements is shown by early Archaean mafic-ultramafic successions. The lateral and temporal variations in ratios of mafic/ultramafic rocks and trace-element distinctions indicated by comparisons between the 3500-3300 m.y. Pilbara and Barberton volcanics and the 2800-2600 m.y. Yilgarn volcanics, indicate significant lateral and temporal heterogeneities in the early terrestrial mantle.

There is a compositional gap between HMB and PK with respect to MgO, Mg' number, and Al_2O_3. In the main this break militates against a crystal fractionation relation between HMB and Pk, although fractionation was likely in some instances. The gap suggests a two-source model for Archaean komatiite derivation: (a) 20-40% partial melting of hydrous pyrolite in a relatively shallow (>50 km) low-velocity zone, accompanied by low-pressure olivine fractionation at shallow depths to produce TB, and (b) episodic ascent of mantle diapirs from depths >180 km and PK magma segregation (~50% melting) at depths of 90-120 km. Green's 1981 model II Archaean geotherm of ca 25°C/km is supported by (1) the quartz-normative to olivine-poor composition of Archaean TB and the orthopyroxene-rich normative composition of Archaean HMB compared to mid-ocean-ridge tholeiitic basalts (MORB), and magnesian and picritic MORB; and (2) the absence of alkaline volcanic rocks in Archaean greenstone belts, except for late Archaean trachytic flows. The indicated instability of orthopyroxene in refractory residues of Archaean magmas thus suggests relatively shallow-level melting in the Archaean.

Evidence exists for geochemical differences between Archaean and modern oceanic mantle sources. Consistently high FeO/TiO_2 ratios pertain to Archaean TB, HMB, and PK, and chondritic or high LREE/HREE (light rare earth/heavy rare earth) ratios pertain to Archaean volcanics, as distinct from the negative LREE anomaly of modern oceanic volcanics. Commonly high CaO/Al_2O_3 and low Al_2O_3/TiO_2 ratios as compared to chondrites is a feature of many Archaean PK. It is considered likely, though by no means proved, that the Archaean mantle was relatively enriched in iron. This observation is relevant to the possible secular segregation of FeO from the lower mantle to the outer core (Wanke, 1982).

Stratigraphic correlation of the Upper Coal Measures of the Sydney Basin with their Equivalents in the Bowen Basin

A.T. Brakel

To understand the sedimentary and structural evolution of the 1750 km-long Sydney-Gunnedah-Bowen Basins trough in Late Permian time, it is first necessary to have reliable region-wide stratigraphic control. The normal correlation tools are inadequate for this task, either because they are inapplicable to coal measure sequences, or because their degree of time resolution is not fine enough. The work of Vail & others established that cycles of relative change of sea level on a global scale have occurred throughout Phanerozoic time, and offer a new means of correlating between basins. To use this method, marine incursions of considerable extent in each basin are interpreted to represent time lines recording global rises in sea level. Such incursions occur at two levels in both the Sydney and Bowen Basins. The Kulnura Marine Tongue (Sydney Basin) can be correlated with the Arkarula Sandstone (Gunnedah Basin) and the MacMillan Formation (Bowen Basin). The higher Denman Formation and its equivalents in the Sydney Basin can in turn be equated with an unnamed burrowed portion of the Burngrove Formation in the Bowen Basin.

Among the implications of this model are (1) the German Creek Formation is equivalent to the basal portion of the Tomago and Illawarra Coal Measure, and Late Permian coal measure deposition started in both basins at about the same time, and (2) the Newcastle Coal Measures are equivalent to the Rangal Coal Measures and the upper tuffaceous section of the Burngrove Formation. No environmental Denman equivalent is known from the Gunnedah region, either because it has not yet been recognised, or because the area stood above sea level at the time of this eustatic high-stand.

It is clear from the literature that correlations of the Sydney and Bowen Basin sequences using marine faunas and palynology give different results. Palynological correlation is also discordant with correlation of the upper coal measures using the global eustacy model, and this leads to the suggestion that certain palynomorph species appeared in the Bowen Basin long before they appeared in the Sydney Basin. It is argued that this occurred because the palynology records climate-controlled vegetation zones which migrated polewards as the edges of the Permian ice cap receded.

