

**ANNUAL
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GOVERNMENT OF
WESTERN AUSTRALIA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REVIEW 1999–2000



DEPARTMENT OF MINERALS AND ENERGY

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Undulose and ripple cross-stratification highlighted by jarosite (iron sulphate) in Lower Permian storm deposits in the Carynginia Formation, near the Irwin River (Southern Branch) in the northern Perth Basin.

Frontispiece:

Stockpiles of salt produced by the evaporation of natural brines at Lake MacLeod in the Gascoyne Region (photograph courtesy of Dampier Salt Ltd).



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GSWA mission statement

Our vision

is to make Western Australia the focus of international mineral and petroleum exploration by becoming the benchmark for the delivery of prospectivity-enhancing, high-quality geoscientific products and services that meet the needs of our customers.

Our commitment

is to provide, in a timely and courteous manner, up to date, quality regional geoscientific data, information, and advice to the mining and petroleum industries, Government, and the public to encourage and support resource exploration and facilitate informed landuse planning and State development.

Our role

is to elucidate the geological framework of Western Australia and reveal the potential for mineral and petroleum resources by providing spatially related geoscientific information, and regional geological, geophysical, and geochemical map products and reports. These products are based on the acquisition and analysis of field data, including submitted statutory exploration reports. As well, the Geological Survey evaluates mineral and petroleum resources as a basis for decision making by Government, and assists and advises on a variety of community needs, including urban planning and landuse matters.

Our strengths

are in field-based research, particularly regional geological mapping in both the Precambrian and Phanerozoic provinces of the State. The Survey also has prowess in the fields of structural geology, basin studies, carbonate sedimentology, mineralization studies, geochemistry and regolith studies, geochronology, palaeontology, petrology, and geoscientific computer applications including database compilation.

Other areas of expertise include mineral economics, and financial modelling and evaluation of resources projects.

As a result of the application of these skills for over 100 years, and of its role as the depository of mineral and exploration reports, the Geological Survey is the custodian of an immense volume of information on the geology of the State and has become the premier pool of geoscientific expertise in Western Australia.



The year in review

by Tim Griffin



David Blight, the previous Director of the Geological Survey of Western Australia, departed at the end of June to take up a new position as Executive Director, Office of Minerals and Energy Resources, Primary Industries and Resources SA (PIRSA). It has therefore fallen to me, as the new Director, to prepare this review. I would like to congratulate David on the excellent work he has done as Director over the past two and a half years and the fine state the Geological Survey of Western Australia (GSWA) is in at this time. This places considerable responsibility on me, not only to maintain the level of excellent work from GSWA and the high standing GSWA has with its customers, but also to ensure that GSWA continues to be an effective organization in the years to come.

The impacts of the significant downturn in mineral exploration spending in Western Australia are still with us, although there is a sense that we are at the bottom of a cycle and an upswing is imminent. Fortunately, Western Australia continues to maintain its share of the Australian exploration dollar, and there is some optimism regarding the impact of Native Title issues and access to land. Commodity prices are still fluctuating, although gold continues to be depressed. Offshore petroleum exploration, by contrast, is buoyant and hopefully this will translate into increased onshore exploration in Western Australia. In recognition of the potential for discoveries onshore, GSWA is continuing to be aggressive in promoting the prospectivity of these very underexplored areas of the State.

GSWA's output was again at an extremely high level, with the production of a large number of maps, reports, and particularly digital data releases. Major advances were made in providing easier access to digital data and derivative products. GSWA has worked very closely with industry on a number of fronts this year, particularly in designing its work programs. The Geological Survey Liaison Committee and its technical subcommittees play a crucial role in determining the direction of GSWA work programs and their geoscience products.

Industry, both through its official representative organizations such as the Australian Petroleum Production and Exploration Association, the Chamber of Minerals and Energy WA, and the Association of Mining and Exploration Companies, and with input from individual companies and geoscientists, has worked effectively in ensuring continuity of funding at present levels into 2000-01. These organizations also supported the setting-up of a small, independent task force to carry out a review of GSWA's activities to provide recommendations for an appropriate level of funding that will enable the Government, through the work of GSWA, to attract more exploration investment to Western Australia.

Under the National Geoscience Mapping Accord (NGMA) we developed a successful partnership with the Australian Geological Survey Organisation (AGSO), which now includes an AGSO officer based at GSWA. Currently, AGSO has settled on a work program for Western Australia, following the funding cuts that impacted most heavily on their 1999-2000 activities. We can

now look forward to new and revised work programs from AGSO in Western Australia, and the establishment of cooperative projects under the National Geoscience Agreement (NGA) that supersedes the NGMA. Work and products from the NGMA were largely finalized in 1999–2000.

Highlights

GSWA once again had a very productive year in 1999–2000, publishing 31 maps at various scales, 47 manuscripts, and 12 digital datasets covering a broad spectrum of geoscience and ranging over the whole State. This work included activities highlighting some of the geological features in Western Australia that attract international interest.

In July 1999, GSWA geologists, accompanied and assisted by ten visiting international experts on early life, collected some well-exposed examples of the oldest macrofossils in the world. This work was undertaken to protect these fossils from the effects of weathering and depredation by commercial fossil collectors. The fossils consist of conical stromatolites that look like egg cartons, and are hosted by 3.4 billion year old rocks of the Warrawoona Group of the granite–greenstones of the eastern Pilbara region. The public can view a large specimen of the fossil outcrop at the Museum of Western Australia.

A feature of GSWA 2000, a day during which the latest releases and future work programs are presented to customers, was a talk that documented the history of discovery and major aspects of the Woodleigh structure, a 120 km-wide buried, concentric impact structure centred just east of Shark Bay. The Woodleigh structure, in a flat sandy landscape with no surface indication, was identified from geophysical data and confirmed by additional geophysical surveys and drilling. Some impact structures in other parts of the world are associated with significant mineral and hydrocarbon resources. Woodleigh is the largest impact structure in Australia and is large enough to have been associated with a major extinction event. However, the age of the structure is not certain, forming sometime between the Late Devonian (370 Ma) and the Early Jurassic (200 Ma).

A presentation on the Quadrio Lake barite vein-related mineralization, discovered by GSWA geologists in an inlier of Bangemall Basin sedimentary rocks on the southern margin of the western part of the Officer Basin, was a major drawcard at GSWA 2000. GSWA also mounted displays and made presentations at the Department of Mineral and Energy's Petroleum Open Day 1999, and the Kalgoorlie Open Day in October. Well over 200 industry people attended these events where GSWA showcased its work.

The seamless database of 1:100 000-scale geological data for 20 sheets in the Kalgoorlie region of the Eastern Goldfields was released, and a comprehensive explanatory note was completed. High-quality maps-on-demand at a range of scales can be generated from this database at the GSWA office in Kalgoorlie and the Department of Minerals and Energy (DME) library in Perth. This map-on-demand process introduces a new era in the delivery of geological maps to customers.

A major development in 1999–2000 was the launch of the DME electronic bookshop (accessed via www.dme.wa.gov.au) where GSWA publications can be purchased on-line. The site includes a full catalogue of more than 1850 titles, and the facility to browse and search with ease.

Improved access to the large volume of statutory mineral-exploration data held by GSWA was provided by two initiatives during the year. A web-browser version of the Western Australian mineral exploration database (WAMEX), with a user-friendly search facility, is now available. This has been complemented by a program to scan reports for open-file release onto CD (as .pdf files), including colour reproduction of maps up to A3 in size. These can be purchased at minimal cost from licensed suppliers and read with Adobe Acrobat Reader. If digital data files for geochemistry are available, they are added to the zip files containing the .pdf files.

GSWA is undertaking a program of documenting abandoned mine sites and creating a database that can be used to assess their associated risks and

provide a sound basis for future planning and rehabilitation. Twenty percent of the State has been covered to date. A similar program to create an inventory of State batteries has been completed to enable a program of risk assessment and rehabilitation to be developed.

Significant progress has been made on constructing a seamless geological map of Western Australia at 1:500 000 scale. The project has developed from the mineralization mapping program that documents all mineral occurrences obtained from exploration reports and other sources. Mineral occurrence maps, Reports, and datasets on the west Pilbara and east Kimberley were released in 1999–2000.

Four areas covered by the regolith geochemical mapping program were published, including some fascinating results from the extensive sand cover on AJANA. In addition, data on two sheets, KINGSTON and STANLEY, dominated by Proterozoic sedimentary rocks of the Earahedy and western Officer Basins were released. The fourth area studied was from the Proterozoic mobile belt in the Fraser Range.

The first maps were released from systematic regional mapping at 1:100 000 scale of the central part of the Southern Cross granite–greenstones. This work is being supported by new geochronological data that, along with the mapping, are providing new insights into these rocks that formed before most rocks in the Eastern Goldfields. Work is progressing northwards.

Ongoing work program

The large amount of sensitive high-resolution ion microprobe (SHRIMP) geochronological data generated during 1999 has been released in Record 2000/2. Of particular interest has been the contribution these data have made in improving our understanding of the evolution of the greenstones in the Pilbara Craton over a time span of some 400 Ma, and the crystalline rocks of the Proterozoic southern Gascoyne Complex.

Major geoscience mapping projects will continue, primarily at 1:100 000 scale, in the east Pilbara, the Capricorn Orogen (mainly in the Bangemall and Earahedy Basins), the northern Southern Cross region, and the east Yilgarn.

A major project that began in 1999–2000 to compile a digital 1:500 000-scale solid geology map of Western Australia will be completed in 2000–01. Geochemical and regolith mapping will continue with work on the BYRO 1:250 000 sheet, and aeromagnetic data will be collected on SANDSTONE.

Mineral occurrence mapping will focus on the east Pilbara, Kimberley Basin, and in the King Leopold Orogen – Lennard Shelf area. The urban and development areas resources mapping group will complete work in the Geraldton and South West areas, and begin work around Kalgoorlie.

The petroleum initiatives team will focus on a synthesis of the northern Perth – Southern Carnarvon Basins and on collecting data in the Gibson area of the Officer Basin. This latter work should lead to the definition of a location for a stratigraphic test to be drilled early in 2001–02.

A major thrust will be in further development of the GSWA spatial database and its capacity to facilitate map production on demand.

Release of up to 3000 scanned open-file mineral exploration reports during 2000–01, and a prototype map-based search facility for the WAMEX database will be launched via the DME web site.

Conclusion

All staff in GSWA had a difficult 1999–2000 as we strived to ensure that we have sufficient funds to be an effective agency in promoting the prospectivity of Western Australia during a period of reduced exploration budgets. It was particularly difficult for the large number of contract staff throughout all parts of GSWA who remain concerned over funding levels. The Government in its 2000–01 budget reinstated \$3.5 m in funding for the petroleum initiative and undertook to have an independent review of the longer term funding required for GSWA, together with a review of its product pricing policy. This is to be presented to Cabinet later this year. I am confident that with the high

level of industry input, the review panel will present a persuasive case for increasing the level of funding for GSWA.

GSWA must ensure that the minerals and petroleum industries continue to grow and that GSWA plays a crucial role in this through more efficiently delivering high-quality, relevant, accessible, and easy-to-use geoscience data and interpretations that facilitate the development of innovative exploration concepts. GSWA will be working closely with industry and cooperating organizations to improve its efficiency in promoting the prospectivity of Western Australia.



Overview of mineral and petroleum exploration in Western Australia in 1999–2000

by D. J. Flint¹ and R. H. Bruce²

In the 1999–2000 financial year, the value of mineral production (including petroleum) rose sharply by \$4611 million (27.7%) and totalled \$21 266 million, making this the first year that aggregate mineral production had exceeded \$20 000 million in value. The value of petroleum products rose sharply by \$3584 million (88%) to a total of \$7649 million, but rises were also recorded for the value of alumina, base metals, coal, diamond, leucoxene, manganese, nickel, spodumene, synthetic rutile, and tantalite. Western Australia continues to lead the country in both gas and liquid petroleum production, and it ranks fourth in the world for liquefied natural gas (LNG) production. Falls were recorded in the value of production of gold, ilmenite, iron ore, rutile, salt, and tin. In a world market context, Western Australia continues to be a very significant producer of gold, iron ore, bauxite-alumina, nickel, diamond, heavy-mineral sand products, salt, tantalite, spodumene (lithium), and LNG.

Exploration in Australia and throughout the world continued to decline during 1999–2000. This is attributed to low metal prices in general in recent years, particularly in the case of gold (the gold price reached a 20-year low point in \$US terms). In recent years, companies had focused on increasing the volume of ore treated and reducing costs, but surveys have shown that mining is often a low-profit activity. Companies concentrated more on corporate return on capital during 1999–2000, and speculative venture capital was directed away from the resources sector to the information and technology sector of world stock markets (the dot.com boom). The perception existed that mining was 'old economy' and that exploration, particularly greenfields exploration, destroys shareholder value. This resulted in reduced exploration activity, less preparedness to risk funds on greenfields exploration, and a lower percentage of profits directed back as exploration expenditure. In Australia, the effect of Native Title issues on land access compounded the problems.

