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New models for extension tectonics, and their implications for Australian geology

Recognition of the significance of shallow-dipping faults of large areal extent in areas subjected to large-scale continental extension has stirred renewed interest in extension tectonics, both in academic circles and in the minerals and hydrocarbon exploration industries. These subhorizontal faults, termed detachment faults, were first investigated in the North American Cordillera, where they are associated with peculiar bodies termed metamorphic core complexes. Metamorphic core complexes — one of possibly several types of detachment terrane — form when rock is dragged to the surface from deep crustal levels (ductile lower plate) underneath a plate of fracturing and extending upper crustal rocks (brittle upper plate). The detachment faults serve as the locus of major movements between the upper and lower plates, and appear to represent the upper levels of major crustal shear zones formed in an extending orogen. The concept of detachment faulting during continental extension will force a radical revision of many aspects of modern geoscientific theory.

Metamorphic core complexes

The basic characteristics of Cordilleran metamorphic core complexes are illustrated in Figure 1. Multiple generations of high-angle normal faults, listric normal faults, and domino-faults, and major rotation of fault blocks, disrupt and extend the upper plate by 100-400 per cent. Rocks immediately below the master detachment fault generally undergo extensive brecciation, cataclasis, and hydrothermal alteration, resulting in the formation of masses of chloritic breccia capped by ultracataclasite. There is usually abundant evidence of palaeoseismic activity near this zone. The lower plate usually contains mylonites which formed in anastomosing ductile shear zones at deeper levels; these zones have the same overall sense of shear as the detachment faults. The formation of core complexes is accompanied by significant igneous activity.

Three models for the formation of metamorphic core complexes are currently in vogue, each model differing in the interpretation of the detachment faults. The different interpretations are that the detachment faults: (a) represent the brittle-ductile transition; (b) pass through the entire

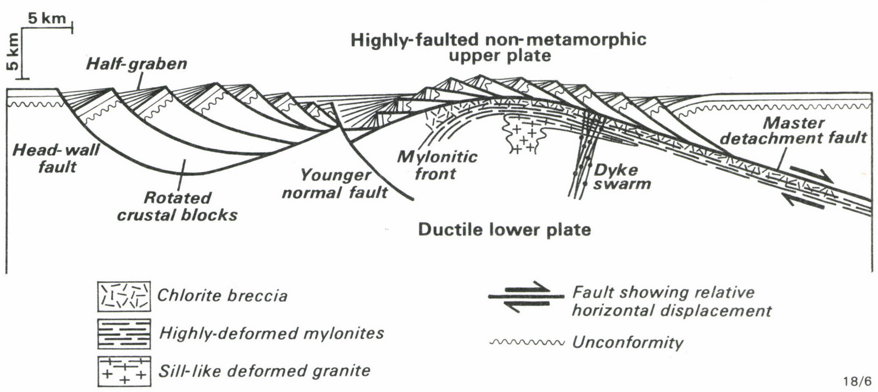

Fig. 1. Schematic representation of some of the more enigmatic features of metamorphic core complexes.

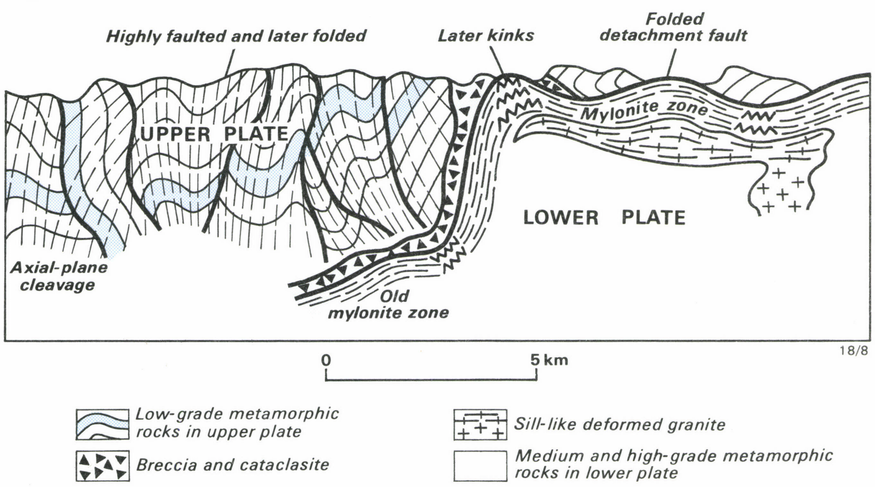

Fig. 2. A schematic view of a metamorphic core complex subjected to compressional orogenesis: the upper plate has developed a slaty cleavage, and the mylonite zone in the lower plate is folded, sheared, and crenulated.

Uranium biogeochemistry in the Pine Creek Geosyncline

The Division of Petrology & Geochemistry has been carrying out research into the biogeochemistry of uranium and its application to exploration, particularly in the flood plains of the South and East Alligator Rivers. Individual species growing over the Ranger One, No. 3 orebody were identified and, where possible, samples of leaves, twigs, trunk wood, and fruit were collected from the nine most widely distributed species of trees and shrubs. These species were also sampled away from the mineralised zone and, in some places, in remote barren (i.e., background) areas.

The distribution of these species over the orebody appeared to be consistent with their distribution elsewhere in the general area and with published information on habitat and distribution — i.e., controlled by topography (essentially proximity to watercourses) rather than by uranium in the soil — and no gross deformities were observed.

All samples were analysed for uranium; although all species showed some uranium enrichment over the orebody, only the larger species gave sufficient anomaly contrast (ratio of anomalous to background values) to be of practical use. These include *Xanthostemon paradoxus* (15-50 ppm U in leaves compared with $<$0.5 ppm from barren areas) and four species of eucalypt—namely *E. tetrodonta* (3-8 ppm,cf. $<$0.3 ppm), *E. miniata* (6-13 ppm,cf. $<$0.4 ppm), *E. porrecta* (1-3 ppm,cf. $<$0.4 ppm), and *E. confertiflora* (2-11 ppm,cf. $<$0.4 ppm). In all species, leaves showed greater and more consistent anomaly contrasts than twigs, fruit, or wood. Though variations in uranium content occur between leaf samples from different parts of the same tree, these proved to be insignificant in relation to the overall anomaly.

Where suitable vegetation exists, geobotanical methods provide an additional exploration tool, particularly in areas where transported surface cover limits the application of soil methods.

For further information, contact Dr Bruce Cruikshank or Mr John Pyke at BMR.

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lithosphere; and (c) disappear downwards into zones of brecciation and cataclasis, which lead to zones of ducile shear.

Fluid flow in detachment terranes

Important types of mineral deposits appear to be associated with metamorphic core complexes and other detachment terranes in the western USA, in particular large-tonnage low-grade gold deposits. To explain these occurrences, we have proposed a conceptual model of fluid flow in a detachment terrane (Fig. 3), as follows.

The upper plate is intensely fractured, and many of its normal faults reach the surface. It overlies relatively hot rocks, because the lower plate consists of deeper-level rocks that have been dragged upwards; in addition, volcanic and magmatic activity adds extra heat. As a result, a large-scale circulation system is set up in the permeable upper plate; this circulation system has hydrostatic fluid pressures, and oxidising chemistry because fractures connect it to near-surface meteoric systems.

Fluid behaviour in the lower plate is rather different, however, perhaps because the upper levels of the lower plate are capped by relatively impermeable ultracataclasites. Abundant tension-gash fillings in the lower plate suggest that fluids there periodically attained lithostatic pressures, and mineralogy suggests that they were in a reducing state. Thus our model invokes two discrete fluid systems. Fluids in the lower plate are at least in part derived from igneous and/or metamorphic sources, and are associated with retrograde reactions — for example, the conversion of biotite to chlorite. Ions taken into solution as a result of these retrograde reactions contribute to large-scale K, Fe, and Mn metasomatism in the upper plate where these fluids leak into it. In the zone where fluids of the lower plate mix with those of the upper plate, the fluids from the lower plate undergo both a sudden drop from lithostatic to hydrostatic pressure and an equally abrupt change in redox potential.

It is not yet known whether gold mineralisation is derived from the circulation system in the upper or the lower plate, but it is clear that the zone in which these two fluid systems mix is one of considerable economic interest.

Detachment terranes in Australia?

What do these concepts mean in terms of Australian geology? Major continental extension occurs in many environments, in particular in back-arc and intra-arc tectonic settings. Continental extension is also associated with major systems of strike-slip faults. The Lachlan Fold Belt may have evolved in such tectonic environments. It therefore is a prime target for the search for Australian metamorphic core complexes and other detachment terranes. However, compressional orogeny probably took place there after the period of exension, so that detachment terranes will be exceedingly difficult to recognise (Fig. 2). An additional problem in Australia may be that characteristic structures of the upper levels of core complexes will have been removed if erosion has exposed deeper levels. The structural studies group at BMR is engaged in an attempt to assess the relevance of detachment-style tectonics to the Lachlan Fold Belt.

Sedimentary basin evolution

The concept of detachment faulting can also be applied to the evolution of extensional sedimentary basins. Extensional faulting typical of that in the Basin and Range has recently been recognised in the Bass, Gippsland, and Otway Basins (see *BMR Research Newsletter* 1), and a possible detachment fault has been recognised in the continental slope south of the Otway Basin (BMR Bass Strait seismic survey, line 22). This has led us to propose a new mechanism for the formation of passive continental margins; our proposed mechanism — based on continental extension by means of detachment faulting (Fig. 4) — assumes that the end result of the processes involved in extension tectonics is the formation of an ocean basin.

The mode of evolution, and the form, of such continental margins and their basins is primarily influenced by the large-scale geometry and the history of the associated detachment faults. Large-scale detachment faulting leads to asymmetric isostatic uplift, and the lower crust is bowed progressively upwards as it is dragged from beneath the fracturing upper crust during the period of extension. Because more than one generation of detachment faulting is to be expected, the result is a complex configuration of faults and fault blocks, as shown in Figure 4. After the period of extension, subsidence related to cooling leads to the development of layer-cake sedimentary basins. The initial detachment-related geometry influences not only the types of structural traps to be expected but also more subtle factors such as the thermal evolution of the basins, which in turn influences the maturation history. A program of geophysical modelling has been initiated.

For further information, contact Dr Gordon Lister, Dr Mike Etheridge, Mr John Branson, Mr Phil Symonds, or Dr Doone Wyborn at BMR.

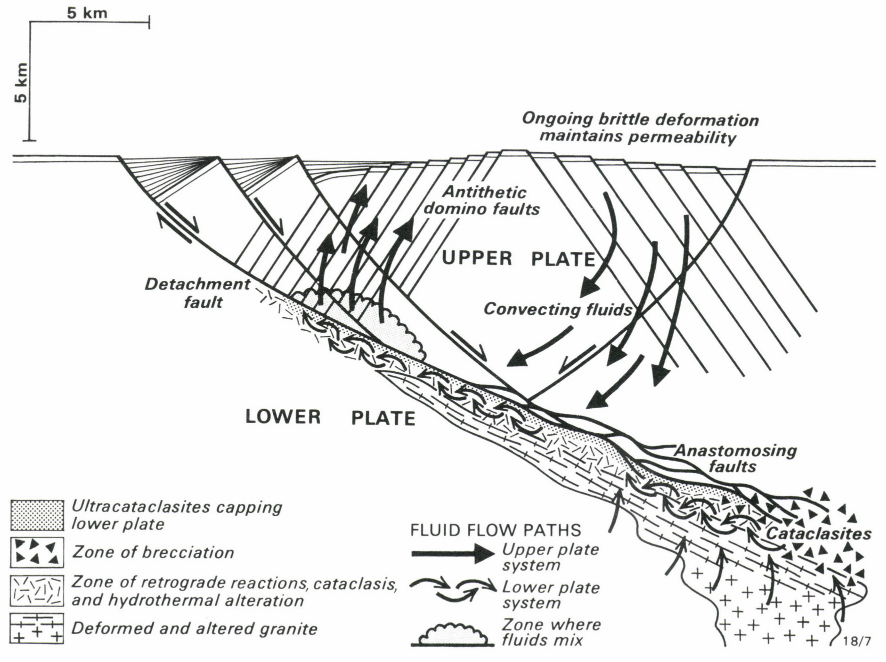


Fig. 3. Conceptual model of fluid flow in a detachment terrane.

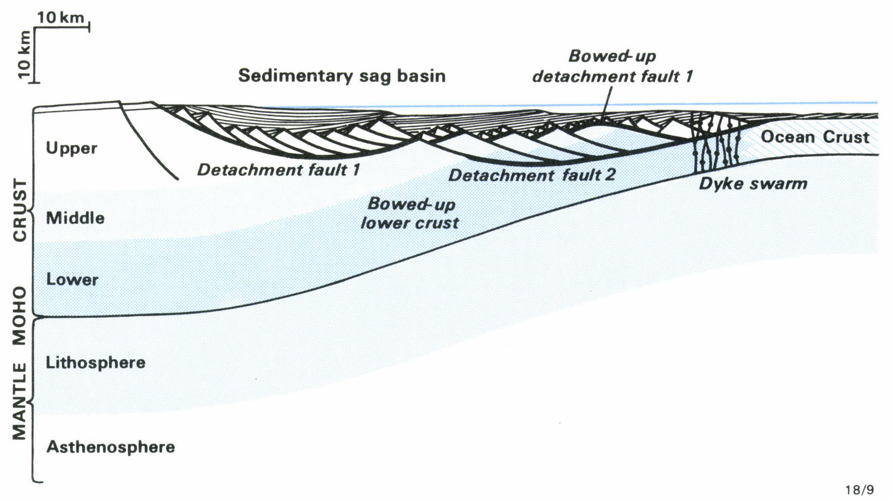


Fig. 4. Evolution of a passive continental margin as the result of detachment faulting.

Honour

David Denham

Congratulations to David Denham, PRS in charge of the Seismic Monitoring Section in the Division of Geophysics, who was made a Member of the Order of Australia 'for services to seismology' in the Australia Day Honours List.

David has authored or coauthored over 40 publications on topics ranging from crustal structure and earthquake risk to tectonics and intracratonic stress, and from 1976 to 1981 he wrote the 'Science in Government' column in *Search*. Between 1978 and 1984 he was Chairman of the Australian Academy of Science Subcommittee on Seismology and Physics of the Earth's Interior. He has been the Australian representative on the Governing Council of the International Seismological Centre since 1977, and was recently appointed Chairman of the IASPEI Subcommission on the Quantification of Earthquakes.

Database advances in palaeomagnetic data processing

The halcyon days of palaeomagnetism, when reputations were built on studies of a few dozen samples, are now a thing of the past. Based on superconducting technology, sufficient advances have been made in the speed and sensitivity of instrumentation that it is now common for palaeomagnetic rock collections to comprise hundreds to thousands of specimens. At the same time, data analysis has become increasingly sophisticated with an approach based on looking at all components of remanence in rocks. In response to these demands the palaeomagnetic group at BMR has developed one of the most advanced database-oriented palaeomagnetic processing systems yet in existence.

For a particular palaeomagnetic study, oriented samples are collected from sites and localities within one or more formations, and may number many hundreds. Sets of specimens drilled from the samples are subjected to detailed stepwise demagnetisation studies, involving 20 or more steps, in order to isolate multiple components of magnetisation; the number of measurements made is generally several thousands. Directional results have to be corrected by the relevant sample orientation parameters, and, for subsequent analysis, ordered data sets are required at the specimen, sample, site, or locality level.

The traditional approach to processing, based on sequential data files, is processing-time intensive during update and retrieval operations, places responsibility for organised data with the operator, and requires considerable operator contact time for data manipulation. Further, the logical connection between various elements in the hierarchical sampling structure is lost, and the potential for devolution of responsibility for routine processing seriously degraded.