Submarine and subaerial diagenesis in coral reefs

John F. Marshall

The earliest stages of diagenesis in coral reefs occur in the near-surface, initially in the marine environment when the reef is actively accreting and ultimately in the subaerial environment when the reef is raised above sea level either by tectonic or eustatic events. Different diagenetic processes occur within these two distinct zones.

In the marine environment alterations to the original reef framework are produced by boring organisms, sediment infilling skeletal chambers, borings, and cavities, and formation of submarine cements. These submarine cements consist of aragonite and Mg-calcite which exhibit varying fabrics and textures. The distribution of these cements indicates pervasive lithification within the relatively massive framework of the windward margin, whereas the cements tend to be less abundant in the more open framework of the leeward margin, and are absent as intergranular cements within the lagoonal sediments.

If the reef is subaerially exposed, the upper part is subjected to diagenesis within the vadose environment where both air and meteoric water are present within the pores. In this zone there is widespread development of secondary porosity resulting from solution of skeletal material. Previously unconsolidated lagoonal sediments are cemented by calcite, and calcite cement begins to infill the moulds and vugs that were produced by solution. Beneath the water table, in the phreatic environment, pores are constantly filled by fresh water, and extensive neomorphism and cement infilling of both primary and secondary porosity takes place.

The geological history of coral reefs, such as those of the Great Barrier Reef, indicates that periods of growth have alternated with relatively long periods of exposure. This repetitive change between marine and subaerial has resulted, in many instances, in superimposition of marine, vadose, and phreatic diagenetic products, resulting in complex changes to the original reef framework.

The Papua New Guinea thrust belt, longitude 141°-144° East

H.L. Davies

The western part of Papua New Guinea, between 141° and 144° east longitude, consists of a central cordillera flanked by the Fly-Strickland plains in the south, and the Sepik plains and north Sepik ranges in the north. The region has the appearance of a classic peri-cratonic orogenic belt, with deformed and crystalline rocks in the north (Sepik complex; north coast complex), a foreland thrust belt in the centre, and craton with virtually undeformed cover in the south.

The north coast complex consists of Late Cretaceous to earliest Miocene intrusive and marine volcanic rocks, unconformably overlain by Early Miocene and younger sediments. The Sepik complex consists of Jurassic to Eocene metamorphic, ultramafic, intermediate intrusive, volcanic and sedimentary rocks, unconformably overlain by Middle Miocene sediments. The foreland thrust belt and cratonic area consist of Permian granite, etc., overlain by a paraconformable sequence of Mesozoic clastic sediments and Cainozoic carbonates, which are in turn overlain unconformably by Plio-Quaternary sediments and volcanics.

The region has evolved by arc-continent collisions in the Oligocene (Sepik complex emplaced) and the earliest Miocene (north coast complex emplaced), and by north-south convergence and east-west left-lateral strike-slip faulting which continues to the present day. The north coast complex has been disrupted by strike-slip faulting. The Sepik complex is thought to be entirely allochthonous and to consist of a thrust sheet, or series of thrust sheets, which have moved as much as 200 km to the south, over possibly cratonic basement.

The locus of convergent tectonic activity has migrated southwards with time and now coincides with the foreland thrust belt which forms the southern slopes of the central cordillera. This is a zone of active folding and thrusting, including both thin-skinned (supra-crustal) and thick-skinned (crustal) tectonism, as indicated by interpretation of surface structures and by strong earthquakes at crustal depths. Magmatic activity, also, has migrated southwards with time, from the line of the Sepik plains in the earliest Miocene, to the southern foothills of the central cordillera in the Pliocene and Quaternary; some of the intrusives are mineralised in copper and/or gold (Frieda River, Star Mountains, Porgera, Ok Tedi). The intrusives are not clearly related to an active subduction system, and possibly were generated by thickening and consequent depression of the base of the lithosphere, induced by continued lithospheric shortening.