However, the year finished with renewed interest in the minerals sector as a result of stronger profits, a falling Australian dollar exchange rate, publicity given to exploration successes, and takeover activity (particularly from large foreign companies) targeting companies yielding acceptable rates of return on equity or with the best exploration potential. This renewed interest has flowed through to more company floats on the Australian Stock Exchange. Prospectuses released during the year that contained properties in Western Australia included Tuart Resources NL, Templar Resources Ltd, Orlando Resources NL, Bullion Minerals Ltd, Western Areas NL, Phoenix Mining Ltd, and Ausgem International Ltd.

Mineral exploration

Western Australia's prospectivity is highlighted by the continuing high proportion of Australian exploration expenditure that the State attracts. However, like the other States, Western Australia experienced a reduction in exploration activity during 1999–2000, with mineral exploration

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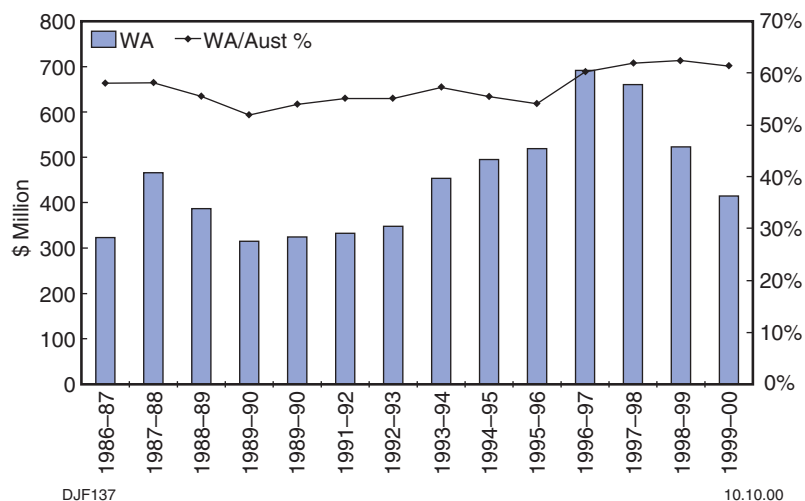


Figure 1. Mineral exploration expenditure in Western Australia, by year (dollars of the day)

expenditure (excluding petroleum) in Western Australia at \$415.0 million, a decrease of \$108.1 million or 20.7% on the previous year. This is the third successive substantial decline in total annual exploration expenditure after seven successive years of growth (Fig. 1), with exploration expenditure (excluding petroleum) in Western Australia having fallen by a total of 40% over the last three years. However, mineral exploration expenditure in Western Australia, on a quarterly basis, showed signs of stabilizing towards the end of 1999–2000, suggesting that the exploration slump may have bottomed out (Fig. 2).

The fall in exploration activity over the last three years, both in Western Australia and the other States, has seen Australia-wide exploration expenditure (excluding petroleum) falling well below the record levels of over \$1000 million that were achieved in 1996–97 and 1997–98. Australia-wide expenditure figures showed a drop of \$161.5 million (19%) to \$676.3 million during 1999–2000. Most of the decrease was in Western Australia, where expenditure fell to \$108.1 million (67% of the national decrease). However, Western Australia still continues to attract the greatest portion of all Australian exploration expenditure (61.4% compared to 62.4%

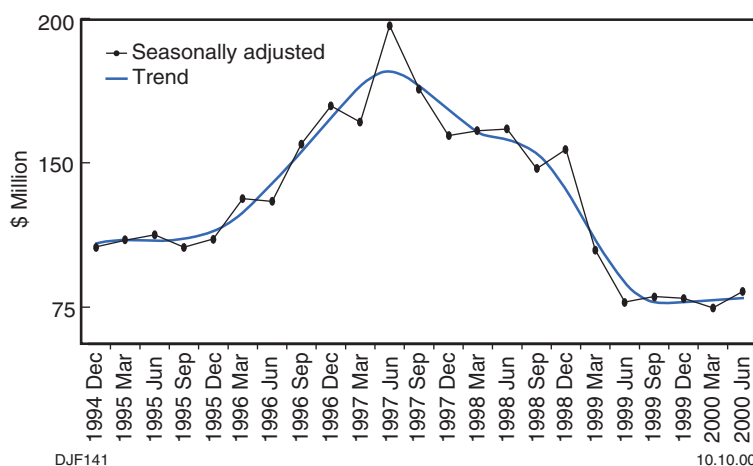


Figure 2. Mineral exploration expenditure in Western Australia, by quarter, on seasonally adjusted and trend terms (dollars of the day)

previously). This has remained relatively constant at 60–62% over the last four years throughout the large cutbacks that have occurred in exploration expenditure (Fig. 1).

Mineral exploration expenditure by commodity

During 1999–2000, gold again bore the brunt of the decline in mineral exploration in Western Australia, as it did in 1998–99. Exploration expenditure for gold fell by \$77.7 million (30.7%) to \$253.0 million, out of the State's total decrease of \$108.1 million for 1999–2000 (Fig. 3). Over the last three years, the fall in annual gold exploration in Western Australia has been dramatic, falling by \$278.7 million in annual expenditure (52.4%). That represents around a total of \$500 million of investment over three years that was not spent in gold exploration in the last three years. Furthermore, there is no evidence that this shortfall in gold exploration has been redirected to other commodities. The seriousness and magnitude of the fall between 1997–98 and 1999–2000 is illustrated by comparing the recent fall with the expenditure fall in the three years following the world sharemarket crash in October 1987 – the two falls are almost identical in dollar terms (1999–2000 dollars) and in the percentage drop.

On a yearly basis, gold exploration activity (about \$250 million per year) is now at levels last experienced in 1992–93 (Fig. 3). On a quarterly basis, gold exploration expenditure in Western Australia showed signs of stabilizing towards the end of 1999–2000.

The gold price did recover slightly during 1999–2000, from monthly averages of about \$US261 in June 1999 to \$US285 in June 2000. The gold sector was assisted by a steadily declining Australian currency during the year, which saw the gold price in Australian dollar terms rise from an average of about \$A400 in June 1999 to \$A480 in June 2000. Any strengthening of the Australian currency in the near future would undoubtedly have an adverse effect on gold exploration and development in Western Australia, unless the gold price in \$US terms also began to rise.

Exploration for base metals (including nickel and cobalt) dropped only slightly during 1999–2000, falling by \$2.6 million (2.9%) to \$88.3 million. The sharper fall experienced in 1998–99 was due to the completion of major exploratory and development work on the lateritic nickel deposits at Murrin Murrin, Cawse, and Bulong, as the mines moved into the commissioning phase. During 1999–2000, there was renewed interest in other nickel projects because of the sustained high nickel price, with fresh exploration at the so-called second-generation lateritic nickel deposits. Nickel prices rose strongly during the year, reaching a ten-year high of over \$US10 000/t, but have since retreated slightly. The copper price improved slightly, but this was

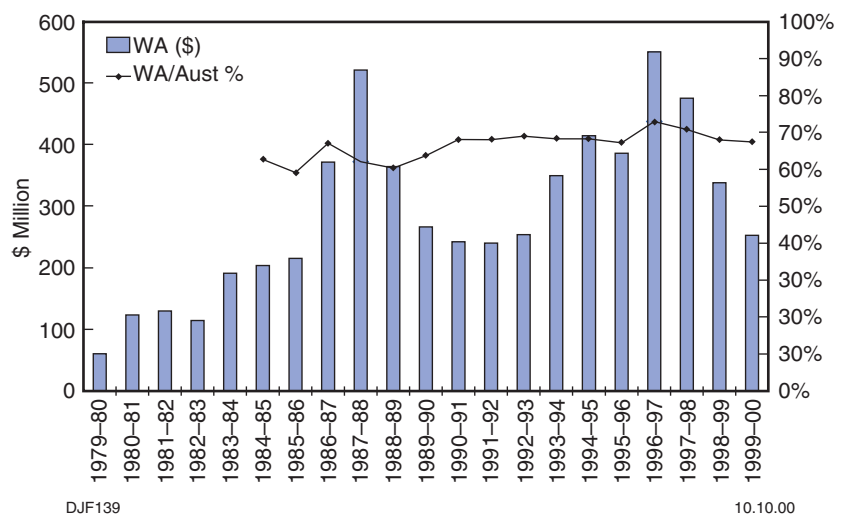


Figure 3. Gold exploration expenditure in Western Australia, by year (1999–2000 dollars)

from a very low base in mid-1999 and thus did little to encourage exploration. Zinc prices firmed by about 10% during the year, but this probably had more impact on the profitability of current producers rather than stimulating more exploration.

Diamond exploration fell by \$8.1 million (24.6%) to \$24.8 million during 1999–2000. This continues the steady decline from the peak in recent years of \$35.8 million that was spent in 1996–97. The fall is due to the generally difficult conditions in raising equity capital, combined with the paucity of significant discoveries in recent years. However, interest in Argyle remains strong, with the competing bids of De Beers and Rio Tinto for Ashton's share in the Argyle Joint Venture. The level of diamond exploration has now fallen by 35.8% in three years, and is well below the historical peak activity in 1981–82 (\$50 million) and in 1993–94 (\$47 million).

Iron-ore exploration expenditure is not expected to increase significantly in the near future as a result of uncertainty over the development scenarios at West Angelas, now that Rio Tinto Ltd has control of North Ltd, and at Hope Downs where access to existing railway infrastructure is yet to be obtained. Funding for the Mid West iron and steel project moved a step closer, with Chase Manhattan Bank appointed by Kingstream Steel Ltd to assist with project development financing.

Although gold remains the main focus of exploration effort in Western Australia, its paramount lead continues to be eroded, though this may not be happening as quickly as the very large drops in gold exploration expenditure (in dollar terms) would suggest at first glance. Gold now accounts for about 61.0% (63.4% last year) of all exploration expenditure in Western Australia (other than petroleum), a sharp fall from 76% of the total in mid-1997. By comparison, the proportion spent on exploration for base metals and nickel–cobalt has increased slightly to 21.3%.

Despite the large fall in exploration activity in Western Australia during 1999–2000, Western Australia still attracts the major part of the Australian exploration dollar for iron ore (96%, estimated), diamond (83.2%), gold (67.5%), base metals including Ni–Co (56.3%), and heavy mineral sands (40%, estimated). For base metals and diamonds, the proportions of Australian exploration expenditure spent in Western Australia are now at the highest levels for those commodities since at least 1984. For example, 1999–2000 was only the second year on record when Western Australia has attracted more than 50% of the Australian base-metal exploration expenditure, although this predominantly reflects the ongoing nickel exploration. For gold, the proportion of expenditure (67.5%) is close to the average for the last decade (around 69%) and has varied little throughout that time. These statistics are encouraging because they apply at a time when companies are being very selective about where to explore, and this undoubtedly indicates that the perceived prospectivity for these commodities in Western Australia is very high.

Mineral resources and reserves

Despite the severe cutbacks in gold exploration and the strong pessimism prevailing in many parts of the gold sector, the State's inventory of measured and indicated gold resources (including any converted to reserves) increased during 1999–2000 (Fig. 4). Gold resources (measured and indicated only) increased by 256 t (7.3%) to 3752 t (Table 1). This substantial increase was double that recorded in the previous year, and was achieved with reduced exploration expenditure, resulting in significantly lower average discovery costs (Table 2). For the first time in at least seven years, gold discovery costs dropped below \$A20 per ounce of measured and indicated resources; these costs are only \$A15 per ounce if inferred resources are included.

For the fourth year in succession, there have been large increases in nickel resources, which have almost trebled in the last four years (Fig. 5). Nickel resources (measured and indicated) increased by 3.46 Mt (20.6%) to 20.23 Mt of contained metal. Inferred resources increased by 15.1%. Contained nickel (in measured and indicated resources) within lateritic nickel deposits eclipsed contained nickel within sulfide deposits for the first time

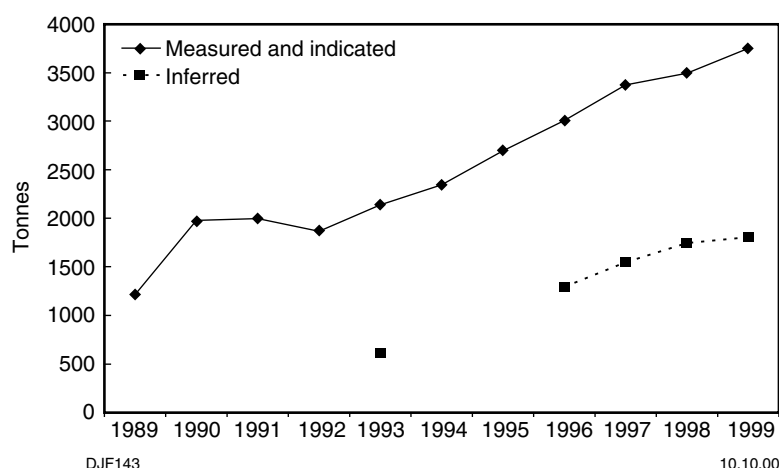


Figure 4. Estimates of gold resources in Western Australia, by year

during 1998–99 (57% versus 43% respectively of total contained nickel) and this trend has been further advanced during 1999–2000 (64% versus 36% respectively). Resources of nickel in sulfide deposits remained essentially unchanged during 1999–2000 at 7.227 Mt, whereas resources of nickel in lateritic deposits jumped by 3.4 Mt (26%) to 12.913 Mt. The 1990s has seen an unprecedented boom in nickel exploration that has been extremely successful in converting exploration effort into resources in the ground.