To overcome the shortcomings of the traditional technique, BMR has developed a novel and sophisticated approach based on the latest methods of information processing. At the core of the system is an Image database, presently 17 Mb. This is serviced by four groups of programs performing the major processing tasks (Fig.5). The database is a structural organisation of master sets containing different values for fundamental attributes of the data, and detail sets which contain other data related to those attributes and to which the master sets are logically linked. Master sets include information such as formation or region, locality, site, sample, and specimen names; detail sets contain data such as specimen measurements, derived components of remanence, mean directions, and the hierarchical relationship between samples, sites, and localities within a formation. The logical connection between the master and detail sets, which the database approach to storing information provides, ensures that data organisation is automatic. This is also the key to fast retrieval of user-defined subsets of data. Typically, such retrieval operations, involving 20 or more entries from a set of many thousands, are performed in a matter of a few seconds. Currently, the database has a capacity of 9300 samples and 89 000 directions.

Operator interaction with the database is under program control. Functions performed by the four groups of service programs are: data accession, maintenance of data integrity, retrieval-reporting, and data analysis.

Data accession comprises a suite of 11 programs acting as an interface between field and laboratory raw data and the database. Two of the programs process field information, storing the sample orientation and hierarchical sampling structure. The remainder process remanence and susceptibility recorded on cassettes at the Black Mountain Palaeomagnetic Laboratory.

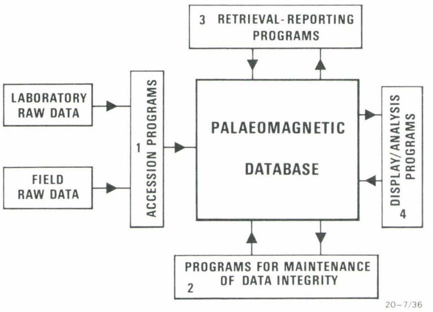


Fig. 5. Schematic overview of BMR's palaeomagnetic data processing system.

Maintenance of data integrity is achieved with three programs. Direct manipulation of data entries — changes, deletions — to rectify errors is not possible because the structural links maintained between entries in the various sets of the database would be disrupted. The purpose of these programs is to facilitate data amendment by allowing transfer of entries to file and straightfoward re-addition of the edited version. The deletion process is particularly useful for extracting data from completed projects for archiving.

The **retrieval-reporting** group of programs provides information on entries and ordering of entries within a data set at a particular level of search. They provide an interrogation facility for measurements, analysed directions, and the sampling structure, with either file or hard-copy output. Ordered data sets are a basic requirement for systematic analysis of data.

Data display and analysis is the final function performed by the service programs. This group acts as a window on the stored data, allowing the operator to view the data graphically on output from a hard-copy plotter, or on a VDU screen; the latter allows interactive analysis. Results can be recorded on a video-copier, and stored in the database for final interpretation.

All of BMR's palaeomagnetic projects — in Australia, Antarctica, Indonesia, and Papua New Guinea — now make use of the new processing system. Its main benefits are: removal of responsibility for organising data from the operator; speed of retrieval of ordered data sets; ease of making alterations and adding new data; and improved quality control and versatility in analysis. As programs are self-explanatory and require minimal knowledge of the system, operators need not be highly experienced.

For further information, contact Dr John Giddings at BMR.

Gold mineralisation at Pine Creek

Research into the structural and hydrothermal evolution of gold mineralisation at Pine Creek (NT) is being carried out in collaboration with Gold Fields Exploration Pty Ltd. The research was initially based on a model of syntectonic veining and gold precipitation from a regional metamorphic fluid. The geometry of veining in the Enterprise mine at Pine Creek had previously been compared with that in the central Victorian goldfields, where a regional metamorphic origin for the mineralisation is widely accepted. The research at Pine Creek has involved a geometric analysis of the veins and folds in the host rocks; a mineralogical, textural, and paragenetic study of the various vein types; and a stable isotope and fluid inclusion study, which is currently under way. The preliminary results of the research are outlined below.

(1) The vein geometry is more complex than previously realised. Syntectonic veins, dominated by saddle-reefs and long bedded veins, are only the first of four discrete stages of vein formation. The stage 2 veins occupy shallowly to moderately east-dipping tension gashes on both limbs of the main mineralised anticline. Veins of stages 3 and 4 are mainly associated with shear zones and faults on a range of scales.

(2) The four vein stages are also mineralogically and texturally distinct. Stage 1 veins are quartz-dominant, and contain minor sulphides but no wall-rock alteration. Stage 2 veins are also primarily quartz, but they commonly contain abundant sulphides (especially arsenopyrite) and are associated with wall-rock alteration (K-feldspar–arsenopyrite–biotite–chlorite). The later-stage veins are characterised by zoned milky quartz, coarse K-feldspar, and botryoidal chlorite. The mineral deposit occurs within the aureole of the Tabletop Granite, and assemblages including cordierite–biotite–andalusite are widespread in the pelites. Textural evidence confirms that the stage 1 veins predated intrusion, and demonstrates that stage 2 veins were contemporaneous with intrusion. There is no evidence of contact metamorphism in the stage 3 or 4 veins.

(3) Preliminary fluid inclusion and stable isotope results are consistent with this scheme of multiple vein episodes and origins. In particular, the stage 2 fluids were generally hotter and more saline than both earlier and later fluids, and had distinctive oxygen isotope values, suggesting a magmatic association.

Gold mineralisation was associated with one or both of the first two stages of veining. There is a gross coincidence of ore grades and concentrations of bedded stage 1 veins on the limbs of the Enterprise Anticline, yet the stage 1 saddle reef on the crest of the anticline is largely barren. A number of larger stage 2 veins are clearly mineralised, and there is a correlation between gold values and stage 2 wall-rock alteration, particularly where arsenopyrite is abundant; stage 2 tension veins are widespread throughout the mineralised zone. The apparent relationship between stage 2 veining and intrusion of the nearby Tabletop Granite raises the possibility of a magmatic hydrothermal contribution to mineralisation. The Tabletop Granite is a pluton of the Cullen Batholith, and a recent study of the Cullen Mineral Field has identified a clear zonation of a number of metals (including gold) around this batholith (see article on p. 8), supporting a genetic link betwen mineralisation and magmatism.

Our preliminary results from the Pine Creek study therefore indicate that either (a) syntectonic gold/quartz-vein mineral deposits have been remobilised and possibly upgraded during intrusion of the Tabletop Granite, or (b) the gold was introduced with the magmatic hydrothermal fluids, and the pre-existing structures exerted some control on fluid migration paths and stage 2 vein location. In either case, the intrusion seems to have been important for the development of ore-grade mineralisation.

For further information, contact Dr Mike Etheridge at BMR, or Mr Peter Holyland at the Dept of Geology, University of Queensland.

Geomagnetic observations at Cape Denison

Cape Denison, a small rocky promontory in Commonwealth Bay on the wind-swept edge of the Antarctic continent 3000 km south of Melbourne, has played a unique role in both the early exploration of the Antarctic and in studies of the Earth's magnetic field.

Here it was that Douglas Mawson's 1911–1914 Australasian Antarctic expedition established its winter quarters — the base for the epic journey inland by Mawson, Mertz, and Ninnis from which only Mawson was to return. Among the extensive exploratory and scientific studies undertaken during the course of this expedition was a remarkable sequence of observations of the geomagnetic field made by Eric Webb under the most appalling conditions (Fig. 6a), including a traverse 650 km inland to the vicinity of the south magnetic pole. The magnetic pole itself (as opposed to the geographic pole) — then at 72.4°S, 155.3°E—was first reached three years earlier by Douglas Mawson, Edgeworth David, and Forbes Mackay during Shackelton's British Antarctic Expedition 1907–1909. Their journey with man-hauled sledges covering 2000 km in 109 days remains one of the most remarkable efforts in Antarctic exploration.

Since 1909 the magnetic pole has drifted more than 1200 km in a north-northwesterly direction and now lies some 100 km offshore (Fig. 6b). It is currently moving northwards at about 8 km per year. Superimposed on this steady drift is a daily movement along an irregular, quasi-elliptical path typically 10 to 20 km in size. In fact the entire global pattern of the Earth's field is continually changing. An accurate knowledge of this secular variation is required not only for modelling and charting the geomagnetic field for navigational purposes, but also for providing information about the dynamics of the Earth's liquid core, the electrical properties of the mantle and lithosphere, and the source of large-scale crustal magnetic anomalies.

In order to monitor the secular change of the magnetic field, BMR operates a group of permanent magnetic observatories (Fig. 6b), together with a network of 68 repeat stations in the Australian region which are reoccupied at five-yearly intervals.

'Project Blizzard'

Few opportunities arise to make repeat measurements at remote sites in the Antarctic. One such opportunity occurred at the beginning of 1985, when a private expedition — 'Project Blizzard' led by William Blunt — visited Commonwealth Bay by sailing boat. The principle objective was to commence restoration of Mawson's hut as part of our national heritage. Before departure last November, a member of the team, Steve Trémont, completed training at BMR, and was provided with instruments to make precise observations of the Earth's magnetic field at Cape Denison, where Eric Webb's pioneering work was conducted.

The expedition has successfully accomplished its objectives and is due to return in April. The magnetic data obtained will be a valuable contribution to BMR's magnetic database for the Australia–Antarctic region; they will considerably improve our knowledge of the local variation of the field, and will be used for computing global models of the Earth's magnetic field.

For further information, contact Dr Charlie Barton at BMR.

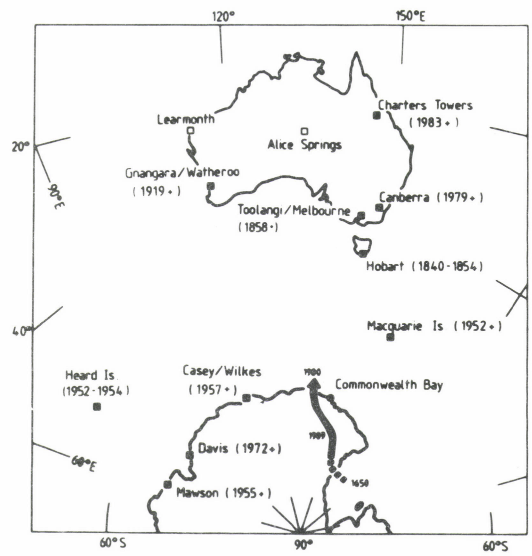


Fig. 6. (a, *left*) Summertime view of the magnetic observatory hut at Commonwealth Bay, 1912-13. The observer is W. H. Hannam, who assisted Eric Webb. (Reproduced from: Australian Antarctic Expedition 1911-1914, Scientific Report Series B, Vol 1, *Government Printer, Sydney,* **1925.) (b, *right*) Australian magnetic observatories. The arrow shows the migration path of the south magnetic (dip) pole from its estimated position in 1650 up to the present day. Dates of operation of the observatories are bracketed. Open squares denote planned new observatories. Casey, Davis, and Toolangi are not run as full observatories.**

New source for daily metal prices

In August 1984, BMR made a computerised database (METPRI) available for public access through the international computer time-sharing network — I.P. Sharp Associates Pty Ltd. METPRI provides ready access to daily metal prices for the eight major metals: aluminium, copper, gold, lead, nickel, silver, tin, and zinc. At least three prices are available for each metal: these prices are representative of Australian and international markets. Daily prices are available as far back as 1971.

METPRI is maintained by BMR's Mineral Commodity Section, which collects, monitors, and publishes prices of metals as an integral part of its mineral commodity studies. The database is updated weekly, and the maximum time lag of prices entered is two weeks.

Access to METPRI is currently restricted to users in Australia, but the database may be offered to overseas users later through the I.P. Sharp network.

METPRI data can be used to provide tables and graphs (Fig. 7) of selected price series, time series price equivalents in foreign currencies, real prices, etc., which can then be stored for future reference or further processing. This can be achieved by linking METPRI to other databases on the I.P. Sharp network, such as ABSDATA (Australian Bureau of Statistics), OECD, IFS (International Financial Statistics), and CURRENCY (currency-exchange-rates database).

For further information, contact Mr Brian Elliott at BMR.

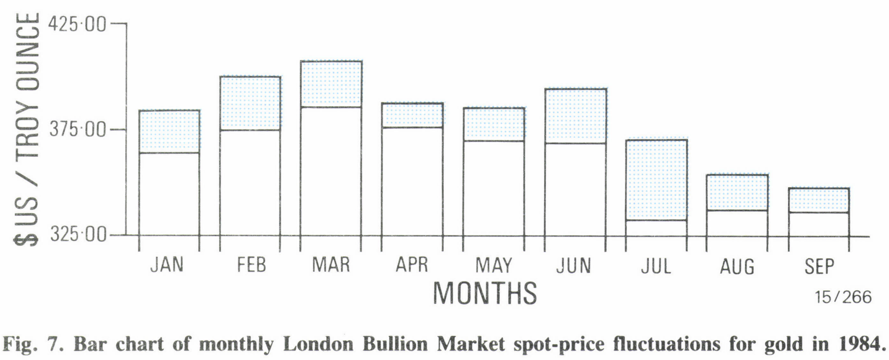


Fig. 7. Bar chart of monthly London Bullion Market spot-price fluctuations for gold in 1984.

Reviews

Selected recent BMR publications

BMR 84: Yearbook of the Bureau of Mineral Resources, Geology and Geophysics, covering geoscientific research, resource assessment, and database development for the year 1 July 1983 to 30 June 1984, edited by G.M. Bladon; 1984; 181pp, 31 figs.; ISSN 0158-7285; $A11.70.

An Annual Report is rarely intended for reading, but rather is a commercial art form which provides a discipline for the staff and a management mechanism for monitoring progress towards corporate objectives. In the non-commercial world of Government departments and instrumentalities, the Annual Report is also a means of justifying work and expenditure in the year under review, and of establishing a hopeful basis for future programs and budget.

BMR 84 is all these things, with the added bonus that it is also readable, at least for those who have an interest in the Australian Earth sciences and who are curious to know how some 250 highly qualified scientific staff are advancing the cause.

Like all Government-funded research institutions, BMR finds it politically essential to claim an economic basis for its research role, and, indeed, the claim is readily sustained. Nevertheless there is also an important element of pure cultural science in the program, needing no other justification than that while being good fun it is also a contribution to the sum of human knowledge — as important in a civilised country as any other cultural pursuit. As the Director of BMR has written elsewhere *(AIMM Bulletin and Proceedings* 289(6), 10–13), the scientific program is designed to ensure that Australia is in the forefront internationally in strategic research concerned with resource potential — and, he could well have added, research concerned with crustal studies and other esoteric geophysical and geological fields of interest.

BMR 84 records the progress made by the various Branches and Divisions with a brief summary of the results of each completed project and a similarly succinct description of the status of those still continuing.

The volume commences with a short overview by the Director, in which he picks out the highlights for the year and draws attention to significant changes or additions to staff or programs. This is followed by a review by each Division/Branch Chief of the work of his group — the groups being the Divisions of Continental Geology, Geophysics, Marine Geosciences & Petroleum Geology, and Petrology & Geochemistry, the Resource Assessment Division, the Baas Becking Geobiological Laboratory, and the Special Projects & Geoscience Services Branch.

The Bureau's program includes many projects which are cross-disciplinary in nature, involving the co-ordination of the total skills of the organisation. Eight programs are scheduled, each with several subprograms. They involve investigations concerned with fossil fuels, minerals, groundwater, earthquake hazards, national and international geoscience maps, overseas programs, petroleum and minerals resource assessment, and national geoscience databases.

The publication concludes with a list of internal and external publications issued during the year, abstracts of papers (some 150 abstracts — related to the eight scheduled programs — are included), and a directory of current staff.