Resources of other commodities (high-grade iron ore, bauxite, and heavy mineral sands) have remained essentially unchanged during 1999–2000 (Table 1).

Table 1. Estimates of mineral resources of major commodities in Western Australia

Commodity	Units	1996	1997	1998	1999
Measured and indicated resources					
Iron ore (high grade)	Mt	21 960	22 539	22 407	22 282
Gold	t	3 009	3 376	3 496	3 752
Bauxite ore	Mt	3 359	3 386	3 387	3 387
Mineral sands	Mt	128.9	163.4	208.7	208.7
Nickel	Mt	10.73	13.41	16.77	20.23
Diamonds (industrial + gem)	Mct	140	177	534	534
Inferred resources					
Iron ore (high grade)	Mt	10 466	10 382	10 525	10 587
Gold	t	1 295	1 549	1 750	1 807
Bauxite ore	Mt	1 326	1 314	1 314	1 314
Mineral sands	Mt	52	53	73	73
Nickel	Mt	6.96	10.58	10.15	11.68
Diamonds (industrial + gem)	Mct	86	59	59	59

NOTE: Data sourced from MINEDEX database. Information nominally as at 31 December for year shown, but data extracted from MINEDEX database on 30 June in following year
For iron ore and bauxite, it is the quantity of resources that is shown. Only high-grade iron ore resources are included. High-grade iron ore is based on iron content only, but cut-off grade (55 or 60% Fe) depends on mineralization type
For heavy minerals, the total of all heavy minerals is shown
For all other commodities, the contained element/mineral in the resources is shown

Table 2. Gold discovery costs per ounce of measured and indicated resources, Western Australia

Year	1993	1994	1995	1996	1997	1998	1999
Cost (\$A) per ounce discovered	21	28	22	26	26	30	17

Mining tenement activity

In general, the reduced activity in the mineral exploration sector has also been reflected by the reduction in the number of mining tenements in force and the area held under tenure as at 30 June 2000 (by comparison with the same time 12 months previously). For all tenement types under the Mining Acts of 1904 and 1978, the area under tenure showed a decrease of 11.5% (3.1 million hectares) to 23.7 million hectares. Much of this decrease (98.7%) may be attributed to fewer and smaller exploration licences (Table 3), which dropped by 2.0% in number but dropped by 12.8% in area. These data indicate that large, greenfields-type exploration licences have continued to be reduced in area during 1999–2000.

For the three years since the boom in exploration in mid-1997, the number of granted exploration licences has dropped by 28%, and the area under tenure has dropped by 45.9%. The cutback in exploration over the last three years has also been reflected in prospecting licences, with falls of 29% in number and 32% in the area held. However, for mining leases the number and area held has gone against the trend, with figures for these having increased slightly over the last three years. These trends of reduced exploration and prospecting areas and increased mining lease areas are perhaps the most reliable available indicators of the swing from greenfields to brownfields exploration.

The number of new tenement applications also gives a guide to the general state of the mineral exploration sector (Table 3). The number of exploration licences and the area under application have dropped by 37% and 46% respectively over the last three years, whereas the number of mining leases and area under application have dropped by 51% and 60% respectively for the same period. However, the same trend is not observed with applications for prospecting licences, where applications for these have remained relatively static over the last three years, declining in number by only 4%, but increasing 5% in the area under application. There may be two explanations for this. Either prospecting licences (for gold) are

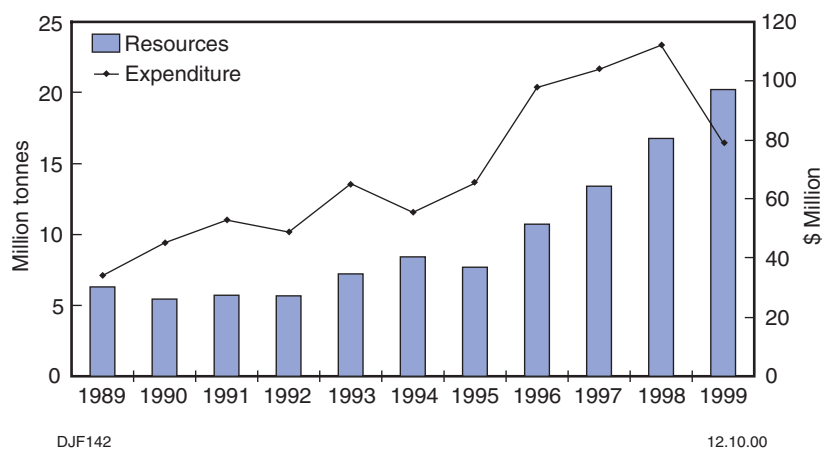


Figure 5. Nickel resources in Western Australia versus base-metal exploration expenditure, by year (dollars of the day)

being taken up over the most prospective sites in the exploration licence areas being dropped, or the level of prospecting licence activity is somehow independent of the broader commodity cycle in exploration.

Again, Native Title issues continued to cause delays to the planning of many exploration and development programs, and these issues added further to the three-year slowdown in exploration activity. Another issue affecting exploration and development is competing landuse, especially in the State's southwest and in or near national parks, but this situation remained unchanged during 1999–2000.

Statistics that highlight Native Title impacts are shown by the large number of tenement applications yet to be granted as at 30 June 2000 (Table 3). Over the last three years, the number of outstanding applications (yet to be granted) for mining leases and prospecting licences has increased each year. The trend for exploration licences is similar, although there was a slight clearance of the backlog of outstanding applications during 1999–2000. The figures clearly show the magnitude of the problem, even for greenfields exploration. Access to highly prospective land for mineral exploration is essential for new discoveries to be made and to thereby enable continuing development of the State's mineral resources to ensure the future economic well-being of the State.

Drilling activity

The trend in drilling activity since the peak of exploration in mid-1997 is clearly evident (Fig. 6). Rotary air blast (RAB) drilling was the first to be adversely affected as companies reduced expenditure and moved away from grass-roots greenfields exploration, and this was followed one year later by declining reverse circulation (RC) drilling, as expenditure cuts deepened. Exploration and resource drilling of all types declined sharply throughout 1998–99 and 1999–2000, with the exception of diamond drilling in 1999–2000. RAB drilling has plummeted by 60% over the last three years, with RC drilling declining by only 35% (but over only the last two years).

Table 3. Mining tenements current as at 30 June 2000, Western Australia

	1996–97		1997–98		1998–99		1999–2000	
	No.	Area (ha)	No.	Area (ha)	No.	Area (ha)	No.	Area (ha)
Tenements current as at 30 June 2000 (1978 Mining Act)								
Prospecting Licences	8 212	1 099 671	7 525	992 392	6 242	808 792	5 827	745 021
Exploration Licences	4 718	38 279 436	4 505	35 992 499	3 463	23 732 102	3 394	20 687 010
Mining Leases and others	6 717	2 135 806	6 717	2 238 301	7 555	2 263 145	6 866	2 297 430
Tenements current as at 30 June 2000 (1904 Mining Act)								
Mineral claims and others	310	34 133	309	34 132	307	34 130	193	21 790
Total (all tenements)	19 957	41 594 046	19 056	39 257 324	17 567	26 838 169	16 280	23 751 251
Tenement applications received for the period								
Prospecting Licences	1 239	159 719	1 146	154 769	976	124 310	1 189	167 755
Exploration Licences	2 484	26 352 760	1 764	14 484 400	1 747	14 078 400	1 557	14 158 480
Mining Leases	1 653	821 268	1 855	1 076 575	944	460 559	803	329 157
Others	169	44 186	148	424 978	1 454	729 574	138	783 789
Total	5 545	27 377 933	4 913	16 140 722	5 121	15 392 843	3 687	15 439 181
Tenement applications yet to be granted as at 30 June 2000								
Prospecting Licences	985	–	1 142	–	1 735	–	1 813	–
Exploration Licences	2 060	–	2 012	–	2 904	–	2 776	–
Mining Leases	3 167	–	4 562	–	4 944	–	5 179	–
Others	357	–	1 493	–	1 512	–	516	–
Total	6 569	–	9 209	–	11 095	–	10 284	–

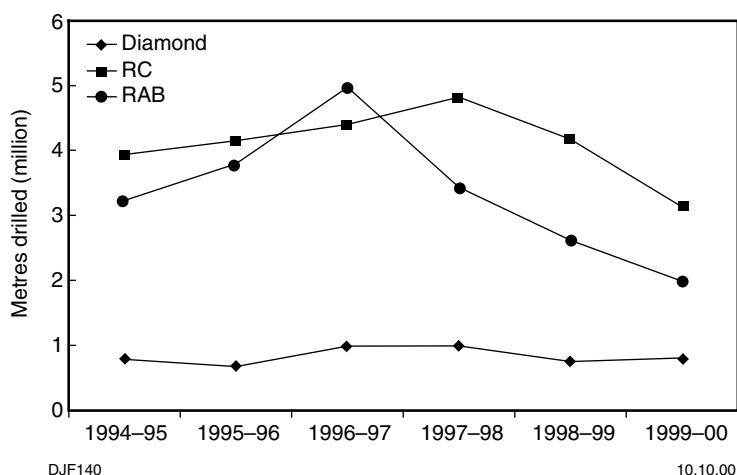


Figure 6. Mineral exploration drilling in Western Australia, by drilling type and year

Because there is a time delay in reporting statistics to the Department, further falls are anticipated in reports received after July 2000; however, the magnitude of the falls is likely to be smaller if the exploration slump is bottoming out. Diamond drilling figures have shown resilience, going against the general falling trend, with a modest rise (estimated at 7.3%) during 1999–2000. This is apparently a result of brownfields exploration where there is a need for the drilling of deep targets close to existing mine sites.

Petroleum exploration

Offshore Western Australia, and the North West Shelf in particular, continues to be recognized internationally as a premier place for new petroleum ventures based on favourable prospectivity, success rates, legislative and taxation regime, and political stability. Previous significant discoveries made on the North West Shelf continue to encourage further exploration, and offshore exploration drilling remains at near-record levels.

In this section on petroleum, the term 'Western Australia' has a broader meaning, referring to the State's onshore and offshore jurisdiction, combined with the adjacent offshore Commonwealth waters (Fig. 7). Excluded from the broad meaning of 'Western Australia' are the Territory of Ashmore and Cartier Islands, and the Zone of Cooperation.

In 1999–2000, petroleum exploration expenditure in Western Australia declined after setting successive records in the previous three years. Petroleum exploration expenditure fell by \$105.9 million (20.0%) to \$424.9 million. However, Western Australia has maintained its share of total Australian petroleum exploration expenditure (60–61%; Fig. 8).

The 1999–2000 financial year has seen the oil price remaining at historically high levels after dropping to very low levels in the previous financial year. However, until recently, industry has been very cautious in regard to increasing exploration expenditure.

In 1999–2000, a total of 66 petroleum wells were spudded in Western Australia, compared with 59 in 1998–99. Of the wells spudded, 40 were new-field wildcat wells, four were extension wells, and 22 were development wells. Extension and development drilling were greater than in the previous financial year, with a combined total of 26 wells compared with 18 in 1998–99. A near-record number of offshore new-field wildcat wells were drilled.

Offshore

The \$3 billion North West Shelf LNG expansion moved closer during mid-2000 as additional sales contracts (letters of intent) were signed with Japanese customers. The project involves a 4.2 Mtpa facility at Burrup

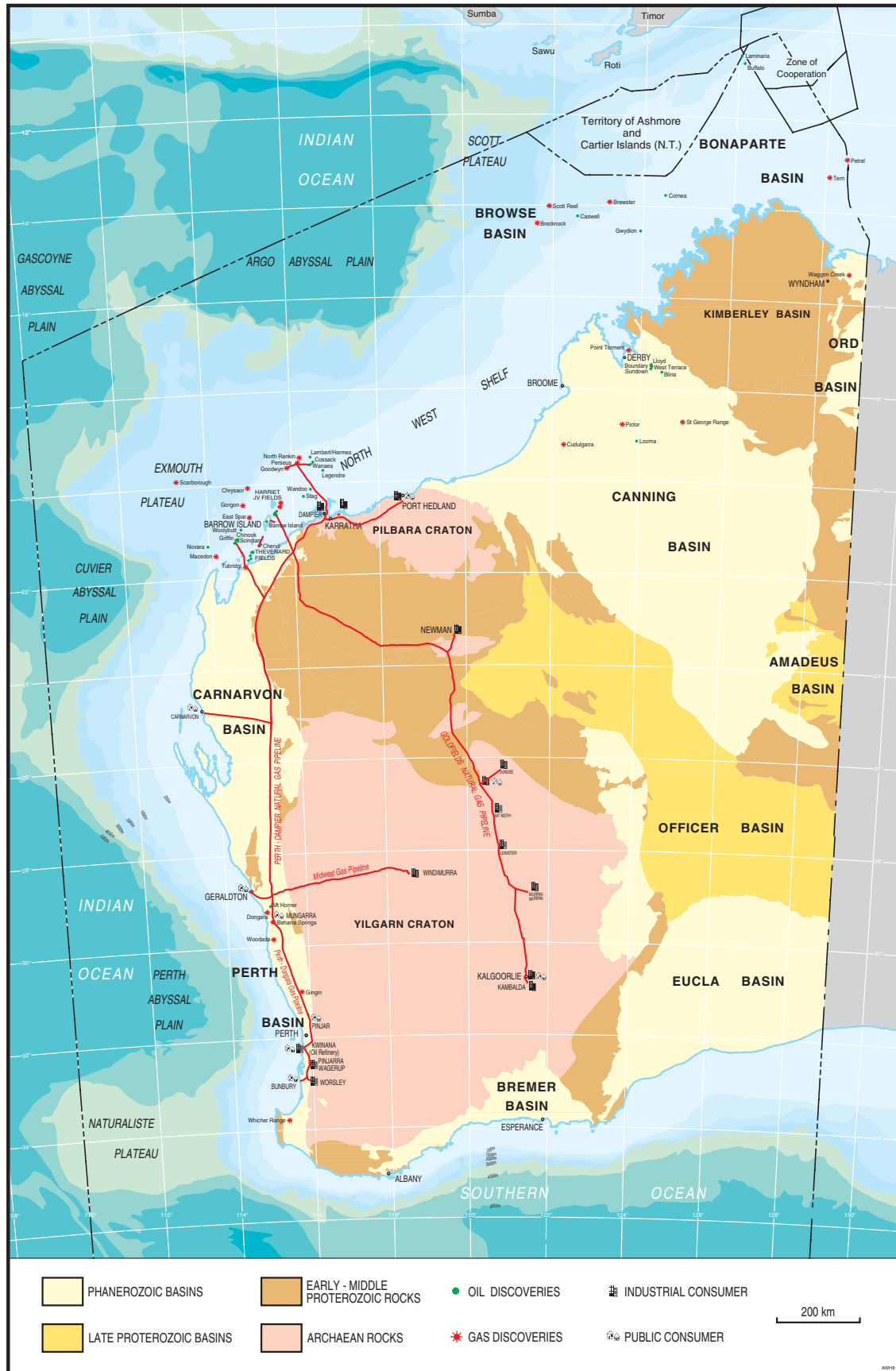


Figure 7. Location diagram of petroleum discoveries and developments in Western Australia

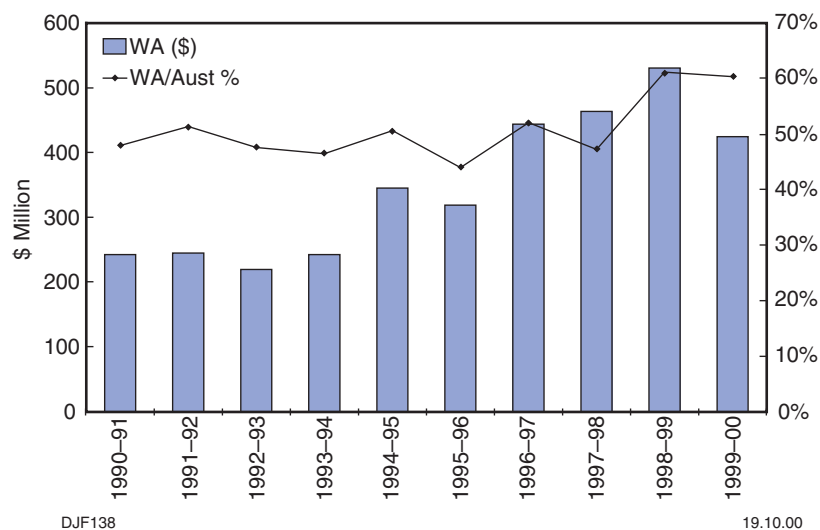


Figure 8. Petroleum exploration expenditure in Western Australia, by year (dollars of the day)

Peninsula (near Karratha), a \$850 million trunk line, and additional offshore development and production work. Negotiations have been ongoing for four years, but Woodside Petroleum plans to have all the necessary contracts signed by the end of 2000. Although the project has not yet been given formal approval to proceed, the timetable is for gas delivery in mid-2004.

Offshore exploration drilling continued at near-record levels, with the primary focus of exploration being the offshore Carnarvon Basin. A total of 36 new-field wildcat wells were spudded in offshore Western Australia during 1999–2000. The corresponding total for 1998–99 was 38 wells.

The Northern Carnarvon Basin continues to be the most actively explored basin in Western Australia. During the 1999–2000 financial year, a total of one onshore and 31 offshore new-field wildcat wells were spudded in the basin. Four deep-water gas discoveries (Geryon, Maenad, Orthrus, and Urania) were drilled in succession by Chevron, proving world-class gas reserves. Numerous other hydrocarbon discoveries were made from north of North West Cape to northwest of Dampier.

Three new-field wildcat wells were spudded in the Browse Basin, two of which were gas discoveries that could contain world-class reserves and have reasonable condensate content.

In the offshore Bonaparte Basin, the Buffalo Oilfield in WA-260-P came on-stream in December 1999 and BHP expects the field to produce 3.5 million cubic metres of oil over a three-year period. In addition, two new-field wildcat wells were spudded.

No drilling took place in the offshore portion of the Perth Basin, but about 670 line km of seismic data were acquired in the northern part of the basin.

Onshore

The level of onshore new-field wildcat drilling activity in Western Australia is at its lowest level in ten years, with only four wells drilled. One extension well and ten development wells were spudded in 1999–2000, and onshore seismic data acquisition remains at very low levels compared with those of the 1980s.

The lack of activity in onshore exploration was particularly evident in the Canning Basin, which was once a highly active exploration area. The Canning Basin may be one of the most underrated basins in Australia, considering the potential of its petroleum systems. However, there is some promise for more active exploration in the future. New Standard Exploration has applied for five exploration permits in the southern Canning Basin, with one of these

granted in February 2000. Numerous prospects, some with giant potential, have been mapped by companies such as Shell and Kimberley Oil.

No wells were drilled in the onshore Bonaparte Basin.

In the onshore northern Perth Basin, 163 line km of 2D and 212 km² of 3D seismic data were acquired and three exploration wells were drilled.

Of concern to industry in the granting of new onshore titles is Native Title and the lengthy process required for the Right to Negotiate process, and the accompanying uncertain outcomes. Although new Commonwealth legislation has been introduced to improve the Native Title process, a number of issues remain unresolved and continue to hinder onshore exploration and development activities.

The Geological Survey of Western Australia continued with its petroleum initiatives projects that focus on the underexplored interior basins (Officer and Canning Basins) and western margin of Western Australia (onshore Southern Carnarvon and Perth Basins). Drilling of a deep stratigraphic well, Vines 1, in the Waigen area (Officer Basin) intersected gas at a depth of 1482.9 m, which was released from a fracture system while coring. The gas show at Vines 1, located 190 km east of Warburton and south of the Aboriginal communities at Blackstone and Wingellina, is thought to be a direct indication of thermogenic gas generated by petroleum source rocks in the Neoproterozoic Officer Basin. This result is regarded as very encouraging to the oil industry, which has investigated smaller hydrocarbon shows elsewhere in the Officer Basin in South Australia and in the Amadeus Basin in the Northern Territory, where both the Mereenie Oil- and Gasfield and the Palm Valley Gasfield are located. Further exploration by petroleum companies is required to determine the commercial significance of the gas show at Vines 1, but it demonstrates the importance of the work being carried out by the Geological Survey to enhance the petroleum prospectivity of the State's extensive and essentially unexplored onshore sedimentary basins.

Petroleum reserves

Petroleum reserves, at the 50% probability level, in developed and undeveloped fields increased during 1999–2000 for oil, condensate, and gas (Fig. 9). Oil reserves increased with the discovery of new fields and the

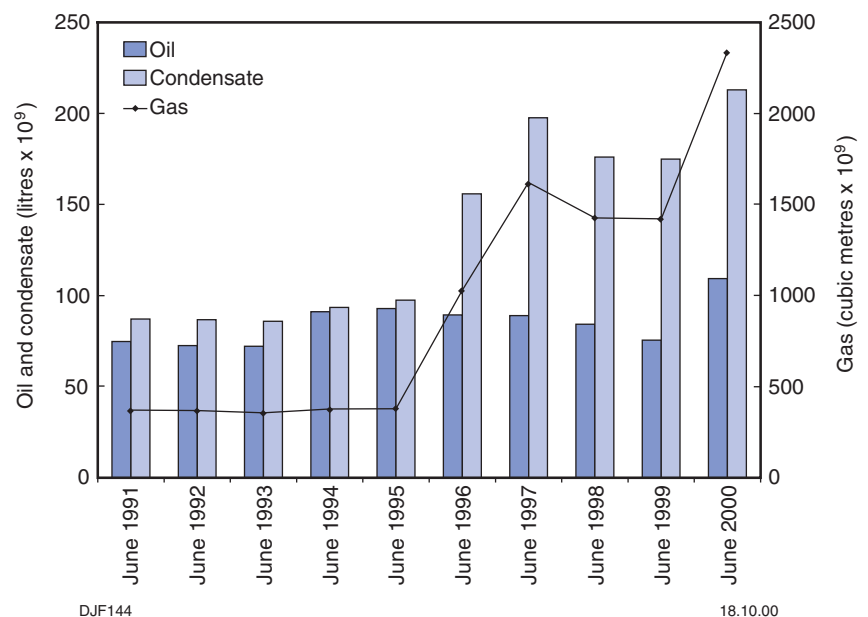


Figure 9. Inventory of petroleum reserves in developed and undeveloped fields in Western Australia, including offshore Commonwealth waters, at the 50% probability level

re-evaluation of previous discoveries, rising from 76 to 109 gigalitres. The production rate also increased significantly from an average of just over 24 000 kilolitres per day last year to over 34 000 kilolitres per day this year. Booked gas and associated condensate reserves rose substantially due to reassessment of the Brecknock, Scott Reef, and Scarborough fields and discovery of the Geryon field. The average daily gas and condensate production rates for 1999–2000 are marginally higher than for the previous year (DME Annual Report, 1999–2000).

Acknowledgements

Mineral and petroleum exploration expenditure data were compiled by the Australian Bureau of Statistics, but petroleum exploration expenditure for the periods prior to 1993–94 were compiled by the Bureau of Resource Sciences (now Australian Geological Survey Organisation).



Inside the GSWA

Staff profiles

Roger Hocking



Roger Hocking recently entered the annals of the Geological Survey of Western Australia by joining those few geologists who have also seen 25 years of service with the Department of Minerals and Energy. Roger describes himself as being 'quite young' when he joined GSWA in 1974, lured from New England in NSW to the Carnarvon Basin, attracted by its proximity to the coast and the prospect of surfing opportunities. Photographic evidence shows Roger to have fitted the archetypal surfer of the 70s — lean and with long sun-bleached hair. His attraction to the coastal areas and the spectacular scenery around the Murchison River Gorges led him to undertake research on the early Palaeozoic Tumblagooda Sandstone at Kalbarri for his Masters degree during the mid-80s. Roger's foundation work on this little-described formation would later be recognized by a work colleague in naming a fossilized arthropod escape burrow after him — *Tumblagooda hockingi*! Further accolades followed during his career, with a coarse and warty textured Permian brachiopod and a short and stumpy Devonian coral also named after him. Roger grins happily when telling people of these claims to fame.

Over the next ten years of field- and office-based studies that included the publication of numerous Explanatory Notes, Records, Reports, papers, and a Bulletin, Roger's name became synonymous with the Carnarvon Basin to petroleum exploration companies and many generations of geology students, and a guru status emerged. During the 1980s Roger also contributed significantly to the understanding of other Phanerozoic basins of Western Australia, as is reflected in Memoir 3 and also by the 1988 State geological map, which he co-authored. In the late 80s to early 90s he continued work on the Carnarvon Basin, carrying out core-based studies of the North West Shelf.