The volume is attractively cloth-bound, featuring on the cover a colour reproduction of the newly chartered marine research vessel, the *Rig Seismic*, and each chapter leads off with a black and white photograph of some spectacular Australian geological phenomenon. In addition, a few of the project summaries are illustrated by maps and diagrams.

Unlike traditional Annual Reports, this one includes a substantial content of technical data, and, for this if not for the other information outlined above, there may be justification for the retail price of $11.70.

The Australian Earth-science community can feel that it is being well served by its national head office.

Reviewed by the Australian Mineral Foundation : AMF Informative Book Review Series No. 907.

Guide to the geology of Australia, by W.D. Palfreyman; *BMR Bulletin* 181; 1984; 111 pp, 94 figs.; ISBN 0 644 02808 4; $5.50

The first and overwhelming impression of *BMR Bulletin* 181 is 'What a good idea; why wasn't it done sooner?' A series of thumbnail geological descriptions and location maps of nearly ninety onshore basins, blocks, troughs, and fold belts is sure to become a standard reference on the shelves of many explorationists, whether they are looking for broad ideas by the compare-and-contrast method, initiating basin studies, or merely compiling the regional chapters of statutory reports. Importantly, each data sheet contains a key reference designed to lead the interested reader further in his/her researches.

Because the concept of this worthwhile little compilation is so good, one hopes that it will lead to second and further editions. The format is such that any or all of the entries could be readily updated as new data become available. The critical comments which follow are minor and are made constructively with the future in mind.

The inclusion of offshore basins would have enhanced the product and widened its interest, especially for the financial paratechnicals who follow the petroleum exploration scene. The notes are a bit on the terse side for some of the larger and more complex structural entities: surely the Canning Basin and the Yilgarn Block, for example, deserve a full page rather than the same space as the Torrens Basin or the Rocky Cape Block. The entities are listed, somewhat erratically, from north to south and west to east; my personal preference would be to have them listed by age from oldest to youngest within each craton. Notable by its absence is any mention in text or map of the geophysical features of the entities listed.

In general the subheading 'margins' for each entity could have been dispensed with, as the margins are evident from the key map. A note on the basement and cover rocks of each basin might have been more appropriate. There is some repetition in wording under the subheadings 'elements' and 'stratigraphy', which could have been combined; a little more lithological, sequential, and abundance data would have been useful here. The subheading 'economic geology' is deficient for some entities — for example, the omission of copper at Mount Isa, the downplaying of copper-zinc in the Yilgarn Block, no mention of uranium in the Eromanga Basin (Lake Frome) or in calcretes on the Yilgarn Block, no reference to a large diamondiferous pipe in the East Kimberley, and a failure to mention that lead-zinc bodies at Broken Hill are of major size. A few of the key references could be improved (e.g., for the Mount Painter and Broken Hill Blocks), but all will allow the reader to follow through.

The impression gained is that this is a labour of love, put together in a somewhat ad hoc way, without the full commitment or co-ordination of BMR management. One wonders how much more of these kinds of data are hidden away in BMR. If there are more, put your research on the side in the meantime fellas, and let's have more like *Bulletin* 181.

Reviewed by Dr D.H. Mackenzie, Chief Geologist (Research), CRA Exploration Pty Ltd, P.O. Box 656, Fyshwick, A.C.T. 2609.

Geology of the Duchess–Urandangi region, Mount Isa Inlier, Queensland, by D.H. Blake, R.J. Bultitude, P.J.T. Donchak, L.A.I. Wyborn, & I.G. Hone; *BMR Bulletin* 219;1984; 96 pp, 79 figs, 22 tables, one 1:250 000 coloured geological map; ISBN 0 644 03743; $17.40

Geologists everywhere, particularly those of Mount Isa Proterozoic persuasion, should welcome the latest 1:250 000 synthesis of field research carried out in the Duchess–Urandangi region, northwest Queensland, by the Bureau of Mineral Resources and the Geological Survey of Queensland.

Produced by BMR in A4 soft-cover format, this synthesis of complex geology has aroused significant controversy and debate in recent, mainly BMR literature. As some well-established tenets of Mount Isa Inlier stratigraphy, correlation, etc. are challenged in this *Bulletin*, a degree of mental flexibility may be required by the reader in order to appreciate the many alternatives raised in the text and map legend.

Three major tectonic elements are recognised in the region. The western, central, and eastern areas are separated by major faults. Stratigraphic and structural correlations between areas are uncertain, and within areas there is considerable lithologic and metamorphic complexity. For each area, stratigraphic descriptions and comment are supplemented by numerous tables, followed by an outline of structure and metamorphism.

An abundance of gneissic rocks, batholithic granites, and extensive, mainly low-pressure amphibolite facies metamorphism strongly suggests that the Duchess–Urandangi region represents a deeper crustal cross-section than contiguous areas to the north. Within basement in the central area, near-pristine 1860 Ma Leichhardt Volcanics are juxtaposed against probable gneissic equivalents of similar age and isotopic signature, and much near-vertical tectonic slicing can be inferred. The possible base of the Leichhardt Volcanics is recognised for the first time as a grit overlying the One Tree Granite, which is now assumed to be older than the Kalkadoon Batholith.

The major fold patterns evident in the region are generally equated with second-generation upright folding about north-trending axes. To the non-expert structural geologist, the inclusion of structurally annotated aerial photos as text figures is a positive bonus, as is the inclusion of many excellent half-page photos throughout the text.

Treatment of basement rocks invites some discussion. Figure 64 in this *Bulletin* indicates that no fewer than seven units may be as old as 2200 to 2400 Ma, including the Corella Formation, which is still considered by many workers to be a major ?1760 to 1740 Ma evaporative carbonate suite. Evidence for the near-Archaean ages is meagre, and one suspects that this interpretation anticipates a future SM–Nd geochronological program

(continued in column 1 on next page)

New focus in the search for uranium deposits

At the meeting of the 27th International Geological Congress in Moscow, 4–14 August 1984, four styles of uranium mineralisation came into special focus as a result of a reassessment of previous known types or the identification of new styles of deposits.

Uraninite veins in ignimbrites

Of the new styles of uranium mineralisation the most unusual was described from a recent volcanic terrane in southeast Peru. The host rocks are a thick pile of flat-lying 4.2-Ma-old ignimbrites covering an area of 2000 km^2; their distribution is apparently controlled by a southeast-trending depression. The ignimbrites, which have a glassy matrix and contain 6–10 ppm uranium, are cut by pure uraninite veins, in two sets, up to 7 cm wide and up to several metres long; secondary uranium minerals are present in the oxidised zone. The two sets of uraninite-filled fracture veins are subhorizontal (parallel to shear joints) and subvertical. There is no alteration associated with the uraninite veins, and additionally there are no gangue minerals. The uraninite is enriched in tungsten and barium. The overall structure suggests that the ignimbrites form part of a resurgent caldera structure. As this deposit was discovered only in 1983, its size and grade have not yet been evaluated.

Alkaline igneous rocks and uraninite veins

Uraninite vein deposits occurring in wall-rocks associated with salic alkaline and carbonatitic intrusives are a new style of deposit that have been reported from Iran, Greenland, and Russia.

It has long been known that some alkaline rocks, particularly the salic undersaturated and carbonatitic varieties, concentrate uranium and can form low-grade large-tonnage deposits (e.g., Kvanefjeld Ilímaussaq Complex, Greenland). Uranium deposits in these primary rocks are usually unattractive owing to their low uranium values (generally 100–300 ppm) and high thorium:uranium ratios.

In Iran, uraninite veins have been identified within fenitised wall-rocks surrounding Alpine carbonatitic dykes. The gangue mineralogy within these uraninite veins is a combination of one or more of the following: aegirine, riebeckite, albite, and carbonates. A feature of these veins is their low thorium:uranium ratio; this enhanced ratio suggests that the uranium, once in solution and travelling through wall-rocks, was transported as a uranyl complex. This style of mineralisation has recently also been identified in fenitised aureoles in basement granite surrounding a central alkaline complex in the Gardar Complex of south Greenland.

A number of Russian papers also addressed 'metasomatic' uranium deposits that have similar characteristics to those described above. Spatially associated intrusive alkaline rocks have been identified in some of these Russian 'metasomatic' deposits.

Bog-type surficial uranium deposits

Of the surficial uranium deposits the bog-type and the newly defined 'young' deposits received marked attention. Uneconomic bog-type deposits have been known for some time, notably in Scandinavia and Ireland. These deposits have not received much attention to date as their economic significance has only recently been recognised. Large deposits have now been identified in Canada, particularly in the Canadian Shield area, as well as in China. The bogs consist almost entirely of sphagnum peat. Uranium concentrations up to 1 per cent (dry weight of peat) extend over several metres thickness. The bog-type deposits make attractive orebodies because the adsorbed uranium is leachable, and ashing has a concentrating effect.

'Young' surficial uranium deposits

The 'young' uranium deposits of North America are associated with organic-rich, poorly drained, fluvial–lacustrine or playa systems. The largest deposits are in southeast British Columbia and northeast Washington; other occurrences are widely distributed in several areas of western USA. The environments that concentrate the uranium also trap molybdenum.

The best known 'young' deposits occur in dry belts where precipitation (mostly snow) averages 25–30 cm per annum. Spring melt water carries heavy concentrations of uranium leached from granitic plutons and salic volcanics. Uranium concentrations in the stream waters are up to 44 ppb, whereas the alkaline lake waters which they feed have uranium contents up to 2000 ppb.

The main host to the uranium is organic-rich sandy silt zones. The uranium concentrations are up to 1 per cent and some are as large as 250 tonnes. As in the bog-type deposits, the uranium appears to be an adsorbed species; in the 'young' deposits the trapping media are organic matter and clay particles. Few, if any, uranium daughter products are present, so at best only mildly radioactive signatures can be recorded. These 'young' uranium deposits offer many mining advantages: the mineralised zones display low radioactivity, the deposits are near-surface, and the high porosity and permeability of the unconsolidated sediments allow the loosely bonded adsorbed uranium to be recovered by in-situ leaching techniques.

For further information, contact Dr John Ferguson at BMR.

New microprobe for Division of Petrology & Geochemistry

In 1983 the Division of Petrology & Geochemistry, in collaboration with the Research School of Earth Sciences at the Australian National University, purchased a new electron probe microanalyser (EPMA). The new instrument — a Camebax Microbeam manufactured by Cameca (France) — was the first of its kind in Australia, and replaced BMR's obsolete Jeol microprobe acquired some fifteen years ago.

The instrument is equipped with three multicrystal wavelength-dispersive spectrometers, which enable elements in the range boron to uranium to be determined at concentrations as low as a few tens of parts per million. It is also fitted with a Link solid-state (energy-dispersive) detector, which is capable of analysing elements above F on the periodic table. A PDP 11 computer operating through a microprocessor effects automatic operation of the spectrometers, stage, and electron beam. On-line automatic data reduction enables rapid non-destructive analysis at the micron size of major and trace elements in a wide range of geological materials.

Full scanning facilities with back-scattered and secondary electron detectors are available on the instrument, enabling its use as a high-resolution (70Å) scanning electron microscope at up to 250 000 times magnification; this facility augments BMR's two scanning electron microscopes. Automatic X-ray imaging and mapping can be carried out by means of the computer control of beam-scanning and camera circuits, so that element-concentration maps and/or profiles of selected samples can be prepared.

In the first year of operation the new EPMA found application in a number of BMR research projects requiring information on mineral chemistry — for example, analysis of ore and gangue minerals from the Lennard Shelf lead–zinc deposit, secondary ore minerals from the Broken Hill orebody, mineral phases in diamond-bearing lamproites from the Kimberley region, mineral inclusions in diamond, and mineral phases within basaltic and andesitic rocks dredged from the Woodlark Basin region during a Tripartite I marine survey. It is expected that the new EPMA will play a major role in providing mineral chemical data on both rock-forming and ore minerals in future BMR research.

For further information contact Dr Lynton Jaques at BMR, or Mr Nick Ware at the Research School of Earth Sciences, ANU.

Reviews

(continued from previous page)

in the region; such dating has recently established ages of about 2400 Ma in both the Tennant Creek and Georgetown Inliers to the west and east of the Mount Isa Inlier respectively.

Sections outlining the regional geophysics, geochemistry, mineral resources, and geological history complete the *Bulletin*. The inclusion of geophysics (gravity, magnetics, radiometrics) and rock geochemistry begins to do justice to the vast amount of data accumulated on the region, and their integration with geology in this multidisciplinary manner is commendable. Most details of economic geology of the region are contained in the respective 1:100 000 Map Commentaries, but some eyebrows will rise at the classification of the Pegmont-type Pb–Zn deposits in the eastern area (Kuridala Formation, Soldiers Cap Group) as Mount Isa shale-hosted type; the distinctive association of the former with BIF, iron–magnesium silicates, graphitic schist, quartz–tourmaline and quartz–garnet–gahnite rocks identify them as probable chemical exhalites contained within a pelitic–psammitic–? felsic volcanic suite, analogous to Broken Hill geology and mineralisation style.

Regarding correlations, this reviewer questions, for example, the separation of the Bottletree Formation from the Argylla Formation, and the somewhat artificial correlations which follow, as depicted in the text and map reference. Argylla Formation U–Pb zircon ages of $1766\pm^{23}_{19}$ Ma and 1785 ± 5 Ma appear to be statistically indistinguishable from Bottletree ages of $1790\pm^{10}_{8}$ Ma and $1808\pm^{23}_{17}$Ma. In this *Bulletin* the two units are grouped together geochemically as A-type volcanics; they are also grouped as an 1800 to 1780 Ma suite of anorogenic felsic extrusives which characteristically form part of a younger volcano–sedimentary cycle in the newly espoused BMR model for the Early to Middle Proterozoic of northern Australia.

Controversy and reasoned argument are no bad thing in geology, and this comprehensive, readable, and never–dull *Bulletin* succeeds both in marshalling the facts and elucidating the differences for the reader. It is typically well-written, highly professional in its presentation, and remarkably free of typographic errors. It warrants space in most geological libraries, and the accompanying map deserves prominent wall space, particularly adjacent to the recently published Cloncurry 1:250 000 Sheet to the north. Regrettably, the two maps are published with different colour schemes. *Vive la difference* perhaps?

Reviewed by Dr G.M. Derrick of G.M. Derrick & Associates, Mineral Exploration Consultants, P.O. Box 184, Corinda, Queensland 4075.

New Ireland Basin petroleum prospectiveness

The New Ireland Basin of northern Papua New Guinea is the subject of ongoing geological and geophysical studies involving BMR, USGS, the Geological Survey of Papua New Guinea, and CCOP/SOPAC (Suva). The aim of all these studies is to better assess the petroleum geology of this arcuate northwest-trending basin, which extends 900 km from northwest of Manus Island to east of New Ireland, and averages 150 km in width (Fig. 8). An initial assessment of offshore petroleum geology (using seismic profiles of the non-USGS ships' tracks) showed that the basin contained more than 500 m of sedimentary strata in places, and pointed to postulated Miocene limestones as exploration targets (Exon & Tiffin, 1984: *Transactions of Third Circum-Pacific Energy & Mineral Resources Conference*, 623–30).

Reassessment of eastern New Ireland Basin

A more detailed study of the eastern part of the basin has integrated the results of detailed stratigraphic studies on New Ireland by GSPNG with further interpretation of offshore seismic data by BMR (Exon & others, expected to be published in *BMR Journal of Australian Geology & Geophysics* in mid-1985).

This study has shown that most of the basin is a structurally simple downwarp which formed as a fore-arc basin lying between an Eocene to Early Miocene volcanic arc in the southwest and an outer-arc high in the northeast. The eastern part of the basin contains up to 5 km of sedimentary rocks interpreted as generally consisting of Lower Miocene and possibly Oligocene volcaniclastics, Lower to Upper Miocene shelf carbonates, Upper Miocene and Pliocene bathyal chalks and volcaniclastics, and Pleistocene to Recent sediments ranging from terrestrial conglomerates to hemipelagic oozes. Plio-Pleistocene volcanism has formed islands in this part of the basin, and has greatly disturbed the older strata.

Petroleum prospects offshore appear to be moderate. Lower to Upper Miocene clastic and carbonate source rocks appear to be present, and presumed reefal bodies in a thick and deeply buried Lower to Upper Miocene platform carbonate sequence, similar to the widespread Lelet Limestone of onshore New Ireland, could form traps.

Major new study of entire New Ireland Basin

The early assessments of the basin (pre-USGS 1984 cruise) showed that there were important gaps in geophysical data in the offshore areas (Fig. 8): a complete lack of multichannel seismic data west of Mussau Island, and lack of a multichannel tie-line in the east. The mid-1984 marine geoscience cruise of the USGS research vessel *S.P. Lee* filled these data gaps with 2000 km of multichannel seismic data, and also obtained dredge samples of Miocene and younger rocks in order to help confirm the seismic interpretation. This cruise took part under the Australian–New Zealand–USA Tripartite II agreement, which was implemented to help assist South Pacific island countries assess their offshore mineral potential.

A full-scale multidisciplinary study of all relevant data is now underway, and Dr Michael Marlow of the USGS will spend a year at BMR to ensure that the study fully integrates the work going ahead at both institutions, and at GSPNG. The results will be published thereafter.

For further information, contact Dr Neville Exon at BMR.

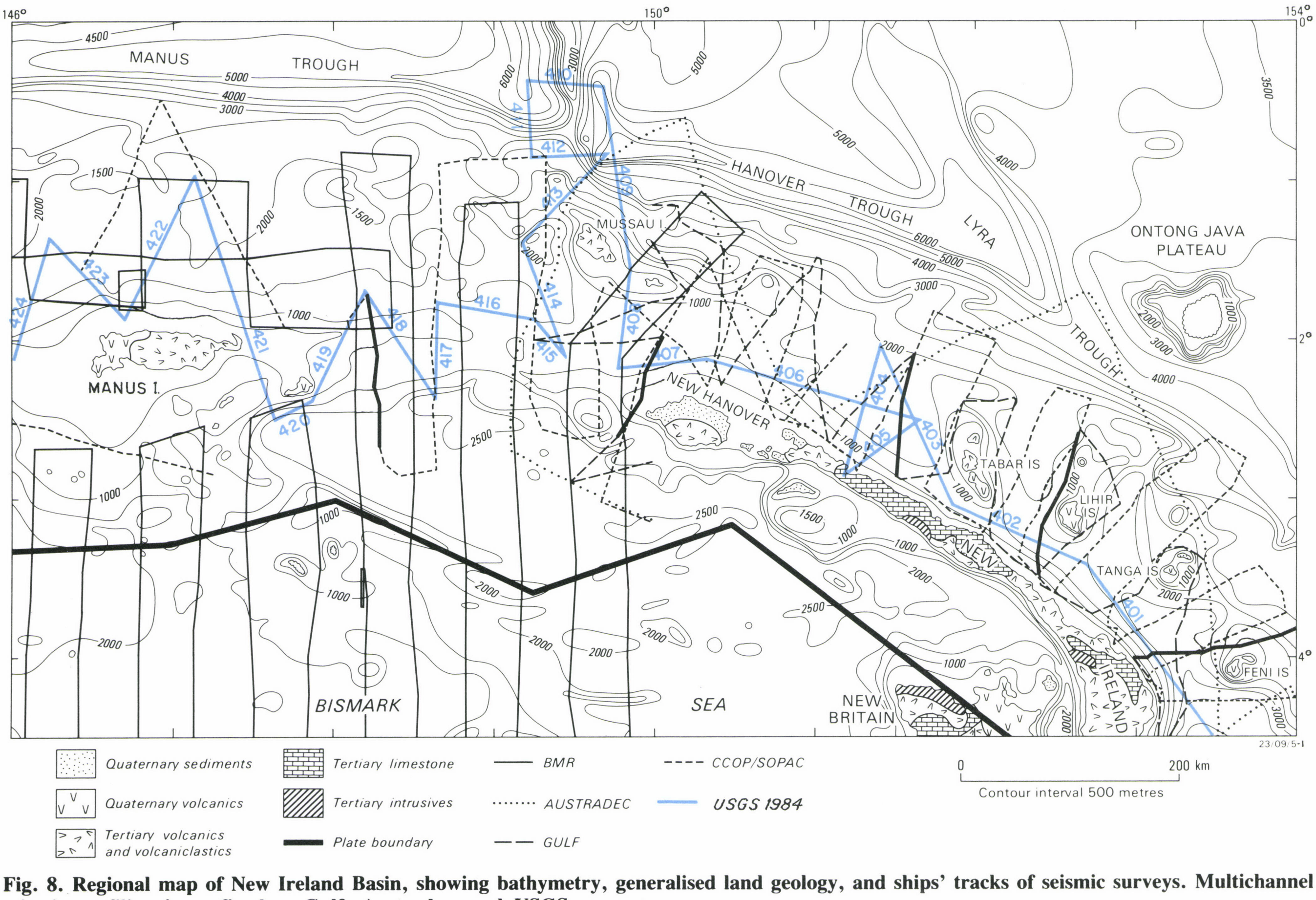


Fig. 8. Regional map of New Ireland Basin, showing bathymetry, generalised land geology, and ships' tracks of seismic surveys. Multichannel seismic profiling is confined to Gulf, Austradec, and USGS surveys.

SG²

GSA's Special Group on Solid-Earth Geophysics

The Geological Society of Australia (GSA) has established a Specialist Group on Solid-Earth Geophysics. The objective of the new Specialist Group is to advance the understanding of the physics of the solid Earth, with emphasis on the Australian region. The group plans to organise seminars, develop communications between Earth scientists in Australia by newsletters and other means, and will represent the interests of solid-Earth geophysicists in Australian education and research fields. The group's interest does not extend to those aspects of exploration geophysics covered by ASEG or PESA.

SG² plans to produce two newsletters each year. The newsletters will contain scientific articles, lists of forthcoming events, membership lists complete with members' interests, book reviews, abstracts of papers presented at group-sponsored symposia, and any other articles of interest to members.

Membership of SG², will be open to Members, Associate Members, and Student Members of GSA.

The annual subscription is $8.00 and can be paid when GSA members renew their membership in 1985. Non-members of GSA who are interested in the activities of SG² should contact Dr Barry Drummond, Honorary Secretary (SG²), at BMR (address on back page), or their nearest GSA Divisional Secretary, for GSA membership application forms.

Ore distribution in the Pine Creek Geosyncline

Now that fieldwork in the Pine Creek Geosyncline is complete, much of BMR's work there during the last 13 years is being synthesised. Two papers presented at the Australasian Institute of Mining and Metallurgy Conference in Darwin late last year synthesise the palaeoenvironmental controls on ore distribution (Needham & Stuart-Smith, 1984: *in* Darwin Conference 1984, *AIMM, Parkville, Vic,* 201–211) and the role of granitoids in ore distribution (Stuart-Smith & Needham, 1984: *in* Darwin Conference 1984, *AIMM, Parkville, Vic.,* 329–338).

Palaeoenvironmental controls

The concentration of stratabound mineral deposits — commonly coinciding with local facies variations — in several formations in the Pine Creek Geosyncline sequence indicates that depositional environment played a major role in ore genesis. Later epigenetic mobilisation and concentration developed ore-grade bodies.

Facies deposited in **supratidal to intertidal environments,** where evaporitic, stromatolitic, and euxinic conditions coexisted — with minimal clastic input — in areas marginal to a mature granitic Archaean landscape, are the most economically important. The Namoona and Mount Partridge Groups (Fig. 9) provide examples of this facies.

Uranium and gold in the lower part of the Cahill Formation in the Alligator Rivers region are stratabound in partly evaporitic and carbonaceous pelites and psammites deposited in a supratidal to intertidal environment. Lithologies that suggest a continuation of this facies extend as far east as Nabarlek. Facies representing a supratidal environment at a similar stratigraphic level crop out in the Rum Jungle region, where — however — the absence of both carbonaceous pelites and uranium deposits implies that reducing conditions were essential to the concentration of uranium.

Mineral occurrences at Rum Jungle are stratabound in the Whites Formation, close to a carbonaceous dolomitic pelite/evaporitic carbonate contact which locally represents the stratigraphically lowest proximal carbonaceous environment.

Distal restricted basins with exhalites provided the second most economically important facies, represented in the South Alligator Group.

The mineral deposits in this group are concentrated in the Koolpin and Mount Bonnie Formations, where the stratified character of most of the larger base-metal and gold deposits implies a syngenetic origin. Minor uranium concentrations in condensed proximal deposits of carbonaceous pelite in the Rum Jungle and Alligator Rivers regions may also be syngenetic. Anomalous tin values in the Gerowie Tuff suggest that the several vein-type tin deposits in the centre of the geosyncline may have formed by epigenetic mobilisation of metal from the felsic volcanics.

An epigenetic volcanic source also accounts for the gold and uranium deposits in the Koolpin Formation at El Sherana (South Alligator Valley). Leaching of the volcanics (in the El Sherana Group) concentrated the uranium and gold, which were precipitated in the reducing environment of Koolpin Formation carbonaceous pelites juxtaposed by faulting against the El Sherana Group.

Role of granitoids

Hydrothermal deposits account for over 90 per cent of mines and prospects within the Cullen Mineral Field, containing gold, silver–lead, tin, tungsten, copper, and uranium. Their main characteristics are their quartz–metal sulphide compositions and their location within north to northwest-trending shear zones and associated minor structures. Some gold occupies saddle reefs, while tin and tungsten minerals may be associated with pegmatite stockworks adjacent to granitoid contacts. Although most deposits are located in shear zones within the Early Proterozoic metasediments, some tin, tungsten, and copper and nearly all uranium occurences are located within late synorogenic to postorogenic granitoids.

A metal zonation pattern from uranium closest to granitoid through tungsten, copper, tin, and silver–lead to gold is apparent with increasing distance from the granitoid contact (Fig. 10). The zonation suggests that mineralising fluids were generated during granitoid emplacement, and that temperature, decreasing with distance from the intrusive contact, was an important control on metal precipitation. In detail, deposition of the quartz–metal sulphide veins was far more complex; it depended on the interaction of the ore-bearing fluids and the host rock, and on the physicochemical changes which took place in the fluids. Chemical interaction with the host rock has been important in the emplacement of silver–lead sulphide veins in dolomitic strata, and in the preferential location of auriferous veins within carbonaceous strata. Wall-rock alteration is also common, particularly in association with uranium, copper, tin, and tungsten vein deposits.

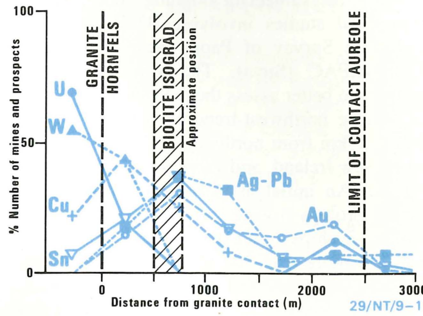


Fig. 10. Zonation of hydrothermal mineral occurrences in the Cullen Mineral Field.

A magmatic source for some metals is indicated by the trace-element distribution in the granitoids. This distribution shows a spatial relationship between uranium, tungsten, copper, and silver–lead deposits and granitoids enriched in uranium, tungsten, copper, lead, and to a lesser degree zinc. There is little evidence for any such relationship involving tin, and no relevant data available to establish any such relationship with gold deposits.

Most of the metal-enriched granitoids are high-level late-stage highly fractionated leucogranites peripheral to the main mass of the Cullen Batholith.

For further information, contact Mr Stewart Needham (palaeoenvironmental controls) or Mr Peter Stuart-Smith (role of granitoids) at BMR.

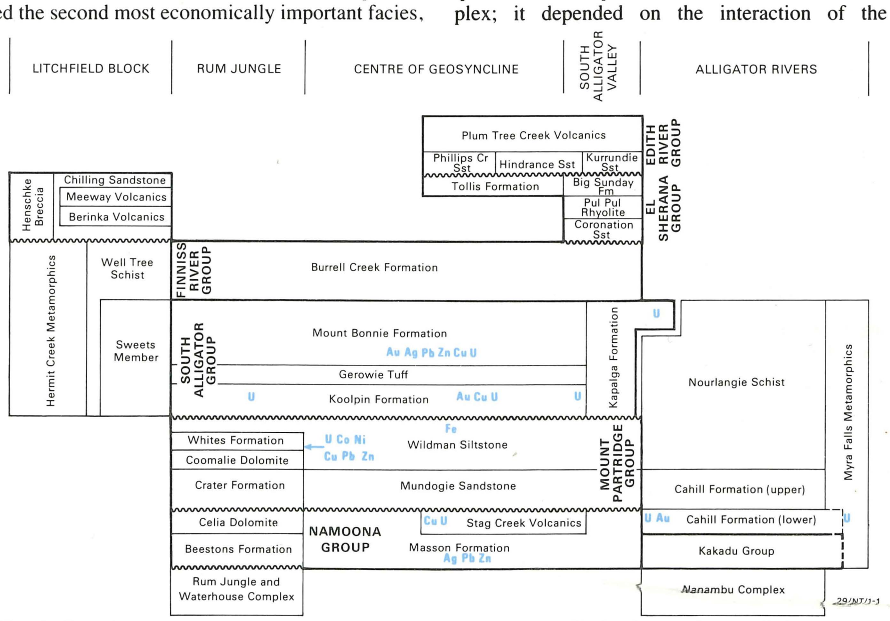


Fig. 9. Stratigraphy of Early Proterozoic rocks in the Darwin-Katherine region, and the levels of stratigraphically controlled mineral deposits. (Note that hydrothermal vein deposits — having no stratigraphic control — are omitted).

Honour

Mike McElhinny

BMR takes this opportunity of publicly congratulating Mike McElhinny, the Chief of the Division of Geophysics, who was recently elected an Honorary Fellow by the Council of the Geological Society of America.

Each year the Society confers Honorary Fellowships on individuals working outside North America who have distinguished themselves as geological investigators. Honorary Fellows are entitled to receive lifetime membership of the Society, affiliation in the specialty disciplines of personal interest, and subscriptions to the Society's three journals.

SG²

Workshop and symposium

BMR is co-sponsoring a workshop — 'The rheology of the lithosphere' — and symposium — 'Intraplate and interplate earthquakes' — of GSA's Specialist Group on Solid-Earth Geophysics between 2 and 5 September 1985 at the Research School of Earth Sciences, Australian ~~National~~ University, Canberra.

Registration forms are available from Dr Marion Leiba, Organising Secretary (SGSG Meetings), at BMR (adresss on back page).

Developing models for gold genesis in northern Queensland

Between them the three large goldfields — Etheridge, Croydon, and Oaks — in the Georgetown region of northern Queensland have yielded about 70 000kg of gold and silver bullion; current ore reserves in the Oaks field alone are at least three times this amount. Because the genesis of the precious metal deposits in this region is so poorly known, BMR is investigating their geology and geochronology in order to aid the development of models that can be applied to assessing gold potential in northern Queensland.