By 1993, Roger was ready for a change and so moved to the mapping of the Lennard Shelf Devonian reef complex. The fossilized reefs, synonymous with his youthful surfing days, kept Roger busy for the next four years, culminating in co-authoring a special map series. He nostalgically recalls the luxury of being able to bathe almost every night in beautiful rock pools during these long field seasons and having a suntan that lasted nearly four years. It was during this time that Roger's prowess at campfire cooking was passed on to those 'younger geologists' that worked with him, as well as his tastes in somewhat obscure 60s and 70s music.

In 1997, Roger commenced regional mapping in the Palaeoproterozoic Earaheedy Basin. His 'holistic view of the scope of the project boundaries' led to him working on neighbouring Neoproterozoic successions, as well as discovering the first recorded gold mineralization at Quadrio Lake in the Little Sandy Desert. In 1998, he co-authored the latest edition of the State geological map.

Roger employs his renowned cryptic sense of humour to evaluate 25 years of service with the GSWA as a progression from 'being the new kid on the block, to being part of the woodwork, and now being one of the white ants'. His notable generosity and approachability, however, are still very much part of the woodwork.

Roger and his wife Marg were married in 1977 and they have two children, Tim and Chris.

Margaret Ellis



Margaret migrated to Australia with her parents from her birthplace in England. Her parents were post-war refugees. Her father had made his timely escape from the spy trade after the Second World War, and her mother had been in a slave-labour camp in Germany. They found a new life in Tasmania, after a brief landing in Fremantle during the boat trip out to Australia. Margaret grew up in Hobart near other relatives who had also immigrated to Australia after the war, to work on Tasmania's hydroelectricity scheme. She didn't learn English until she started school, as Polish was the language spoken at home. She was a promising ballet dancer as a child, and received a scholarship with the Australian Ballet Company, but grew too tall to continue pursuing a career in dancing.

Her graduation from the University of Tasmania, with a degree in geomorphology while working in the university library, was the start of Margaret's lifelong association with geoscience databases. While at the University of Tasmania, she met her husband Peter. They then moved to Wollongong, where Margaret pursued further studies in geology and worked in the University of Wollongong library. While there, she was fortunate to be employed in the new university's library, where she played a significant role in building up the physics, chemistry, and geology collections. Margaret also obtained her library qualifications. After leaving Wollongong, Margaret worked for a short time for Aberfoyle at the Cleveland tin mine, on the west coast of Tasmania. Her next role was Chief Librarian for the Tasmanian Mines Department, where she was in charge of information management for the whole department, including open- and closed-file reports and the establishment of the TASXPLORE database to manage mineral exploration data. During this time, Margaret took extended leave to join Peter in West Sumatra while he pursued a job opportunity. Margaret's next assignment was as Chief Librarian and head of information services for Western Mining in Melbourne. This turned out to be a fly-in, fly-out arrangement from Hobart to Melbourne for 10 months, which was followed by her move to Perth to work on Western Mining's Western Australian operations. Her nomadic life continued with a stint in Temora in country New South Wales, where Peter worked at the local mine while Margaret undertook post-graduate studies at Charles Sturt University in commercial law, and accounting and financial management, while working on various database consultancies within the region.

Margaret joined GSWA in January 1997 and continues to manage the Statutory Exploration and Information Group of the Survey. She has two teenage daughters, George and Toni. Margaret loves travelling, snow skiing (but doesn't get much chance to ski here in Western Australia), scuba diving, trout fishing, and going to the ballet.

George Karniewicz

The son of Polish migrants, George was born and raised in Perth, where he attended Saint Maria Gorettis Primary School and La Salle College. Before commencing work within the Department, George worked as a builder's labourer and with the Forests Department.



George's first stint with the Geological Survey of Western Australia was from 1984 to 1989, when he was involved in tasks related to the effective management of statutory petroleum and mineral exploration data. George also spent a short time as a field assistant in and around the Fitzgerald River National Park.

In 1989, George left for a nine month working holiday across New Zealand, North America, and Europe. Lack of funds, and the poor wages he earned in London, forced George back to Perth, where he secured employment with Marathon Petroleum. Originally intended for only a short period of time, this job lasted until 1994.

George returned to the Department in 1994, once again within the Geological Survey, where he is involved in tasks similar to those he undertook here initially. George's major responsibility has been to release petroleum exploration data to open-file according to the requirements of Commonwealth and State legislation. George completed his Associate Diploma of Science in Library Technology at Edith Cowan University in 1996. For most of the time spent studying, George also worked full-time.

Outside of work, George is involved in the Abilympics (ability olympics movement). Abilympics involves organizing work-skills competitions (ie. technical, trade, and craft skills) at state, national and international levels. Abilympics aims to encourage the employment of people with disabilities into mainstream employment. George recently returned from the 5th International Abilympics, which were held in Prague, Czech Republic. At these Abilympics, the Aussie team scored two gold and two bronze medals. George's other interests include brewing and drinking his own beer, and supporting the Perth Glory Soccer Club (just don't mention the last grand final).

George married in 1999, but does not have children, yet!

Obituary

Angelo Alfredo Crostella 1929–2000



Angelo Crostella died peacefully in his sleep in the early hours of 15 July 2000. Angelo worked for 40 years in the petroleum exploration industry before joining the Geological Survey in 1994. He was greatly respected by everyone who worked closely with him, particularly the geoscientists in the Western Margin Team, who are especially indebted to him for sharing his experience and for being a friend and mentor.

Angelo Alfredo Crostella was born in Treviso, Italy, on 12 August 1929, and at the age of 18, when his father died, was forced to work as a labourer on the Italian railways while he finished his schooling. His father had wanted him to study engineering but, because he excelled in geography and wanted to travel, he enrolled for the shorter course in geology at the University of Pisa, from which he graduated with a doctorate in 1954. In the early 1950s, Italy was neither renowned nor widely explored for petroliferous reserves, so Angelo was fortunate that Petrosud (50% Gulf Oil and 50% Montecatini) began an exploration program in southern Italy in 1954. The company immediately hired him because of his excellent academic results, and Angelo began his petroleum geology career as a well-site geologist and later as a field geologist mapping the Apennines. It was on one of these field trips in the Little Dolomites that he met his future wife, Carla. By 1969, Angelo reached the position of Senior Petroleum Geologist in the company, which eventually became Montedison. While with Montedison, Angelo was involved in the discovery of several gasfields and two subeconomic oilfields in peninsular Italy, previously considered a barren frontier region. However, the company was nationalized and amalgamated with several other related disciplines, and Angelo found the resulting bureaucracy stifling.

Not wishing to be caught up in a bureaucratic company, Angelo left the comfort of home for Australia. He arrived in Perth during the nickel boom in 1970, and within two days found himself in the Pilbara as a field geologist for a small consulting group exploring for uranium, nickel, and heavy minerals. He was soon confronted with a new culture. One Sunday morning during a weekend off in town, while enjoying a breakfast of bacon and eggs, he asked the publican for a glass of wine, as he considered such a substantial meal should be accompanied by wine. He was bewildered to find it was not only illegal to serve alcohol before 10 am, but that such sales were totally banned on Sundays. Luckily for a man who loved a glass of good red wine, the laws were changed within a few years.

Fortunately for Angelo, Burmah Oil (later to become BOCAL and then Woodside) opened an office in Perth in 1971, at which he was employed as a District Geologist, initially responsible for geological activities in the Browse and offshore Canning Basins. In 1973, Angelo became a Senior District Geologist in charge of the Beagle Sub-basin, and in 1974–75 he was in charge of exploration in East and West Timor. In the latter region, he found himself in similar terrain to that of the Apennines in Italy, and relished the opportunity to study and unravel the island's complex geology. However, Woodside's activities in Timor were terminated once the political situation became unstable in 1975.

Back in Perth between 1976 and 1977, Woodside put Angelo in charge of the Dampier Sub-basin, where there had been the significant discoveries of the North Rankin, Angel, and Goodwyn fields, and in 1978 he was promoted to Chief Geologist responsible for all geological activities of the company. During the ten years Angelo spent with BOCAL/Woodside, he was involved in extensive work on the North West Shelf that essentially unravelled the geological framework of the area, and which still provides the basis for present exploration. A further personal triumph for Angelo was the authoring and presentation of several papers on the geology of Timor and

northern Australia — a considerable achievement for someone who had had a very limited knowledge of English when he first arrived in Australia.

In 1981, Angelo left Woodside to become Exploration Manager with Hudbay Oil in Jakarta, to manage their Indonesian interests. Angelo established an office in Jakarta, and by the time he left in 1985 he had been responsible for the oil discoveries of Lalang (40 million barrels), Mengkapan (20 million barrels), and Melibur (20 million barrels). Before these discoveries, the area had been regarded as having low potential for petroleum. When Hudbay's interests in Indonesia were taken over by BP-Lasmo, Angelo was offered the opportunity to set up an office in Rome. In July 1985, as the General Manager of Lasmo's Italian interests, he established a new office and progressively expanded its operations, leading up to the discovery of the Tempa Rossa oilfield in 1991, with a 1000 m gross reservoir within Cretaceous fractured carbonates.

In 1992, Angelo retired from Lasmo in Italy to return to Perth, where his children had remained. However, as geology was both his work and hobby, he did not stay retired for very long. Between 1992 to 1993, he carried out some short-term consultancies in Perth for Minora Resources and Western Mining Corporation, and at the end of 1994 joined the Geological Survey of Western Australia as a consultant. While with GSWA, Angelo was very productive and was the principal or sole author of eight reports and three papers. Initially, he led the Western Margin team, but later eschewed such managerial responsibilities to concentrate on research. He was an inspiration to all he worked with, and enjoyed sharing his knowledge with colleagues.

In the last four years of his life Angelo battled with cancer, but continued an active role at GSWA until March this year, when he began working from home. He is survived by Carla his wife, his children Luca, Max and Anna, and four grandchildren.



Staff list (30 June 2000)

BLIGHT, David (Director)

Regional Geoscience Mapping Branch

GRIFFIN, Tim (General Manager)

TYLER, Ian (Acting Chief Geoscientist)

Bangemall Basin

MARTIN, David

THORNE, Alan

Earaheedy/Glengarry Basins

HOCKING, Roger

JONES, Amanda

PIRAJNO, Franco

Eastern Goldfields

GROENEWALD, Bruce

PAINTER, Matthew

ROBERTS, Ivor

Southern Cross

CHEN, She Fa

GREENFIELD, John

RIGANTI, Angela

WYCHE, Stephen

Southern Gascoyne Complex

OCCHIPINTI, Sandra

SHEPPARD, Steve

Pilbara Craton

BAGAS, Leon

FARRELL, Terry

HICKMAN, Arthur

SMITHIES, Hugh

VAN KRANENDONK, Martin

WILLIAMS, Ian

Geochemical Mapping

MORRIS, Paul

SANDERS, Andrew

Lennard Shelf

PLAYFORD, Phillip

Geochronology

NELSON, David

Geophysics

HOWARD, David

WATT, John

Publications

CARROLL, Peter

COSGROVE, Lisa

DAY, Lyn

DOWSETT, Suzanne

EDDISON, Fiona

EDWARDS, Tara

FERDINANDO, Darren

FORBES, Alex

GOZZARD, Margie

HOFFMAN, Arthur

JOHNSTON, Jean

JONES, Murray

MIKUCKI, Jennifer

NOONAN, Kath

REDDY, Devika

SMART, David

STRONG, Caroline

SUTTON, Dellys

TETLAW, Nathan

URBINI, Simon

Map Production and GIS

BANDY, Stephen

BRIEN, Cameron

BURDEN, Phillip

COLDICUTT, Shaun

COLLOPY, Sean

DAWSON, Brian

FLETCHER, Greg

FOX, Alistair

FRANCOIS, Annick

GREEN, Ellis

GREENBURG, Kay

HAMILL, Sammy

JOSE, Geoffrey

KIRK, John
 KUKULS, Liesma (Les)
 LADBROOK David
 LENANE, Tom
 LOAN, Geoff
 PRAUSE, Michael
 McCABE, Marian
 TAYLOR, Peter

THEEDOM, Erica
 VICENTIC, Milan
 WALLACE, Darren
 WILLIAMS, Brian

Data Integration
 GOZZARD, Bob
 DOWNING, John

Mineral and Petroleum Resources Branch

ROGERSON, Rick (General Manager)

Petroleum Initiative Basin Studies

APAK, Sukru (Neil)
 BLUNDELL, Kelvin
 CARLSEN, Greg
 CROSTELLA, Angelo¹
 DE LEUW, Lorraine
 GHORI, Ameen
 IASKY, Robert
 IRIMIES, Felicia
 MOORS, Henry
 MORY, Arthur
 SHEVCHENKO, Sergey
 STEVENS, Mark

Regional Mineralization Mapping

FERGUSON, Ken
 HASSAN, Lee
 PEIRIS, Elias
 RUDDOCK, Ian

Resource Assessment and Advice

ABEYSINGHE, Pathmasekara (Abey)
 FLINT, Don
 PAGEL, Jutta
 TOWNSEND, David

Inventory of Abandoned Mine Sites

ADAMIDES, Nicos
 COOPER, Roger

Urban and Development

Areas Geology

HALL, Glennis
 LANGFORD, Richard
 MARNHAM, Jodie

Palaeontology

GREY, Kath

Library

CHEUNG, Eunice
 CROSS, Robert
 KNYN, Brian

Administration and Executive Support

BRADSHAW, Brian
 CRESSWELL, Brian
 ELLIOTT, Ian
 EVANS, Elaine
 SLATER, Elizabeth
 STOYANOFF, Nell

Special Projects

GOSS, Andrew

Carlisle Operations

BONER, Peter
 BRADLEY, John
 BROOKS, Chris
 BRZUSEK, Marianna
 CAREW, Eugene
 CLARK, Dean
 HOLMES, Mario
 LOCKYER, Stuart
 MOORE, Brian
 WILLIAMS, Gary
 WILLIAMS, John

Statutory Exploration Information Group

ARATHOON, Claudette
 BELL, Ann
 DALY, Matthew
 DODD, Fiona
 ELLIS, Margaret
 EMMS, Rosie
 FETHERSTON, Michael
 FITTON, Ann
 HAWORTH, Jeffrey
 HUGHES, Bernard
 KARNIEWICZ, George
 LESIAK, Irena
 MASON, Jan Sandra
 McCORQUODALE, Fiona
 McGORRIN, Yvonne
 NAGY, Pearl
 STAPLETON, Gladys
 WONG, Henrietta

¹ deceased 15 July 2000



Staff movements (1 July 1999 to 30 June 2000)

Internal transfer

LESIK, Irena — to CAMP for 7 months

Internal reclassifications

DE LEUW, Lorraine — to Level 3

FOX, Alistair — to Level 3

MORRIS, Paul — to Level 8

Commencements

DWYER, Justin

VEALE, Anthony

Resignations

BROWN, Brad

PYE, Karen

Transfers out

GAO, Mai — to Land Access Unit

Secondments

O'NEIL, Paola — to GSWA (9 weeks)

WONG, Henrietta — to Petroleum Division

Voluntary severance

TOMICH, Don

Casual and Fee for service

APTHORPE, Marjory

ARDEN, Lorraine

COKER, Julian

COPP, Iain

CROSTELLA, Angelo

D'ERCOLE, Cecilia

FLINT, Richard

JABLON, Marianne

JOCKEL, Fergus

LUCKETT, Jordan

MacKAY, Anthony

McGUINNESS, Sally

McGRATH, Bob

MAJOR, Tim

McKEATING, Joan

NOWAK, Ian

PARRY, Jade

SEARSTON, Stella

VANDERHOR, Fop

VEALE, Anthony



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MANAGER**

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9222 3172

**REGIONAL GEOSCIENCE
MAPPING BRANCH**

Geoscientific Specialist Support

- *Acting Chief Geoscientist*
Ian Tyler: 9222 3192
- *Chief Geophysicist*
David Howard: 9222 3331
- *Geochronologist*
David Nelson: 9222 3613

Publications

- Alex Forbes: 9222 3163
- *Map and Text Editing*
Jenny Mikucki: 9222 3568
 - *Publication Drafting and Design*
Peter Carroll: 9222 3276

Geoscience Data Management

- Steve Bandy: 9222 3201
- *Geographic Information System*
Phillip Burden: 9222 3175
 - *Computer Assisted Map Production*
Brian Dawson: 9222 3122
 - *Data Integration*
Bob Gozzard: 9222 3594

Geochemical Mapping

Paul Morris: 9222 3345

East Yilgarn Terrane Custodian

- Ivor Roberts: (08) 9022 0401
- *Southern Cross*
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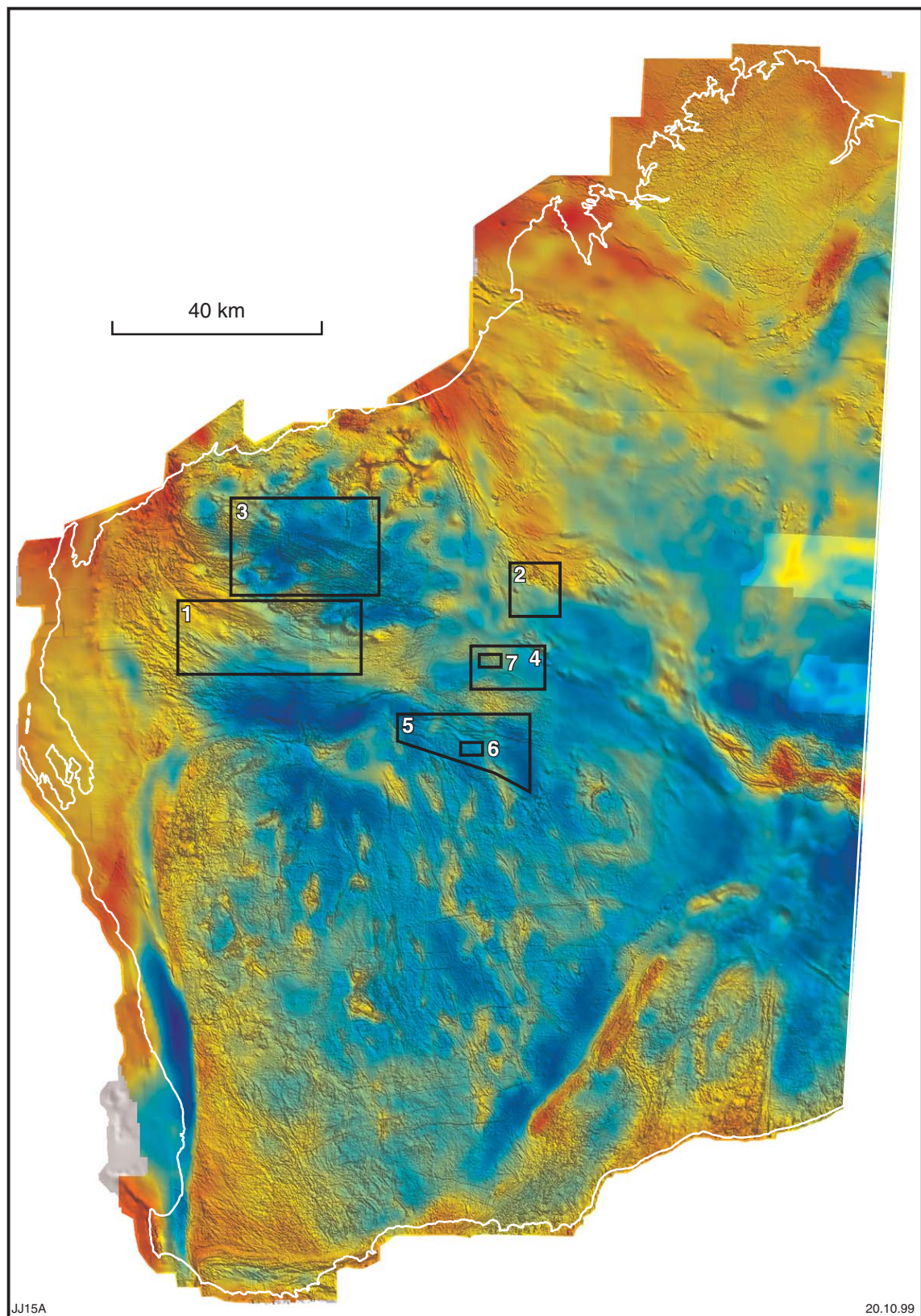
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Map of Western Australia showing the locations discussed in the seven technical papers on the following pages. Pseudo-colour Bouguer gravity image and grey-scale Total Magnetic Intensity. Blue = gravity low; TMI highlights structural information. Data courtesy of Australian Geological Survey Organisation



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Another Jillawarra-style sub-basin in the Bangemall Supergroup — implications for mineral prospectivity

by D. McB. Martin¹ and A. M. Thorne

Abstract

Recent regional mapping and revisions to the stratigraphy of the Bangemall Supergroup suggest close similarities between the geology of the southwestern part of the EDMUND 1:250 000 sheet and the Jillawarra sub-basin. These similarities include lithofacies, structural setting, and intrusion of felsic rocks into the lower Bangemall Supergroup. The presence of the large Abra lead-copper-barium deposit and other base metal mineralization in the Jillawarra sub-basin implies enhanced mineral prospectivity for the EDMUND sheet area.

KEYWORDS: Bangemall Supergroup, Edmund Group, Collier Group, Abra, Mesoproterozoic, base metals

Introduction

The 1.64 – 1.00 Ga Bangemall Supergroup hosts several stratabound base metal occurrences (Cooper et al., 1998), the most significant of which are in the Jillawarra sub-basin (Fig. 1). Perhaps the best known of these is the large, low-grade polymetallic Abra deposit at the eastern end of the sub-basin. Abra was discovered in 1981 and is Western Australia's largest known lead-copper-barium deposit, containing minor silver and gold (Boddington, 1987; Vogt and Stumpfl, 1987; Collins and McDonald, 1994; Vogt, 1995). The best known base metal prospects, including Abra, are in the lower part of the Bangemall Supergroup, but variations in stratigraphic nomenclature have made it difficult to apply specific regional

correlations. Rationalization of the stratigraphy of the Bangemall Supergroup (Copp, 1998; Martin et al., 1999) suggests that the dolomites and carbonaceous siltstones of the Irregularly, Blue Billy, Kiangi Creek, and Discovery Formations on EDMUND* are the most prospective lithologies.

In this paper, the facies and stratigraphy of the Jillawarra sub-basin on MOUNT EGERTON and COLLIER are compared to those of the Irregularly Formation on EDMUND, in order to assess regional prospectivity for Abra-style deposits.

Regional geology

There is strong evidence on EDMUND for a two-fold subdivision of the

Bangemall Supergroup into an older Edmund Group and a younger, unconformably overlying Collier Group (Martin et al., 1999). The Edmund Group unconformably overlies Palaeoproterozoic rocks of the Ashburton and Capricorn Formations to the north, and the Gascoyne Complex to the south (Fig. 1). Within the Edmund Group, the basal Irregularly Formation has been redefined (Chuck, 1984; Copp, 1998) to include only the lowermost major carbonate unit (Wongida Dolomite Member of Daniels, 1970). The thin, locally developed, basal siliciclastic unit, the 'Yilgatherra Member' of Daniels (1970), is here elevated to formational status, and may be equivalent to the Tringadee Formation of Chuck (1984) and Muhling and Brakel (1985).

Initial basin subsidence was controlled by extension and growth faulting (Chuck, 1984; Muhling and Brakel, 1985), which is reflected in the distribution and thickness of the basal units of the Bangemall Supergroup, as well as in the style of later deformation. Upright, open to tight folds in the Edmund Fold Belt are interpreted as the result of reverse reactivation of earlier horst and graben structures (Muhling and Brakel, 1981, 1985). The east-west trending Jillawarra sub-basin is one of these early grabens that has been filled with a mixed siliciclastic-carbonate succession (Vogt, 1995). No other grabens have been described from the region, although their presence is inferred in models for the tectonic evolution of the Bangemall Supergroup (e.g. Chuck, 1984).