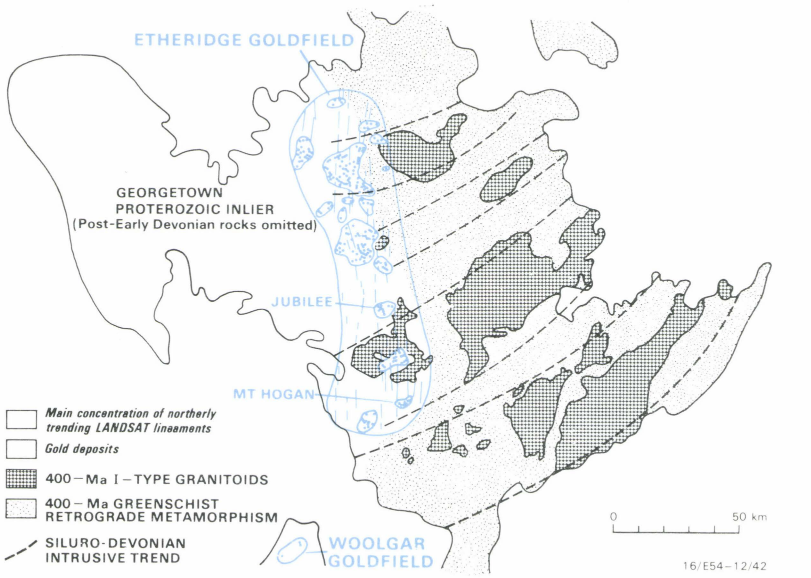


Fig. 11. Siluro-Devonian geological elements and related gold deposits. Gold deposits are confined to a zone of northerly trending lineaments immediately west of the Siluro-Devonian greenschist facies retrograde metamorphic front, and clustered where Siluro-Devonian intrusives intersect this zone.

The Etheridge Goldfield (Fig. 11) lies in a complex Proterozoic terrane in which amphibolite facies metasediments are intruded by Middle Proterozoic and Siluro-Devonian granitoids and late Palaeozoic igneous rocks. A typical gold deposit in this field is hosted by a quartz vein 0.1–4.0m wide in a steeply dipping fracture or shear zone, or by a zone of subparallel veinlets or stringers of quartz. Most veins have only narrow generally chloritic or propyllitic alteration envelopes, although some (e.g., Jubilee Plunger and Mount Hogan) have extensive propyllitic, argillic, and sericitic envelopes that are amenable to isotopic dating if fresh drill core is available. A few other deposits, of which Kidston (Oaks Goldfield) is by far the largest and best known example, occur within hydrothermally altered breccia zones, generally in association with late Palaeozoic igneous rocks.

Deposits of the Etheridge Goldfield have at various times been related to Early Proterozoic metadolerite, the Middle Proterozoic Forsayth Batholith, an ill-defined Siluro-Devonian (400 Ma) thermal event, and Permo-Carboniferous felsic magmatism. Some recently acquired isotopic age, fluid inclusion, and stable isotope data, together with some newly recognised aspects of the regional geology, place some constraints on these hypotheses and provide the basis for a crude genetic model.

Isotopic ages

Hydrothermally altered wall-rocks from the Jubilee Plunger reef in the northern part of the Siluro-Devonian Robin Hood Granodiorite have yielded a model 4 Rb–Sr isochron with an age of 407 ± 6 Ma and initial Sr^{87}/Sr^{86} of 0.719. Similarly sericitised wall-rocks (originally Proterozoic biotite granite) of the quartz veins that comprise the Mount Hogan deposit yielded concordant K–Ar ages with a mean of 400± 4 Ma, which is interpreted as the age of mineralisation.

Pervasively sericitised polymict breccia of the Kidston breccia pipe has produced a preferred Rb–Sr age of 321 ± 15 Ma and an initial Sr^{87}/Sr^{86} of 0.723.

Fluid inclusions and stable isotopes

Preliminary fluid inclusion and oxygen isotope data (the latter analysed by S.D. Golding, University of Queensland) indicate that siliceous fluids associated with the mineralisation event in the Etheridge Goldfield had temperatures of about 200°C and low positive calculated $\delta^{18}O$ values (of about +2‰). These data suggest that the mineralising fluids were dominantly meteoric; though fluid inclusion salinities suggest that a magmatic or metamorphic fluid component was also present.

Regional geological relationships

It is now apparent that 400 Ma I-type granitoids are a major component of the eastern part of the region and closely associated with extensive greenschist facies retrograde metamorphism of that age. Fracture patterns, metamorphic zones, and the characteristics and regional distribution patterns of the granitoids indicate that the eastern part of the region was elevated during Siluro-Devonian time along a diffuse fracture zone of northerly trending lineaments. The Etheridge Goldfield lies along this fracture zone, close to but mostly west of the retrograde metamorphic front. Deposits are clustered where the northeasterly trending granitoid batholiths intersect this fracture zone (Fig. 11).

A few deposits, such as Kidston, lie beyond the Etheridge Goldfield. They are generally of epithermal aspect (i.e., have formed within about 1 km of the surface) and lie within or immediately adjacent to late Palaeozoic volcanic and intrusive rocks, generally within the regional gravity low, and in areas affected by late Palaeozoic hydrothermal systems or explosive hydrothermal or volcanic activity. Therefore they can be regarded as probably having formed in the Carboniferous (like Kidston) although some may be Permian, especially if located within the Agate Creek trend. Continuing research in BMR is aimed at acquiring a better understanding of this important class of deposits, as well as the numerous deposits of the Etheridge Goldfield.

The model (Fig. 12)

The favoured model for the genesis of the majority of deposits in the Etheridge Goldfield is one in which deposits formed from meteoric waters heated to over 200°C by large volumes of I-type granitoids that rose into the upper crust about 400 Ma ago. These magmas caused extensive greenschist retrograde metamorphism, uplift, and fracturing along the western edge of the elevated region. The fluids emanating from some of them provided essential components such as metallic, hydrogen, sulphide, and chloride ions, and mixed with the meteoric waters circulating in the fractured zone above and adjacent to the granitoids. High fracture density, which was strongly influenced by uplift, proximity of subjacent intrusions, and the mechanical properties of

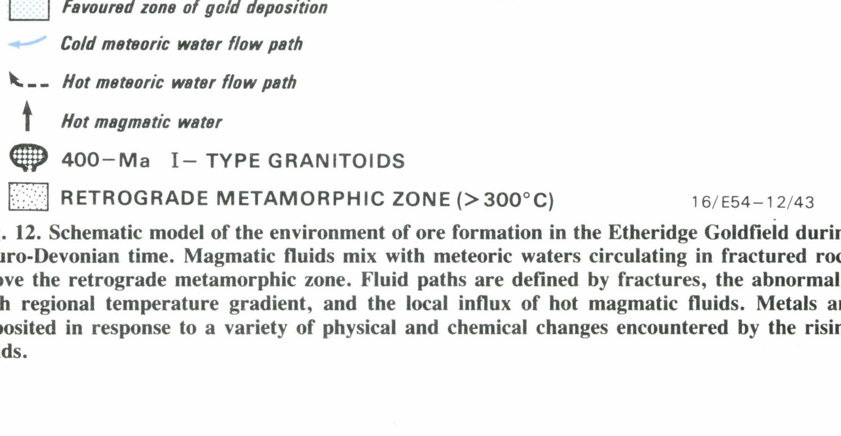


Fig. 12. Schematic model of the environment of ore formation in the Etheridge Goldfield during Siluro-Devonian time. Magmatic fluids mix with meteoric waters circulating in fractured rock above the retrograde metamorphic zone. Fluid paths are defined by fractures, the abnormally high regional temperature gradient, and the local influx of hot magmatic fluids. Metals are deposited in response to a variety of physical and chemical changes encountered by the rising fluids.

the mainly Proterozoic granite host rocks, provided optimum structural conditions for the circulation of ore fluids and deposition of metals in areas overlying heat, fluid, and metal sources.

This model may well apply to similar but widely spaced goldfields from Cape York to Charters Towers, thus linking them all to the emplacement of Siluro-Devonian I-type granitoids. Other models will have to be developed to explain the formation of the various Permo-Carboniferous (e.g., Oaks Goldfield) and Proterozoic (Croydon Goldfield) deposits.

For further information, contact Mr John Bain at BMR.

Gravity units — correction and apology

An article — 'New gravity standards' — was published in *BMR Research Newsletter* 1 to advise transfer of gravity data to new international standards and to clarify the size of the new (SI) unit. Problems in the printing of the Greek letter μ (mū) resulted in three errors in a brief paragraph, which is reproduced below with corrections. We apologise for adding further confusion rather than clarification.

The new unit is the appropriate SI unit of acceleration, the micrometre per second squared ($\mu m\ s^{-2}$), where $1\ \mu m\ s^{-2} = 10^{-6} m\ s^{-2} = 0.1$ mGal = 1 old American gravity unit (g u) = $1\ \mu N\ kg^{-1}$ (micronewton per kilogram).

For further information, contact Mr Brian Barlow or Mr Alan Murray at BMR.

Retirement

Keith Carter

Keith Carter retired from BMR in December 1984 after 46 years in the Commonwealth Public Service — nearly 37 of them with BMR.

Keith derived his initial experience as a geologist from preliminary investigations for the Snowy Mountains hydro-electric scheme (before SMHEA was formed), in the Kowen district of the ACT, in the Cobar district, at Tennant Creek, and at Rum Jungle. Between 1952 and 1960 (and as party leader from 1953) he was engaged in the field mapping and reporting of one of BMR's major programs in the 1950s — the first systematic map coverage of the mineralised Precambrian rocks in northwest Queensland. During this period he found time to complete a thesis on the Precambrian stratigraphy, structure, and tectonic evolution of northwest Queensland, for which he was awarded a PhD from the Australian National University.

From 1960, Keith's experience and skills were used in a supervisory role: in geological mapping in the ACT, PNG, and NT; map editing and compilation; stratigraphic nomenclature; and engineering geology. He was active in engineering geology until 1975, and continued to provide advice on engineering geology and environmental matters until his retirement.

Keith made a contribution to Australian geology as Convenor for several years of the Stratigraphic Nomenclature Committee of the Geological Society of Australia. He produced the first draft of the 'Field geologists' guide to lithostratigraphic nomenclature in Australia', which will shortly be published by GSA.

Keith proposes to remain physically and mentally fit through part-time consulting.

Keith's many friends in the exploration and geotechnical industries will no doubt join his colleagues at BMR in wishing him well for the future.

Oolong earthquake series, August–December 1984

On 9 August 1984 at about 4.30 pm EST an earthquake of Richter magnitude 4.4 occurred within 4 km of one of BMR's accelerographs at Oolong (NSW). The earthquake produced the greatest ground acceleration yet recorded in Australia (Fig. 13), and was reported to be the strongest felt at Oolong since the Dalton earthquake of 10 March 1949. It caused significant cracks to the internal brick wall of the old homestead there.

The ground shook for 10.0 s at an acceleration exceeding $5 \times 10^{-2} m\ s^{-2}$, which is about equivalent to the threshold of human perceptibility. The resultant peak ground acceleration of $3.8\ m\ s^{-2}$ at Oolong was measured at a mean ground period of $0.055 \pm\ 0.018$ s, which is shorter than any previously measured from a damaging earthquake.

About 100 aftershocks of Richter magnitude greater than or equal to 2.0 occurred between August and December 1984. Twenty of these were big enough to be recorded on the accelerograph. From recorded S–P times the distance between the fault and recorder was calculated to vary from 2–4 km. The azimuth of this fault relative to the recorder was roughly north-northeast.

Recordings such as these at Oolong are used to determine attenuation relations of seismic signals from earthquakes in different tectonic regimes throughout Australia. These relations are used for earthquake risk studies.

For further information, contact Mr Brian Gaull or Dr Marion Leiba.

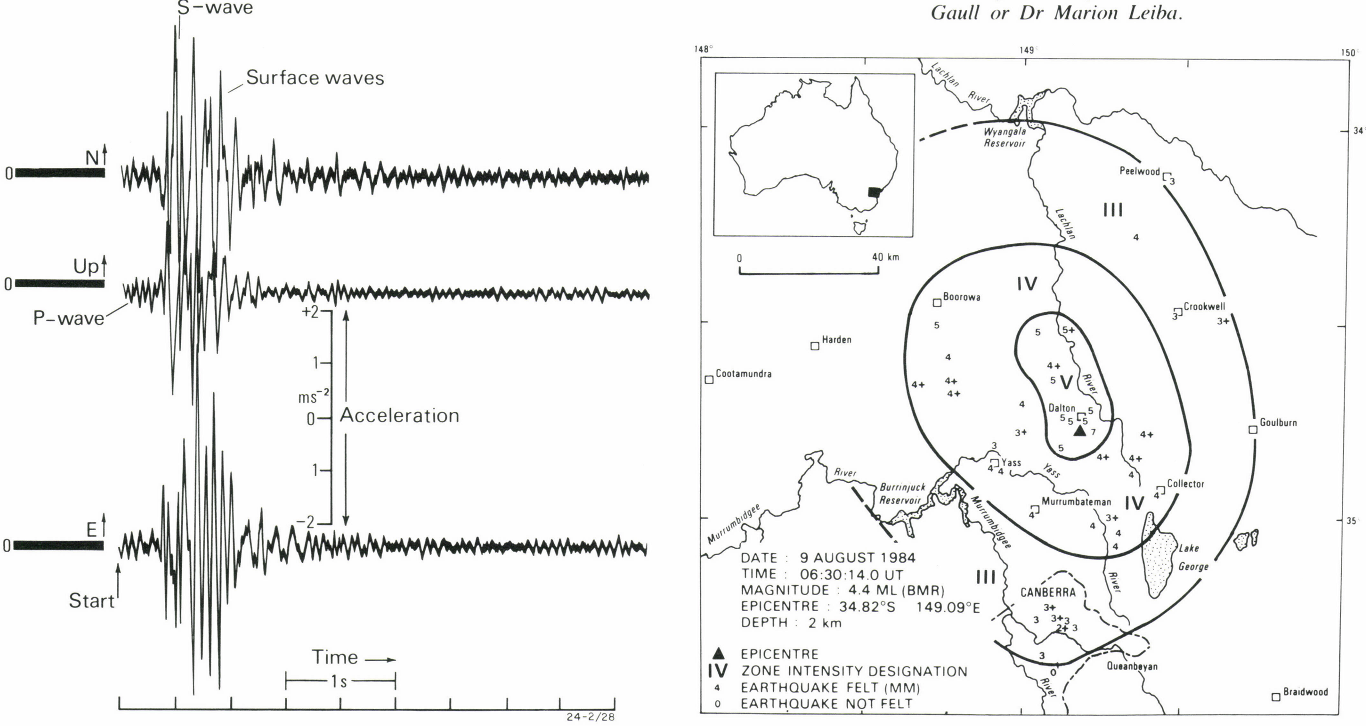


Fig. 13. Oolong earthquake of 9 August 1984; (a, *left*) ground acceleration at Oolong; (b, *right*) isoseismal map.

Nappe tectonics in the Mount Isa Inlier

In a radical reinterpretation of the structural evolution of the northern part of the Mount Isa Inlier, Bell (1983: *Nature*, 304, 11 Aug.,493–497) proposed a major thrust complex involving over 200 km of horizontal transport. The substantial tectonic and palaeogeographic implications of this interpretation demanded that it be assessed as part of the BMR's multidisciplinary study of the inlier.

Principal preliminary results of BMR's study

(1) The first deformational event (D1) that affected rocks younger than 1860 Ma over most if not all of the inlier is of nappe (thin-skinned) style, in which both thrust and fold-nappes have been identified (Fig. 14). As previously documented by Bell and his group at James Cook University, the early thrusts and folds are overprinted by open to tight upright north-trending folds (D2). Subsequent deformation was mainly associated with north-northwest and north-northeast-trending shear zones.

(2) Directions of movement of the thrust and fold-nappes very considerably across the inlier (Fig. 14). East of the Kalkadoon–Leichhardt Block, evidence of consistent westerly to northwesterly movement has been found in the Deighton Pass–Mary Kathleen, Mitakoodi, Cloncurry–Soldiers Cap, Duchess, and Selwyn areas. To the west, Bell interpreted southerly transport in excess of 200 km in the northern part of the Leichhardt River Fault Trough; our preliminary investigations in this area suggest southerly to southeasterly transport of somewhat lesser magnitude. Fold-nappes in the Sybella Granite to the south of Mount Isa have apparently moved eastwards. If this complex movement pattern is substantiated, it implies an unusual tectonic setting and possibly progressive development of the nappes. Distances of nappe transport are more difficult to determine, but the scale of the structures so far identified suggests tens of kilometres of movement.

(3) In addition to north–south folds, steep shear zones with near-vertical movement developed during D2. The largest zones extend along strike for tens of kilometres and define, at least in part, some of the major subprovince boundaries. Movement along these shear zones has exposed a range of D1 structural and metamorphic levels.

Significance of results

Tectonic, stratigraphic, and palaeogeographic interpretation must take into account the major movements associated with both the D1 nappes and the D2 shear zones. For example, stratigraphic evidence suggests that the Kalkadoon–Leichhardt Block, which comprises Early Proterozoic 'basement' as well as the oldest Carpentarian granites and volcanics, was a high during Haslingden Group sedimentation; however, the boundary between the sedimentary rocks and the 'basement' block is at least partly defined by D2 shear zones, and nappes have been recognised in both terranes. The current distribution of these terranes may have little bearing on major palaeogeographic elements.

The identification of nappe-style deformation may have implications for the search for base-metal deposits north of Mount Isa, where much of the Mount Isa Group may be allochthonous and represent juxtaposed originally distant facies. Thus, precise facies reconstruction of the Mount Isa Group may be an important tool in exploration for stratiform lead–zinc mineral deposits.

A final specific example of the stratigraphic implications of the nappe tectonic style concerns the relationship between the Mount Albert and Mary Kathleen Groups in the Mary Kathleen 1:100 000 Sheet area. Derrick & others (1977: *BMR Bulletin* 193) proposed that the Mount Albert Group unconformably overlies the Mary Kathleen Group with substantial angular discordance, implying a major folding event between the two. However, the Mount Albert Group can be interpreted as a series of tectonic klippen which overlie an imbricated sequence of Mary Kathleen Group on a roof thrust. In this structural interpretation, which does not preclude the Mary Kathleen and Mount Albert Groups from being considered as correlatives (a suggestion that gains support from the gross similarity of the two groups), the Mount Albert Group has been transported tens of kilometres westwards to its present position.

These and other reinterpretations of the geology of the Mount Isa Inlier will be compiled on to a series of 1:250 000 structural, metamorphic, and metallogenic maps. We also plan to develop a geographically keyed database containing lithological, structural, petrological, geochemical, geophysical,and metalliferous information.

For further information, contact Dr Mike Etheridge, Dr Gordon Lister, Dr David Blake, or Dr Alastair Stewart.

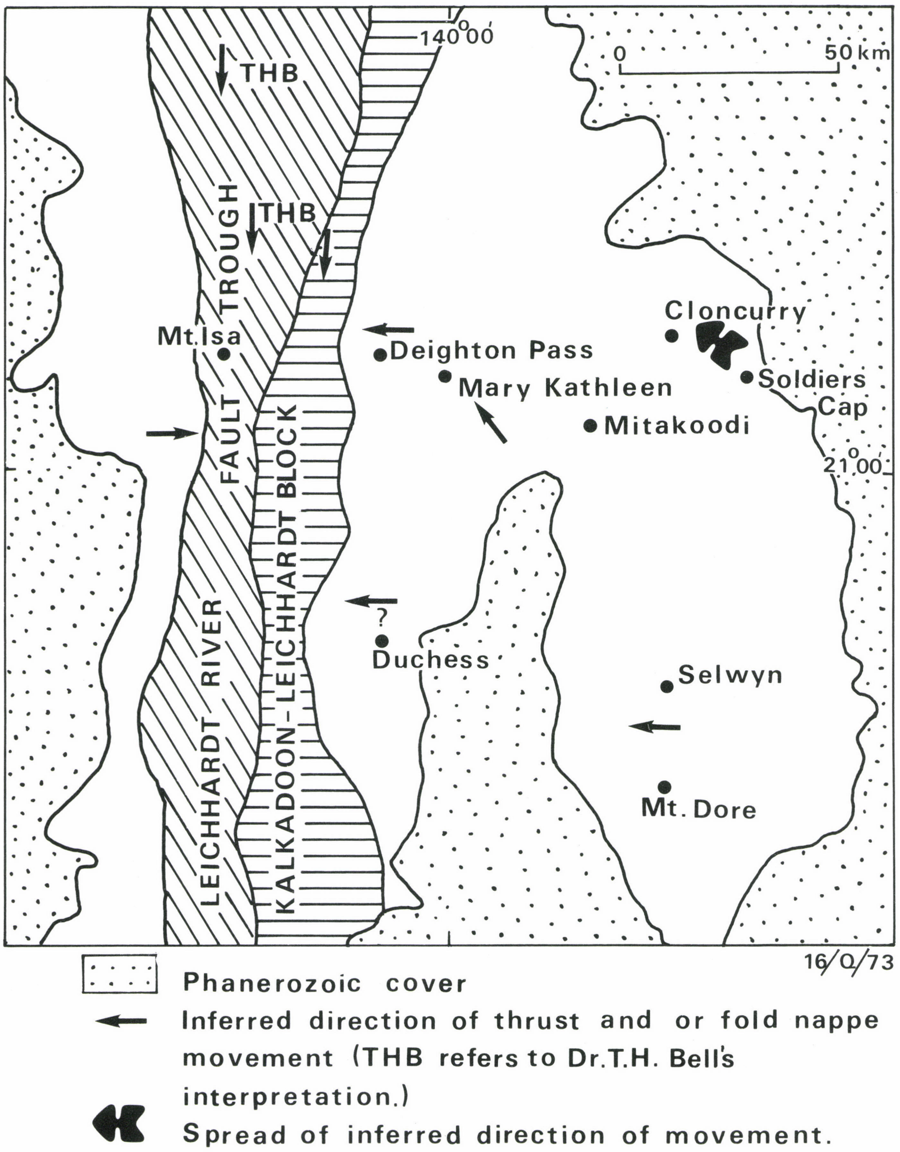


Fig. 14. Locations, and directions of movement of fold and thrust-nappes in the Mount Isa Inlier.

West Woodlark Basin

Structure and potential seafloor mineralisation

BMR, in co-operation with CCOP/EA (Bangkok) and the Geological Survey of Papua New Guinea, recently completed a marine geophysical survey in the west Woodlark Basin. The survey vessel, MV *Tapini*, spent seven days in the area, resulting in the acquisition of 660 line-km sparker seismic and 1000 line-km magnetic data.

The aims of the survey were to study the tectonic evolution of the basin, and to assist identification of favourable sites at the spreading axis for future investigation and sampling of polymetallic hydrothermal mineral deposits. Being an active rift system with seafloor opening at an early stage of development, the west Woodlark Basin is considered highly prospective for hydrothermal sulphide emanations and accumulations. Very little exploration in the basin for such mineral deposits has been done in the past. Rift environments in other parts of the world are known to contain sulphide deposits in excess of 30 $\times 10^6$ tonnes.

Five north-south lines were surveyed across the basin, including two which coincide with lines mapped by *HMAS Cook* in 1983 using the SEABEAM multibeam bathymetric swath survey system.

(continued in column 3, p.14)

Australia's first Laser Raman microprobe

The first Laser Raman microprobe facility in Australia is currently being commissioned in the Central Science Laboratory, University of Tasmania, as a joint Bureau of Mineral Resources/University of Tasmania research project. Using the Australian Research Grants Scheme and university funding (about $20 000) a team at the University of Tasmania (Solomon, Higgins — both now with BMR — Waterworth, and Bignall) began in 1982 the design and construction of a Laser Raman microprobe attachment to the Carey 82 Laser Raman Spectrometer.

With a Laser Raman microprobe it is possible to qualitatively and quantitatively analyse fluids and solids within fluid inclusions in crystals. An accurate knowledge of fluid composition allows numerical modelling of the processes of element transport and deposition. The development of a Laser Raman microprobe facility is important to the field of ore genesis, in which traditional qualitative methods of visual observation and destructive methods such as bulk extraction and mass spectrometry are fraught with imprecision and uncertainty.

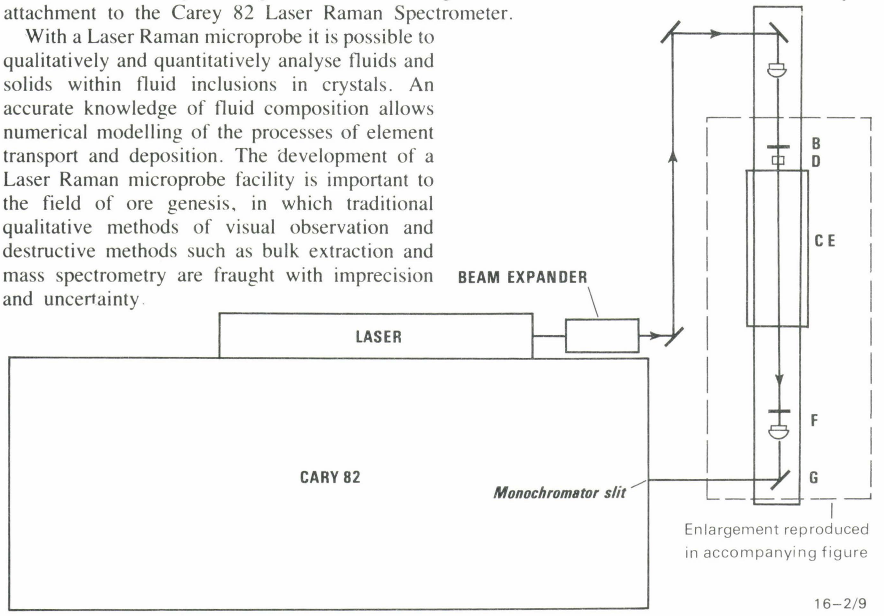


Fig. 15. General layout of the Laser Raman microprobe system.

A lack of information on ore solution composition has limited previous studies of ore genesis, and there is a particular need for accurate information in high-temperature (300–600°C) systems (such as Sn–W deposits at Aberfoyle, Anchor, Mount Bischoff, etc.) where fluid inclusion studies indicate a complex fluid evolution involving variable salinities and compositions with time and the presence of gases such as CO_2,CH_4, and N_2.

The Laser Raman microprobe attachment is mounted with the Raman Spectrometer on a vibration-free table (Fig.15). The unit has a 4W argon ion laser and a Coherent Radiation tunable dye laser, providing special advantages for coloured samples. The output beam is expanded in diameter and spatially filtered before entering a pinhole which eliminates the non-lasing emission lines from the laser radiation. A long-focal-length microscope objective (C, Fig. 16) focuses the beam (2 μm diameter) on to a sample through a hole in an ellipsoidal mirror collector (E). The focusing objective is also used to view the sample by means of a beam splitter (D) and eyepiece. The sample holder may be cooled by liquid N_2, and is mounted on a double-axis translator to allow exact positioning of the sample. The scattered light is collected by a high-numerical-aperture (–0.86) ellipsoidal mirror (E) whose major axis is centred on the back-scattering direction. The scattered light is focused at the far focal point of the mirror, which is the location of the exit pinhole. This beam is imaged on the entrance slit of the Cary monochromator (Fig. 15).

In fluid inclusion applications the microprobe system focuses a laser beam (of less than 2 μm diameter), and the laser radiation may be used to excite vibrational spectra, even from individual phases (solid, liquid, gas) in multiphase inclusions. If polyatomic species (e.g., SO_4^{2-}) are present the internal vibrations of the free ions are characteristic, and quantitative analysis is possible. A detection limit of 200 ppm has been demonstrated for SO_4^{2-} concentration in the aqueous phase of an inclusion. Monatomic ions have no vibrational spectra, but their presence can be qualitatively determined by forming crystalline hydrates at low temperature (e.g., $NaCl.2H_2O$, $CaCl_2.6H_2O$).

Laser Raman studies of fluid inclusions also have included measurements of:

— the pressure of gaseous CH_4,
— N_2/CO_2 and $CH_4/CO_2/H_2S$ ratios in gases
— and carbon isotopes ($^{13}C/^{12}C$) in liquid CO_2 and organic fluids;

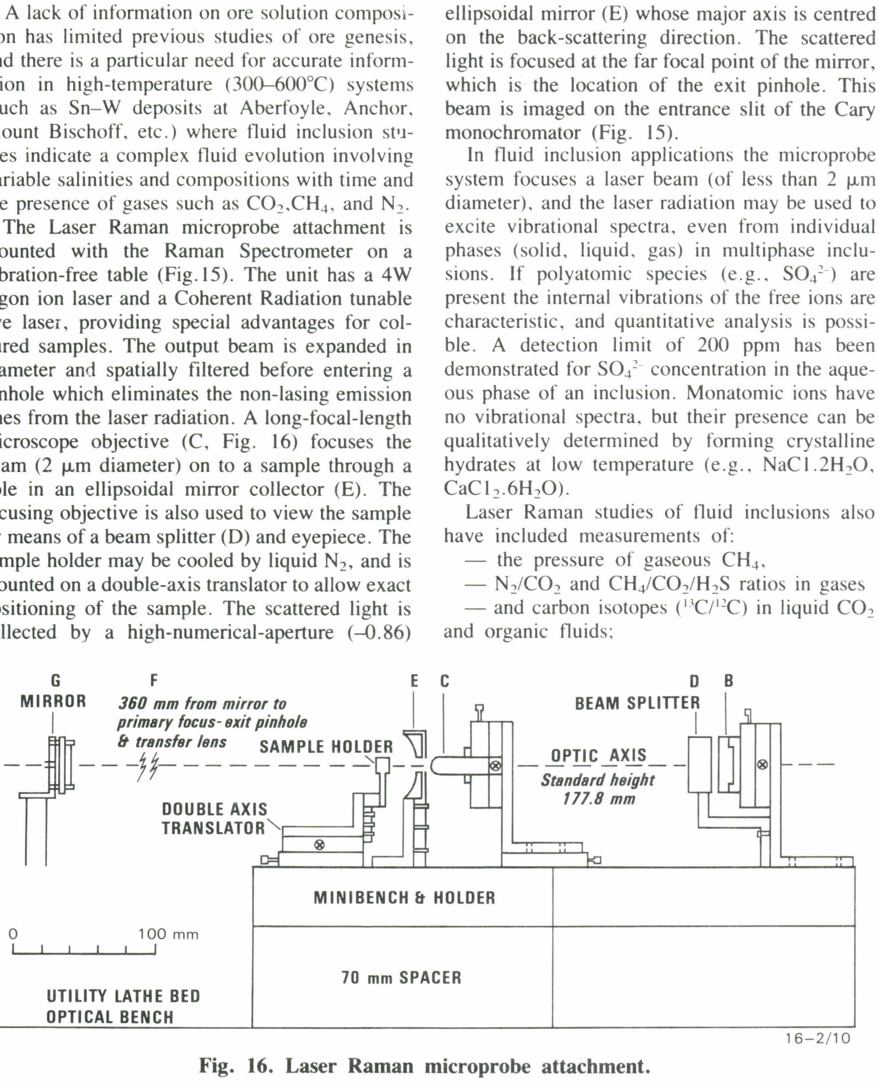


Fig. 16. Laser Raman microprobe attachment.

determination of H_2S and HS^-, and CO_2 and CH_4, in aqueous solution; and identification of liquid CO_2 and many daughter crystals such as anhydrite, apatite, etc.