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* Capitalized names refer to standard 1:250 000 map sheets

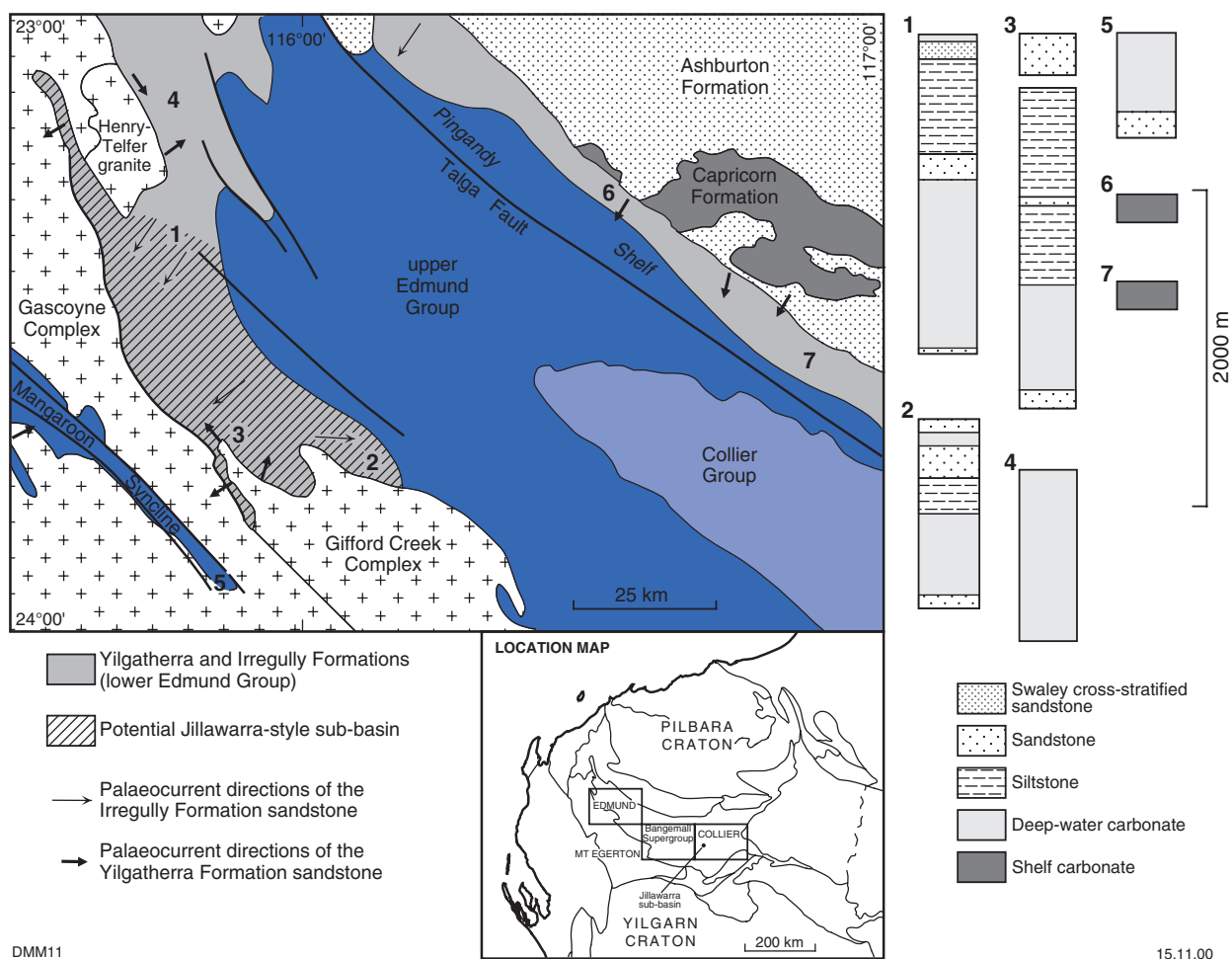


Figure 1. Sketch map showing the simplified geology of EDMUND and the thickness, facies distribution, and palaeocurrent directions in the Yilgatherra and Irregully Formations of the lower Edmund Group. The distribution of the Bangemall Supergroup in Western Australia, and location of the Abra lead-copper-barium deposit in the Jilgarn sub-basin are also shown

Facies distribution and thickness in the basal Bangemall Supergroup on EDMUND are strongly controlled by the syndimentary Talga Fault (Fig. 1). North of the Talga Fault, on the Pingandy Shelf, the Yilgatherra Formation commonly consists of a few metres of fluvial sandstone and conglomerate, with palaeocurrents directed toward the south. The Irregully Formation unconformably overlies basement where the Yilgatherra Formation is absent. These basal siliciclastic rocks are considerably thicker (tens of metres) south of the Talga Fault, where they are either overlain by, or interbedded with, a unit of planar-laminated siltstone. Palaeocurrent directions in this area are highly variable and suggest that, in addition to a northerly source area, a few of the basement inliers were

topographic highs at the time of deposition (Fig. 1). These highs are represented by the Henry-Telfer granite (Daniels, 1966) and the Gifford Creek Complex (Pearson et al., 1996). Rapid erosion of these highs produced immature arenaceous and rudaceous successions in adjacent grabens.

The Irregully Formation on EDMUND

North of the Talga Fault, the Irregully Formation consists primarily of peritidal dolostone and sandstone with minor siltstone (Copp, 1998). Stromatolites have been recorded from several horizons and although they have not been studied in detail, they act as useful

stratigraphic markers (Grey, 1985; pers. comm.). Two thin peritidal sandstone horizons are present in the lower Irregully Formation, which also contains the stromatolite *Conophyton garganicum australe* Walter 1972, and local evaporite pseudomorphs. The peritidal facies consists mainly of thin upward-shoaling cycles of intraclast breccia overlain by stromatolitic dolomite (mainly containing *Paniscollenia* Koroljuk 1960). Towards the top of the Irregully Formation there is a horizon of club-shaped stromatolites – *Colonella* Komar 1964. The upper Irregully Formation is characterized by the branching columnar stromatolite *Baicalia capricornia* Walter 1972. Immediately south of the Talga Fault, the Irregully Formation thickens considerably (Fig. 1), and is dominated by thick

subtidal cycles of intraclast breccia and dololutite, with rare stromatolites and siliciclastic facies.

The siliciclastic component of the Irregully Formation increases progressively towards the southeastern corner of EDMUND. In this area, the Irregully Formation is dominated by interbedded dololutite, dolomitic siltstone, siltstone, and sandstone. Sandstone units within the Irregully Formation in the southeastern part of EDMUND are characterized by large-scale trough cross-stratification and palaeocurrent directions predominantly towards the south-southeast. Terrestrial to shallow-marine siliciclastic facies, comprising trough cross-stratified sandstone and interbedded planar- and ripple-laminated siltstone, dominate the Irregully Formation around the western margin of the Gifford Creek Complex, where cross-bed sets are up to 2 m thick. In the southeastern part of EDMUND, a distinctive marker horizon in the upper Irregully Formation is characterized by swaley cross-stratified, shallow-marine sandstone interbedded with stromatolitic dolomite (*B. capricornia*). This horizon is interpreted to correlate with similar occurrences of *B. capricornia* in the upper Irregully Formation north of the Talga Fault.

Abra and the Jillawarra sub-basin

To date, the Jillawarra sub-basin is the only area where significant base metal mineralization has been found in the Bangemall Supergroup (Cooper et al., 1998). The sub-basin is bounded to the north and south by the Quartzite Well Fault and West Creek Fault respectively, and lies between the granitic inliers of the Coobarra Dome to the east and Woodlands Dome to the west (Vogt, 1995). The Abra deposit is hosted within dolomitic siltstone and shale of the upper Gap Well Formation, which forms the lower part of the Bangemall Supergroup in this area. Although stromatolites are present in the succession, they have not been formally identified (Grey, K., pers. comm.).

The polymetallic mineralization at Abra consists of a lower funnel-shaped stringer zone and an upper

stratiform zone, and is unconformably overlain by conglomerate, sandstone, and siltstone of the West Creek Formation (Boddington, 1990; Vogt, 1995). The ore minerals are mainly galena, chalcopyrite, and barite, with an alteration halo of chlorite and hematite. Previous workers have interpreted Abra as a syngenetic hydrothermal deposit, related to elevated heat flow during the development of the Jillawarra graben and nearby, possibly coeval, felsic volcanism (Boddington, 1990; Collins and McDonald, 1994; Vogt, 1995).

Igneous activity

Elevated heat flow in the Jillawarra sub-basin has been interpreted as the result of intrusion of high-level granitoids in the Coobarra and Woodlands Domes (Boddington, 1990; Vogt, 1995). Granodiorite in the Coobarra Dome has been dated at 1797 ± 8 Ma and forms part of the Gascoyne Complex basement. However, local high-K rhyolite lava flows and plugs in the basal Bangemall Supergroup have been dated at 1638 ± 14 Ma (Nelson, 1995). Igneous activity is also known from the EDMUND area. Pearson et al. (1996) documented high-level dykes and sills of carbonatitic affinity intruding the basal Bangemall Supergroup southeast of the Edmund

Homestead. A small granophyric plug intrudes the Yilgatherra Formation about 2 km north of Horse Well (MGA 354100E 7431200N)*, on the western flank of the Henry-Telfer granite. The wider distribution of igneous activity in the basal Bangemall Supergroup has important implications for regional mineral prospectivity.

Mineralization potential of the EDMUND area

Regional mapping and resultant stratigraphic revisions to the Bangemall Supergroup on EDMUND indicate that a re-evaluation of the economic potential of this area is warranted. In particular, the common similarities in stratigraphy (source and host rocks), structure (fluid pathways), and regional geology (heat flow) between the Jillawarra sub-basin and the southwestern part of EDMUND (Table 1 and Fig. 2) suggest that the latter area has potential for Abra-style deposits. Facies and thickness changes within the Irregully Formation in this area

* Locations mentioned in the text are referenced using Map Grid of Australia coordinates, Zone 51. All locations are quoted to the nearest 100 m.

Table 1. Comparison of ore controls in the Jillawarra sub-basin and the southwestern part of EDMUND

Geological feature	Jillawarra sub-basin	Southwestern EDMUND
Lithostratigraphic units	Gap Well and West Creek Formations	Irregully Formation
Lithology	Mixed siliciclastic-carbonate succession	Mixed siliciclastic-carbonate succession
Faulting	East-west graben	Talga Fault and northwest-southeast graben
Associated basement highs	Woodlands and Coobarra Domes	Henry-Telfer dome, Gifford Creek Complex
Syn depositional magmatism	Tangadee Rhyolite	Granophyre plugs and alkaline intrusives
Potential source rock	Arkose (Tringadee Formation)	Immature sandstone (Yilgatherra Formation)
Alteration	Chlorite-siderite	–
Ore minerals	Galena, chalcopyrite, barite, tetrahedrite, sphalerite	–
Gangue minerals	Hematite, magnetite, carbonate, pyrite, quartz, jaspilite	Quartz veins, hematitic sandstone, pyritic siltstone

JILLAWARRA SUB-BASIN (VOGT, 1995)		EDMUND AREA (THIS STUDY)	
FORMATION	LITHOLOGY	LITHOLOGY	FORMATION
Discovery Chert	Massive to laminated chert	Laminated chert	Discovery
Jillawarra	Silica and iron-rich shale Dolomite, dolomitic shale, shale, sandstone	Sandstone, lesser siltstone Sandstone, siltstone	Kiangi Gooragoora, Blue Billy
West Creek	Coarse-grained sandstone, conglomerate lenses Siltstone, dolomitic siltstone, minor sandstone Shale, conglomerate, minor rhyolite Siltstone, sandstone, conglomerate	Stromatolitic dolomite Interbedded coarse-grained sandstone, siltstone, minor dolomite Dolomite and / or siltstone	Irregully
Gap Well	Siltstone, dolomitic shale, stromatolitic dolomite Siltstone and sandstone, stromatolitic dolomite Coarse-grained sandstone (Woodlands Arenite) Siltstone and sandstone Dolomite, dolomitic shale, minor sandstone Siltstone, sandstone, minor dolomitic siltstone	Coarse-grained sandstone, siltstone, dolomitic siltstone, dolomite, dolomite breccia	
Tringadee	Arkose	Coarse-grained sandstone, siltstone, minor conglomerate	Yilgatherra

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Figure 2. Comparative lithostratigraphy of the basal Bangemall Supergroup on EDMUND and in the Jillawarra sub-basin

suggest the presence of a fault-bounded basin north of the Mangaroon Syncline and south of the Talga Fault (Fig. 1) in the basal Bangemall Supergroup. Filling of this sub-basin was strongly controlled by uplift of the adjacent basement domes, which appears to have coincided with felsic and alkaline magmatism.

Previous exploration activity in the southwestern part of EDMUND focused heavily on uranium and diamonds, and the potential for base metal deposits has not been thoroughly tested. Base metal exploration programs have commonly been more regional in nature, and target generation for stratabound deposits has relied heavily on an outdated stratigraphic framework. Although the potential of this area was recognized by Alcoa (Shackleton, 1982), Chuck (1984), and BHP who recorded a pyrite-cemented fault breccia and anomalous zinc, nickel, and cobalt

in the Yilgatherra Formation (Surman, 1985), there is scope for further exploration. A detailed assessment of the similarity of the southwestern part of EDMUND to

the Jillawarra sub-basin will rely on continued systematic mapping and application of the revised Bangemall Supergroup stratigraphy.

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Copper and associated polymetallic mineralization along the Camel–Tabletop Fault Zone in the Paterson Orogen, Western Australia

by L. Bagas¹ and Z. Lubieniecki²

Abstract

Copper and associated polymetallic mineralization has been identified in the remote eastern part of the northwestern Paterson Orogen along the Camel–Tabletop Fault Zone. The mineralization is in the Palaeoproterozoic Rudall Complex and the basal Neoproterozoic part of the Officer Basin, in diverse settings controlled by stratigraphy, unconformities, and shear structures. Copper mineralization is commonly associated with gold, silver, lead, zinc, nickel or platinum-group elements.

The Camel–Tabletop Fault Zone is the collisional boundary between the Tabletop Terrane and the western Talbot and Connaughton Terranes of the Rudall Complex. The Camel–Tabletop Fault Zone was reactivated at about 800 Ma, forming a 3–10 km-wide graben where sedimentary and rare volcanogenic rocks of the Officer Basin were deposited. The copper mineralization in both the Rudall Complex and Officer Basin is structurally controlled and unconformity associated, and may have been at least partly contemporaneous with the formation of the graben structure.