In 1984, Dr T.P. Mernagh joined BMR and has been outposted to the University of Tasmania to commission the instrument, to develop spectral information useful in the study of ore solutions, and to prepare standards and data reduction computer software programs.

Initially the system will be used for determining the Raman spectra from a suite of minerals and fluid mixes of geological and chemical interest. This will involve, for example, powdered and oriented single-crystal studies of minerals common as daughter salts in fluid inclusions or as trapped phases (e.g., hematite, apatite, carbonate), and vibrational-spectroscopic investigations of the CO_2–H_2O, CH_4–H_2O, N_2–H_2O, H_2S–H_2O, $NaCl$–H_2O, KCl–H_2O, $MgCl_2$–H_2O, $FeCl_3$–H_2O, and $CaCl_2$–H_2O systems.

The Laser Raman microprobe will benefit genetic studies of several Sn–W and Au investigations currently being undertaken by the Division of Petrology & Geochemistry. These include Aberfoyle (Tas.), Mount Paynter (NSW), Mount Carbine (Qld), and Red Dome and Starra mines (Qld). The instrument will also be used in petrological and chemical studies by staff in the Geology and Chemistry Departments at the University of Tasmania.

For further information, contact Dr Mike Solomon or Dr Neville Higgins at BMR, or Dr Terry Mernagh at the University of Tasmania.

Distribution of phosphate deposits around the Precambrian–Cambrian boundary

In a recent article in *Nature* (Vol.308, p.231–236) P.J. Cook and J.H. Shergold of the Division of Continental Geology concluded that many of the well-documented features at the Precambrian–Cambrian boundary can be related to a major phosphogenic event at about that time.

A demonstrable sustained period of phosphogenesis commenced towards the end of the Late Proterozoic, and reached a maximum at the beginning of the Early Cambrian. During this time more than 100 major deposits and occurrences of phosphorites accumulated in many parts of the world. This event was probably related to a period of enhanced circulation within the oceans, particularly oceanic overturn, following a prolonged period of anoxia, during which high-phosphorus waters were formed in the deep ocean. Whilst the reasons for the phosphogenic event are unclear, the final glaciation of the Late Proterozoic may have been a possible trigger mechanism. Alternatively, and more probably, the modification to oceanic circulation was induced by a phase of continental drift which provided an ocean–continent configuration (possibly a narrow latitudinal near-equatorial ocean) that in turn produced an increased rate of oceanic overturn. An important component may also have been major sea-level rises and the formation of extensive shallow epicontinental seas, which were available for colonisation and also provided 'traps' for phosphate grains. These various changes are reflected in the isotopic signatures (a major change in δS^{34}) of the Yudomski Event.

The Yudomski Event and the associated phosphogenic event were in turn followed by the

(continued in column 3, p.14)

BMR's down-hole EM omnidirectional probe

Surface geophysical methods have an important role in the search for deep metalliferous targets. In particular, effective down-hole exploration tools are necessary in order to maximise the effectiveness of expensive drilling programs.

BMR investigations into commercially available down-hole EM instruments showed that deficiencies exist in their ability to detect steeply dipping targets, mainly because they use single-axis detectors. As there were no commercial plans to redress this deficiency, BMR embarked on the development of a frequency-domain EM system with a probe containing three mutually orthogonal detectors.

Initially a three-component probe was developed, and 'off-the-shelf' electronic measuring equipment was used for the up-hole electronics. Following successful field testing, project work has continued to the stage of producing a prototype instrument.

Background

To optimise the detection of a subsurface conductor, it is imperative not only to ensure that the primary field couples well with the conductor but also that the secondary field couples strongly with the detector. In conventional single-axis down-hole EM, these conditions are frequently not achieved. This is due to only part of the information available being observed by a single-axis system, thus resulting in poor coupling of the detector with the secondary field. To minimise this problem may require large transmit loops and/or careful system alignment. The effect of these problems in single-axis systems may reduce the anomaly amplitude and introduce geometric noise.

These geometrical limitations do not apply to an omnidirectional system, which produces quantities independent of the orientation of the probe and always measures and separates — from the resultant field — the full secondary component. Hence small, vertical, or otherwise complex loops can be employed with an omnidirectional system to maximise the detection of conductive targets.

BMR omniprobe system

The receiving end of the system consists of a probe (Fig. 17a) containing receiving coils able to measure the field in three mutually orthogonal directions, instead of solely along the axis of a drillhole. The probe is slender and so can be used to log holes down to BQ (60 mm diameter), an important requirement in metalliferous exploration. The signals from the three sensors are brought to the surface by separate pairs of wires in a multiconductor cable.

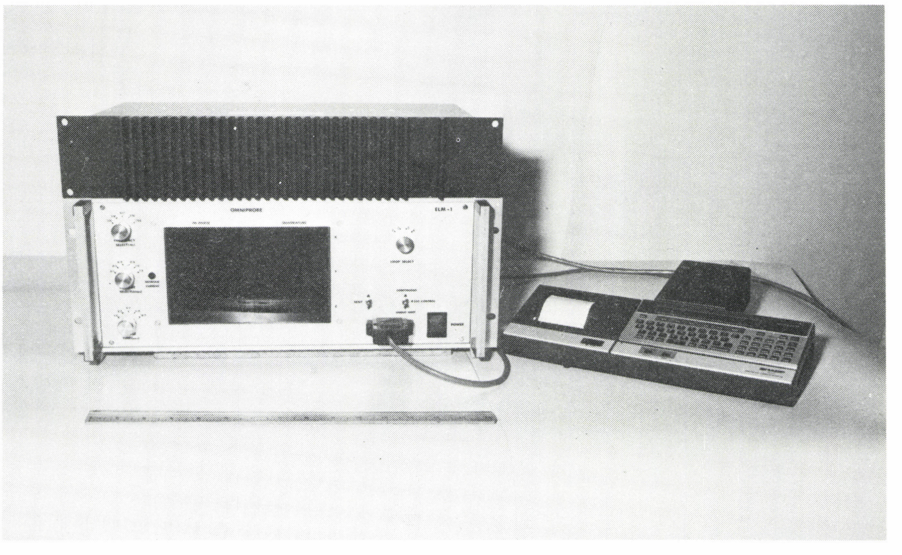
The signals from the probe are filtered and preamplified in the front end of the surface instrumentation (Fig. 17b). The amplified signal is fed into a three-component autoranging vector voltmeter. This instrument uses a voltage-to-frequency conversion technique, and is a fully integrated device, thereby providing excellent noise-reduction properties. This procedure is followed by up/down counting to measure the in-phase and quadrature components of the signals simultaneously.

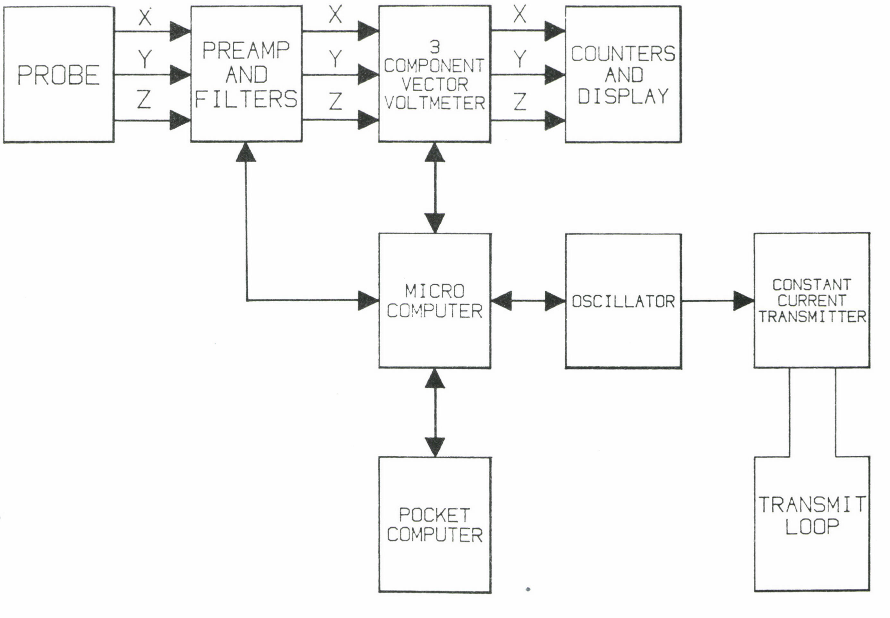
The signal sent to the transmitting loop originates in a hybrid digital/analogue-switched oscillator that is locked in frequency and phase to a quartz crystal. A 300-watt constant-current amplifier, with overload protection, excites the transmit loop.

The various control and data acquisition functions are handled by the central microcomputer. A pocket computer allows the operator to interact with the microcomputer via an RS232 serial line. The pocket computer performs the reduction and allows plotting of results on an in-built four-colour printer/plotter. Although the plots are small (58 mm paper width) the information plotted has sufficient resolution to allow first-look interpretation. If desired the pocket computer may be connected to an audio-cassette recorder for data-file archiving.

(continued in column 3, p.14)

Fig. 17. (a, ***below*****) Omniprobe; (b,** ***top right*****) surface instrumentation: acquisition electronics, constant-current amplifier (in overlying black box), and pocket computer; (c,** ***bottom right*****) omniprobe system block diagram.**





?Lower Proterozoic migmatites in the Mount Isa Inlier

A belt of probably Lower Proterozoic migmatitic rocks up to 8 km wide has been traced for about 70 km along the western margin of the Kalkadoon–Leichhardt Block, to the east of Mount Isa. The migmatites are multiply folded, and consist of thinly banded metasediments, represented by grey micaceous gneisses with fine to coarse leucosomes, and generally subordinate metamorphosed igneous rocks of probably both extrusive and intrusive types, represented mainly by grey felsic gneisses with thin wispy leucosomes. These rocks were intensely deformed and highly metamorphosed before they were cut by a variety of igneous intrusions — including fine-grained tonalite, granodiorite, and pale grey granite, coarsely porphyritic Kalkadoon Granite and associated veins of leucogranite, felsic dykes of Bottletree and Argylla-type chemistry, and many amphibolite dykes — and before they were overlain unconformably by metasediments and metavolcanics of the 1790 Ma old Bottletree Formation to the west. The migmatitic sequence may therefore be appreciably older than the Kalkadoon Granite (~1860 Ma) and comagmatic Leichhardt Volcanics (~1865 Ma), which have generally been regarded as the oldest rocks of the Kalkadoon–Leichhardt Block, and possibly includes rocks similar in age to the Yaringa Metamorphics (exposed west of Mount Isa), which are older than 1900 Ma.

The migmatites of the Kalkadoon–Leichhardt Block have been mapped previously as part of the undivided Tewinga Group (Duchess Region 1:100 000 geological map) and Leichhardt Metamorphics (Mary Kathleen 1:100 000 geological-map). On the 1:500 000-scale geological map of the Mount Isa Inlier, currently being prepared, they will be distinguished as a separate stratigraphic unit. Like the possibly correlative Yaringa Metamorphics, they do not appear to contain any significant mineral deposits.

For further information, contact Dr David Blake at BMR.

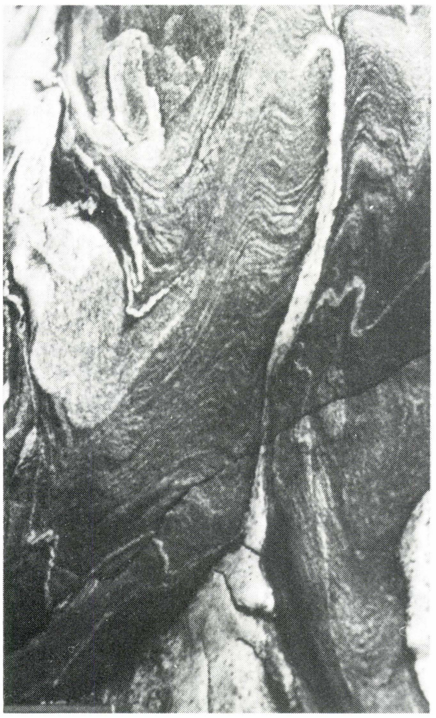


Fig. 18. Folded metasedimentary migmatite and leucogranite veins exposed 60 km south-southeast of Mount Isa. The field of view is 20cm wide.

Chemical evolution of Proterozoic felsic igneous rocks

Two distinct groups of Lower to Middle Proterozoic felsic igneous rocks based on age and geochemistry can be recognised in northern Australia. The older group ranges in age from 1900–1820 Ma, and the younger group from 1800–1600 Ma. Both groups are largely derived from Early Proterozoic lower crustal sources.

Granites and their comagmatic felsic volcanics of the 1900–1820 Ma group are compositionally uniform, and occur in every Australian Proterozoic orogenic domain, covering at least 30 000 km^2. Petrographically most rocks belonging to this time slot are I-type, and formed principally by restite unmixing. Compared with Phanerozoic I-type granites they have higher contents of K_2O, Rb, Zr, La, Ce, Th, and U, and lower MgO, CaO,Ni, and Cr contents (even at relatively low SiO_2 values of 60–65%). In addition, these rocks have high Rb/Sr and low Sr^{87}/Sr^{86} initial ratios (0.7029–0.7065), and modelling of their source ages implies that they had a short prehistory (not more than 200 Ma) and that the source of these rocks was a major crustal accretion event between 2300 and 2000 Ma. This accretion event is believed to involve significant underplating of Archaean crust by mantle-derived mafic material that was relatively enriched in K_2O and LREE.

Felsic plutons and volcanics of the 1800–1600 Ma group are essentially anorogenic and similar to A-types. They were emplaced principally at 1740–1720 Ma, and 1670–1640 Ma. They are more variable in composition and more enriched in K_2O, Th, U, Zr, Nb, and Y than the 1900–1820 Ma I-types, and they commonly contain accessory fluorite. Unlike plutons of the 1900–1820 Ma group, those of the 1800–1600 Ma group frequently show evidence of fractional crystallisation. They are thought to have been derived by small degrees of partial melting from mafic sources which were underplated at various stages in the evolution of the Proterozoic mobile belts, particularly during times of basaltic volcanism.

This evolution of compositions of granitic rocks with time is proving useful, as it can give a preliminary guide to the age of the various felsic igneous rock suites. Economically, the 1800–1600 Ma group of felsic igneous rocks is the more important as it is dominated by granites which have undergone fractional crystallisation (see article on Lachlan Fold Belt, p. 15), and hence is particularly prospective for U, Sn, W, and Be, especially where affected by subsequent metamorphic and deformational events.

For further information, contact Dr Lesley Wyborn at BMR.

3rd ICGI

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

Résumés of papers to be presented at the Conference must be with the Secretariat by 1 May 1985.

For further information, write to:
The Secretary
Organising Committee Third ICGI
Australian Mineral Foundation
Private Bag 97, Glenside
SOUTH AUSTRALIA 5065

West Woodlark Basin

(continued from p. 11)

The preliminary results of the survey indicate that the central part of the basin with water depths of 2–3 km is floored by young oceanic crust with rough surface expression and little or no sediment cover. Extensive normal faulting is evident throughout the basin, though most spectacularly displayed in the steep slopes and escarpments at the margins of the basin. Magnetic anomaly 1 (0–0.72 Ma) is very distinctive on all lines, and occurs as an essentially linear band from the postulated transform at longitude 154°12'E to the termination of the spreading system at longitude 151°45'. Minor deviation at about longitude 152°50' suggests the possible existence of a transform with dextral offset in the spreading axis of about 14 km. Seafloor spreading began at about 1.8–2.5 Ma, proceeding during the last 1 Ma at a rate of about 4.6 cm y^{-1} in the east of the west Woodlark Basin, decreasing to about 2.7 cm y^{-1} in the west.

Survey details and preliminary results are documented in the cruise report *(BMR Record* 1984/32).

For further information, contact Mr Peter Hill at BMR.

Distribution of phosphate

(continued from p. 12)

so-called Cambrian radiation event, which is recorded in the fossil record by the initiation of biomineralised skeletal tissues in various organisms all at about the same time. A significant proportion of these early skeletons was built of calcium phosphate, which may be interpreted as an opportunistic or alternatively a crisis reaction to the high levels of phosphorus in the water column of the photic zone. As phosphorus was withdrawn progressively from the shallow seas into the phosphorus sink represented by phosphorites, the phosphorus content of the photic zone gradually decreased to the point where phosphorus was no longer so readily available for biomineralisation.

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

BMR's EM probe

(continued from p. 13)

External controls allow the operator to select different transmit loops, to change transmit frequency, to set the current, and to control the effective sampling time. The above control choices, probe depth, and EM data are accumulated into a data file for later analysis. However, a plot of the data may be made at any time.

Future program

The prototype system has developed to the point where it is currently being bench-tested and has a patent pending. A program of field testing is being formulated to determine the overall capability of the system. An important aspect of this testing will be a comparison of the omniprobe with other EM equipment currently available.

For further information, contact Mr Tim Barton or Mr Bob Cobcroft at BMR.

Terrains or terranes?

There is considerable confusion among Earth scientists on the use of the terms *terrain* and *terrane*. It is often thought that *terrane* is simply the American version of the English word *terrain*. This is definitely not so. Each of the two words has the same meaning in both English and American usage, and the meanings of the two words are quite distinct.

Terrain. This is used in reference to topographic features or to aspects of an area related to topography — for example, 'terrain corrections' in gravity, 'digital terrain modelling', and the expression 'terrain around Canberra' refers to the landforms of the area.

Terrane. This is an old geological term that has been resurrected and become common nowadays, especially the 'suspect terranes' or 'displaced terranes' being studied in western North America. *Terrane*, both in English and American usage, refers to an area over which a particular rock or group of rocks occurs. Thus there are 'exotic terranes' or 'Proterozoic terranes', or terranes with a specific name such as the 'Gympie terrane' of Queensland, which would be classified as a tectonostratigraphic terrane under new nomenclature (see, for example, Jones & others, 1983: *in* Hashimoto & Uyeda — Accretion tectonics in the circum-Pacific regions, *Reidel Publishing Co., Boston*, 21–36*)*.

Dr Mike McElhinny is the terrain–terrane *authority in BMR.*

Lachlan Fold Belt

Magmatic controls of mineralisation

A joint study of the Lachlan Fold Belt by the BMR Division of Petrology & Geochemistry and the ANU Department of Geology is helping to pinpoint zones associated with different types of mineralisation.

The work involves analysing major and up to 33 trace elements in the granites and volcanic rocks, which occupy 50 per cent of the exposed fold belt. A model of magma genesis (developed by Dr B.W. Chappell at ANU) applied to these analyses has shown that the granites and volcanics can be divided into geochemically coherent groups (or suites as they have been termed) which are arranged in belts or confined geographical areas. The chemical differences between suites are thought to be dominated by differences in the original compositions of the source regions. It is becoming clear now that these differences are exerting important controls on the processes of felsic magma-related mineralisation.

The magmas of some suites carry with them abundant refractory minerals from the source (termed restite), and the liquids in these magmas find it difficult to escape from their restite before solidifying. The potential for fractional crystallisation and metal concentration is severely limited in such suites. These magmas are probably derived by large degrees (~ 40%) of partial melting, corresponding to what has been termed the rheological critical melt percentage, where flow as a granular mass changes to flow as a dense suspension.

Other magma suites are able to evolve in a largely liquid state, probably because the physical conditions at the source (which are poorly understood) allow separation of liquid from restite before the rheological critical melt percentage is reached (i.e., low degrees of partial melting). These suites have a much greater potential for concentrating valuable metals; however, the magmas must also carry sufficient quantities of the metals and their transporting agencies at subsolidus temperatures (e.g., chlorine, fluorine, sulphur dioxide), and be of an optimum oxidation state (fO_2), to form the appropriate metal complexes. Such features largely depend on the source rocks of the magma, so that subdivision of a granite terrane into suites related to different source rocks is a first step in extending exploration from known mineralised areas to unexplored areas.

Several of the now-constrained granite suites in the Lachlan Fold Belt have characteristically associated mineral deposits. A suite of high-Rb, P, Al, Ga, Nb, K, and U granites has been outlined in a belt extending north-northwest and south-southeast of the Ardlethan tin deposits. A meridional suite of granites and high-K diorites is associated with tungsten mineralisation through central and southern New South Wales and possibly extends into Victoria. A suite of very oxidised granites in the central part of the Bega Batholith seems to be characterised by gold mineralisation. Other suites may prove to be associated with other types of mineralisation — for example, the massive sulphide orebodies at Woodlawn and Captains Flat.

For further information, contact Dr Doone Wyborn or Dr Lesley Wyborn at BMR.

(continued from back page)

intensively cultivated and has little outcrop; thus the anomalies represent an essentially covered but pervasive system of magnetic sources.

We have interpreted the linear anomalies as magnetic basic dykes in Figure 19a, which shows about five times as many linear anomaly sources as Figure 19b. Most of these dykes do not crop out. The dykes, some of which extend for more than 500 km (outside the Albany Sheet area), have probably at some time exercised a strong control on palaeodrainage. As such they could present a target for alluvial heavy minerals.

Lithostratigraphy and granite contacts

A second prominent feature evident on the Albany greyscale magnetic map (Fig. 20) is the broad belt of anomalies across the bottom of the area. Close inspection of this belt, which is about 20 km wide, shows that it consists of quite remarkably subparallel narrow curvilinear magnetic anomalies. The belt is wrapped around a relatively quite zone with a few lozenge-shaped narrow anomalies scattered about.

Our interpretation (Fig. 19) is that the belt of narrow curvilinear anomalies is caused by steeply dipping metasediments fringing a large granite pluton in the south; the lozenge-shaped anomalies represent preserved roof pendants of folded metasediments, probably of various compositions. The interpretation of the granite pluton is supported by the presence of a gravity low that coincides with the magnetic quiet zone; its approximate position has been shown in scattered outcrop on geological maps. What is clear in the new presentations is the prominence of the contact along the northern side and the apparent simplicity of the preserved folds of metasediments. A few scattered mineral occurrences in this area of extensive cover suggest that it may be of great interest for exploration.

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

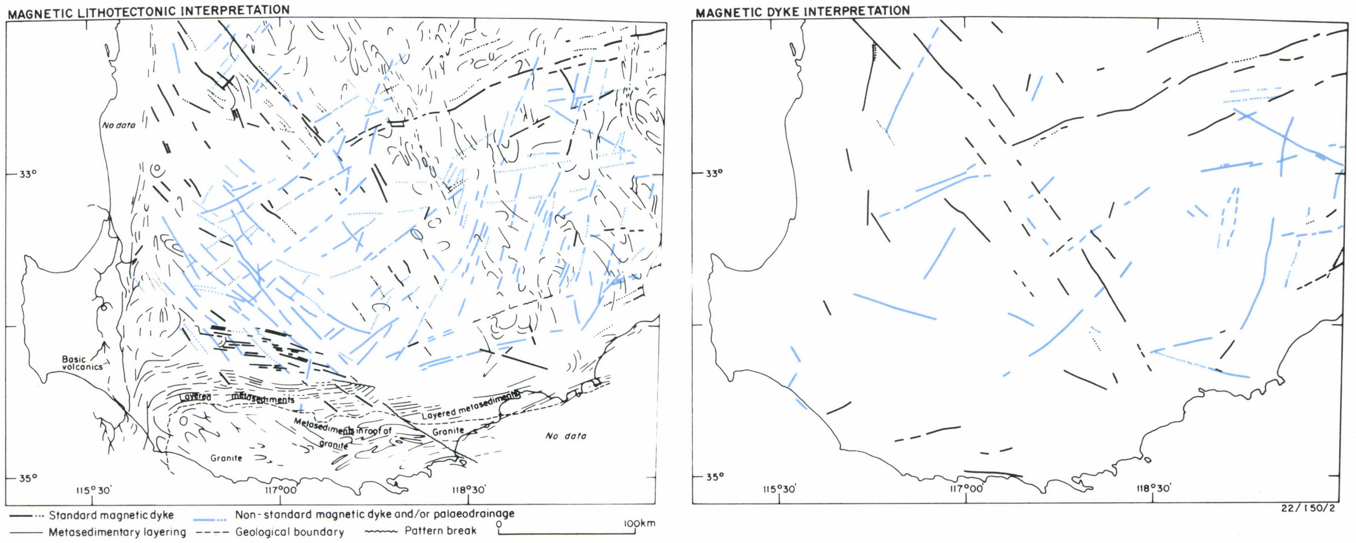


Fig.19 Magnetic interpretation of the Albany 1:1 000 000 Sheet area: (a, *left*) from image-processed airborne magnetics, 400 m grid, showing dykes and lithostratigraphy; (b, *right*) from BMR profile and contour maps, showing dykes.

Image-processed data

Key to the compilation of magnetic maps for enhanced interpretation

BMR is carrying out research in a project which will produce a series of 1:1 000 000 digital magnetic maps of Australia within the decade. As part of this research, we are generating image-processed presentations of the one hundred and eighty 1:250 000 Sheet areas for which digital data are available. Techniques that may be applied to the generation of the magnetic maps are being tested on the magnetic data available for the Albany 1:1 000 000 Sheet area (southwest WA), which is serving as a pilot for the project.

Using a quarter-minute cell size (about 450m), our regridding of these 180 sheets is well advanced. From these grids, at least four types of map are produced: greyscale and pseudocolour images of total magnetic intensity, and north-south and east-west shadowgraphs.

Figure 20, which is roughly the same size as the original negative from the laser printing process, shows the greyscale magnetic map of total magnetic intensity for the Albany 1:1 000 000 Sheet area. The amplitude has been scaled in 256 divisions of grey over a range of 1500 nT, giving an effective interval of 6 nT; the highest amplitudes are represented by white and lowest by black. The 1:1 000 000 maps produced will necessarily be blank in areas with no digital data at present; for the Albany Sheet seven of the 16 quarter million sheets have no data. All the maps will fit the Lambert Conformal projection of the standard 1:1 000 000 series of topographic maps.

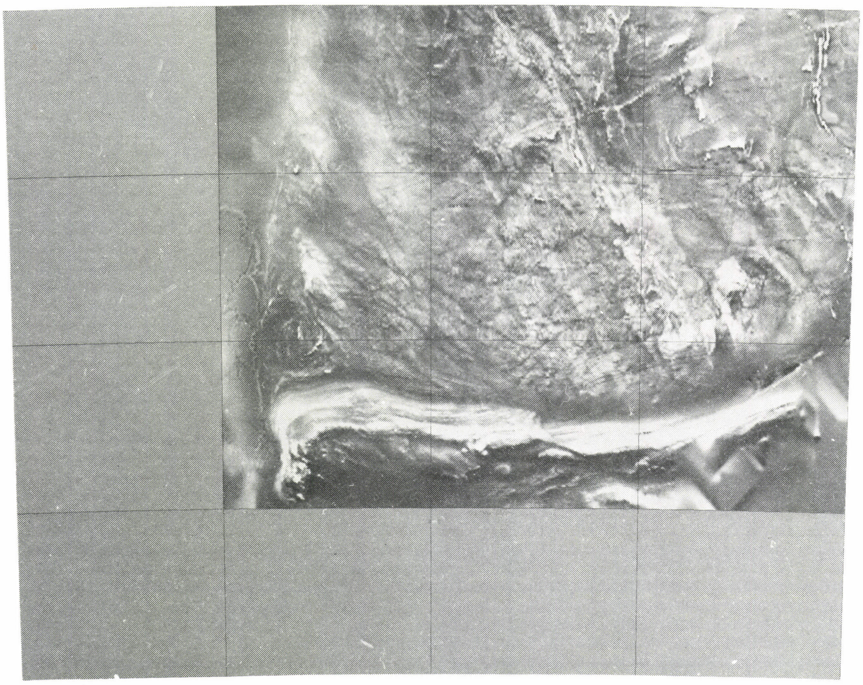
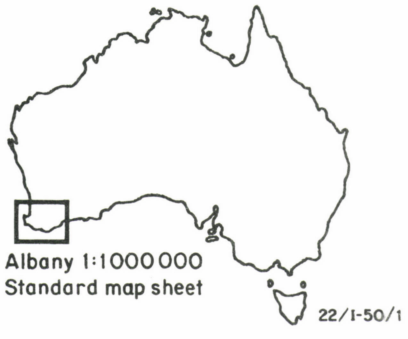


Fig. 20. **Albany 1:1 000 000 Sheet area total magnetic intensity greyscale map reduced to 1:5 000 000 scale for presentation.**



Compared with the existing contour maps, the imagery processed from the digital data shows a dramatic improvement in resolution and in definition of magnetic sources at the scale used. This improvement is partly because we are able to represent more effectively the dynamic range of the data, but more so because we are able to take advantage of the ability of the human eye to distinguish subtle changes of intensity, colour, and hue. To illustrate this improvement, interpretation maps of the Albany Sheet area derived from the greyscale image at 1:1 000 000 and from the contour maps and profiles are shown in Figure 19a and b. We draw attention to only two of the features here: dykes and lithostratigraphy.

Dykes and palaeodrainage controls

One prominent feature disclosed by the Albany greyscale magnetic map is the abundance of long linear magnetic anomalies criss-crossing the Sheet area. Only some of these newly disclosed anomalies correspond to Landsat-defined linear fractures, present drainage lines, and mapped basic dykes. However, much of the area — particularly in the south — is

(continued on p.15)

A new style of mineralisation in Australia — fact or fantasy?

A trio of Australian geologists (M. Solomon, L. Schmidt, and J.L Walshe) is proposing that the gold–base-metal deposits at Elura and Cobar were formed, during the development of cleavage, by groundwater circulating through a thick column of sedimentary rocks undergoing deformation.

The idea that these ores were precipitated after the onset of cleavage development, and before its cessation, appears to explain many of the apparently conflicting pieces of evidence concerning the amount of deformation that the ores have undergone (see 'Cobar Symposium' *in* Sixth Australian Geological Convention, Canberra, 1983, *Geological Society of Australia, Abstract Series* 9). A few earlier workers have proposed similiar ideas, and there has been little disagreement that certain quartz–gold deposits in New Zealand (Henly, 1973: *Transactions of the Institute of Mining & Metallurgy*, 82, B1–B8) and Victoria (Wall & others, 1983: Proceedings of the Fourth International Symposium on Water–Rock Interaction, Japan, 527–34) were formed in shear zones during orogenesis.

The gold–rich ores of the Tennant Creek Field appear to have formed in much the same way as the Cobar and Elura deposits (Stewart & others, 1976: *25th International Geological Congress (Sydney), Guidebook Excursion* 47C). In both fields the thesis not only explains the structural observations but also correlates the chemical composition of the rock pile beneath the deposits with that of the ores, particularly in relation to oxidation state. Preliminary calculations indicate that sufficient water could have been available from dehydration, during greenschist metamorphism, to form the major deposits in the two ore fields, provided that the rock column beneath the ore is at least 5km thick and that most of this water was focused from a catchment area of the order of 25 km^2. Addition of magmatic water and heat would have facilitated the process, and indeed may have been a necessary component of ore genesis. One of the problems for the thesis which is currently under examination is identifying the depositional mechanisms.

If the thesis is correct, and a new style of mineral deposit is confirmed, the range of terranes favourable for gold–base-metal mineralisation is substantially increased.

For further information, contact Dr Mike Solomon at BMR.

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