KEYWORDS: Rudall Complex, Officer Basin, Camel–Tabletop Fault Zone, greenschist facies, metamorphism, hydrothermal alteration, mineralization

Introduction

Mineral exploration by companies and mapping by the Geological Survey of Western Australia (GSWA) have identified numerous occurrences of copper and associated mineralization in the Palaeoproterozoic Rudall Complex and the Camel–Tabletop Fault Zone in the Paterson Orogen (Fig. 1).

The Paterson Orogen (Williams and Myers, 1990) is a northwesterly trending belt of Palaeoproterozoic to Neoproterozoic rocks that, on geophysical evidence, occupies a 1200 km-long arcuate zone across the central part of Western Australia (Williams and Myers, 1990; Myers et al., 1996). The orogen is exposed along the eastern margin of the Pilbara Craton and in the Musgrave Complex (c. 1550–1150 Ma) of central Australia (Williams and Myers, 1990; Camacho and Fanning, 1995). These regions are connected

by the unexposed Paterson–Musgrave structural link (Austin and Williams, 1978), indicated by a strong gravity high initially known as the Anketell Gravity Ridge (Fraser, 1976), but more recently referred to as the Warri Gravity Ridge (Iasky, 1990). Myers and Hocking (1998) showed the structural link as a series of concealed thrusts.

Economic mineralization in the northwestern Paterson Orogen is present at the Nifty copper deposit, the Kintyre uranium deposit, and the world-class Telfer gold deposits (Fig. 1). In addition, Croesus Mining NL and Gindalbie Gold NL discovered significant gold, copper, and silver mineralization in 1998 at the Magnum prospect, where further exploration is in progress. This prospect is about 100 km north of the Telfer deposit, in part of the Paterson Orogen concealed beneath the Phanerozoic Canning Basin (Fig. 1). The presence of mineral deposits and mineralized zones in the Paterson Orogen indicates that it is highly prospective for various types of mineralization. However, the mineral prospectivity of adjacent parts of the Neoproterozoic Officer Basin (Fig. 1) has been largely unrecognized until recently. The presence of economic copper, lead, and zinc mineralization at the Maroochydore deposit, near the northwestern extension of the Camel–Tabletop Fault Zone (Fig. 1), and new copper discoveries near No. 23 Well (Fig. 2) suggest that economically viable deposits may be present within the Neoproterozoic Officer Basin.

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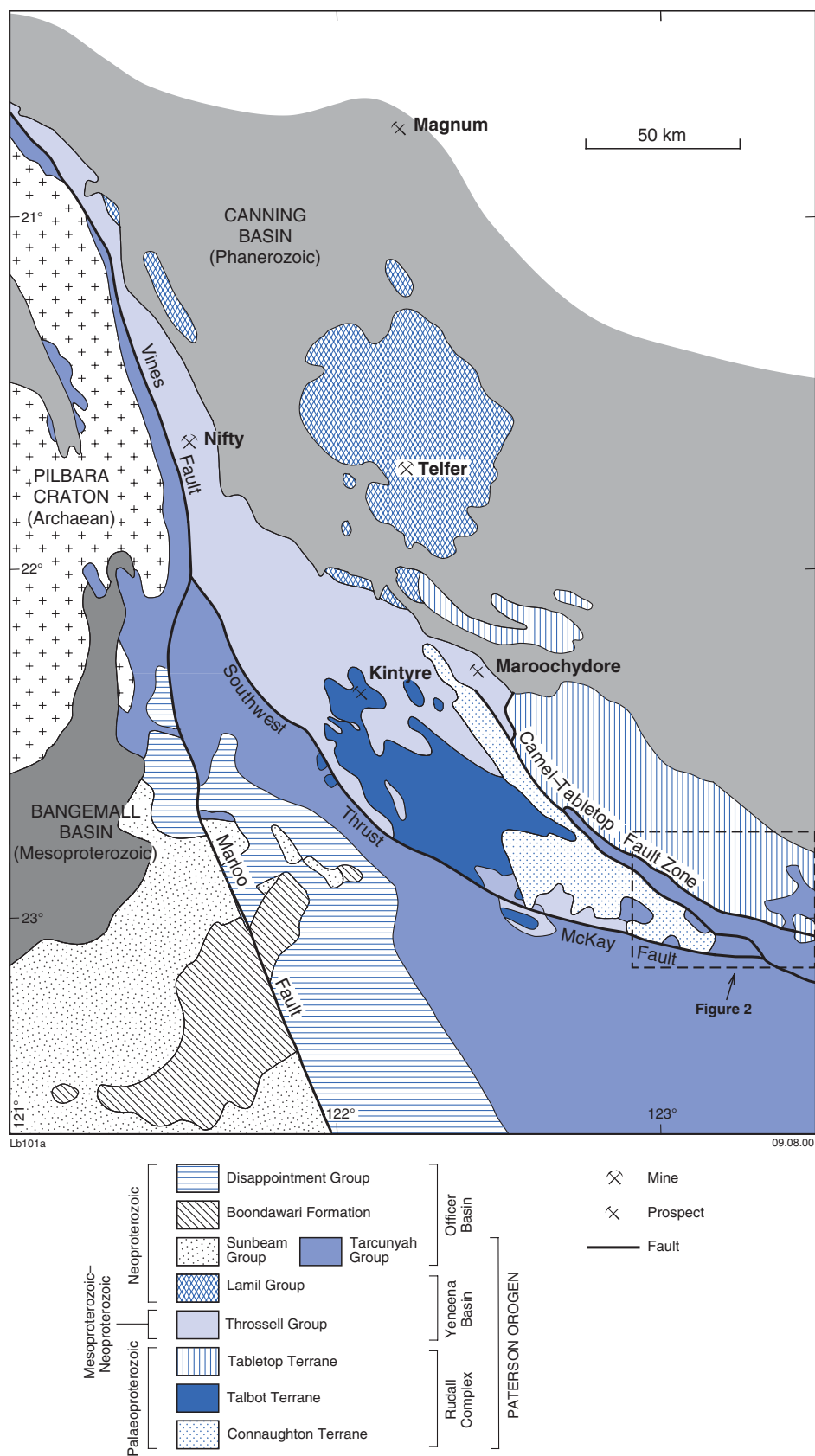


Figure 1. Regional geological setting

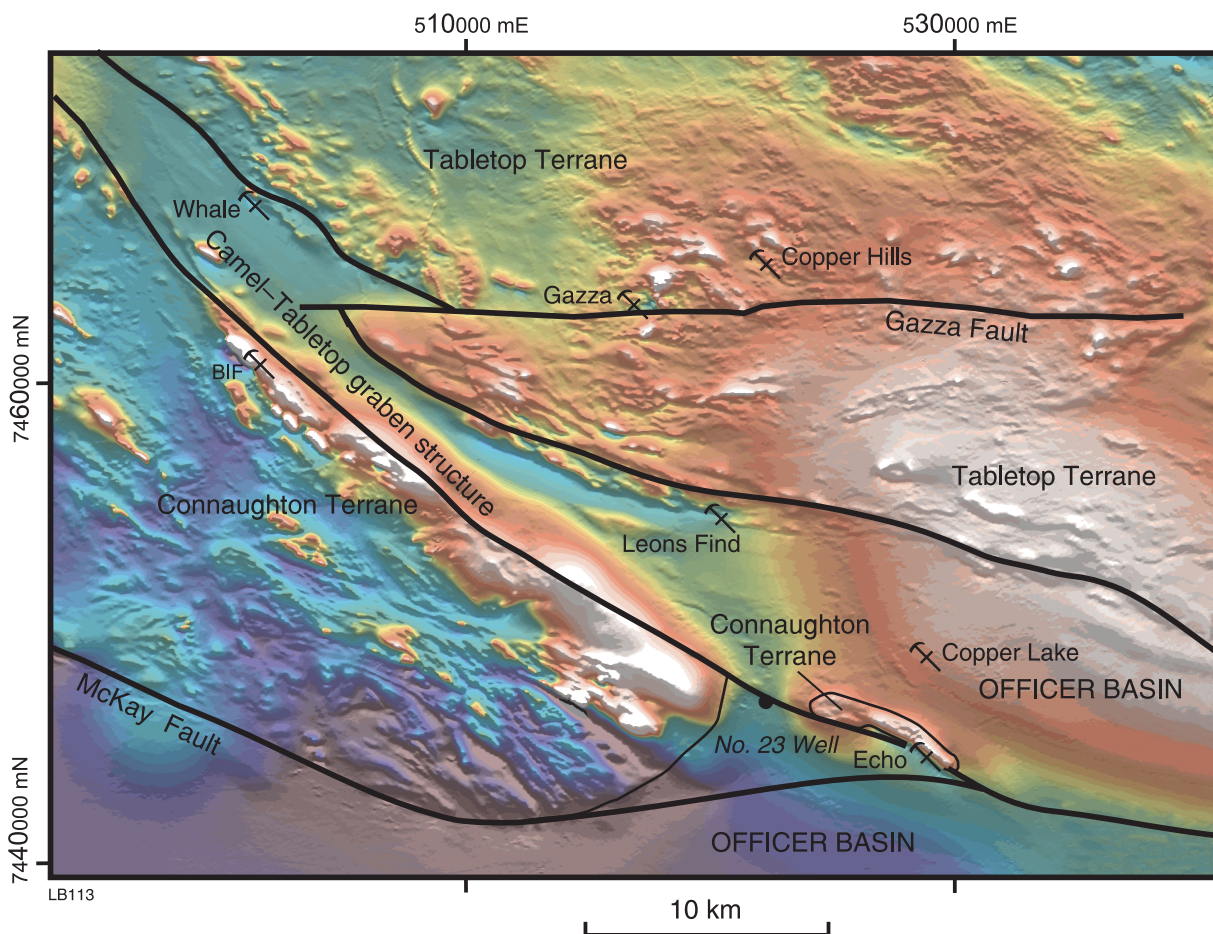


Figure 2. Magnetic image showing the location of the Camel-Tabletop graben structure and nearby copper occurrences

The Camel-Tabletop Fault Zone is in the poorly exposed eastern part of the northwestern Paterson Orogen (Bagas and Smithies, 1998), and hosts an outlier of the Neoproterozoic Officer Basin (Fig. 1). The area is geologically important because it:

- lies on or near the boundary between three terranes in the Paterson Orogen;
- contains a graben structure filled with Neoproterozoic sedimentary rocks of the Officer Basin;
- contains a diverse range of mineralization styles, including structurally controlled, unconformity-associated, and sediment-hosted stratiform mineralization, and complex associations of copper-gold and platinum-group elements (PGE).

Regional geology

The northwestern component of the Paterson Orogen includes the

Palaeoproterozoic Rudall Complex, Mesoproterozoic to Neoproterozoic Throssell Group, and Neoproterozoic Lamil and Tarcunyah Groups (Bagas et al., 1999; Bagas, 2000). The Tarcunyah Group unconformably overlies the Throssell Group and is part of Supersequence 1 of the Centralian Superbasin. The Tarcunyah Group is a correlative of the Sunbeam Group in the lower part of the northwestern Officer Basin (formerly 'Savory Basin'; Bagas et al., 1999).

The outcropping Rudall Complex extends for about 120 km from near the Kintyre prospect (Fig. 1) to the Copper Hills area (Fig. 2) and can be subdivided into three distinct tectonically juxtaposed packages of rocks, referred to as the Connaughton, Talbot, and Tabletop Terranes (Fig. 1; Bagas and Smithies, 1998).

The Talbot Terrane is in the western part of the complex, and comprises

banded orthogneiss and paragneiss metamorphosed to amphibolite facies at moderate pressure (Smithies and Bagas, 1997a).

The Connaughton Terrane, in the central part of the complex, consists of a succession of mafic gneiss and schist, orthogneiss, and paragneiss. These rocks are metamorphosed to the amphibolite-granulite transitional facies at high pressures (Smithies and Bagas, 1997b).

The Tabletop Terrane is poorly exposed and forms the eastern portion of the Rudall Complex. The terrane comprises a sequence of mafic schist, amphibolite, and metasedimentary rocks that resemble the sequence in the Connaughton Terrane. However, there is no evidence that the peak metamorphic grade exceeded upper greenschist facies or that it was accompanied by high pressure. The Tabletop Terrane is also characterized by the presence of weakly

foliated tonalite and leucogranite (Smithies and Bagas, 1997a), which are dated at 1490 and 1300 Ma respectively (Bagas and Smithies, 1998). As there are no known granitic intrusions of that age range in the terranes to the west, the Tabletop Terrane may have been geographically separate until at least 1300 Ma. The Tabletop Terrane probably collided with the Connaughton and Talbot Terranes before the Mesoproterozoic to Neoproterozoic Miles Orogeny that culminated before deposition of the c. 800 Ma Tarcunyah Group (Bagas and Smithies, 1998).

The intensity of the foliation developed in the Tabletop Terrane increases closer to the Camel-Tabletop Fault Zone, which marks

its boundary with the Connaughton Terrane (Bagas and Smithies, 1997). The fault also corresponds to the southwestern margin of the regional Warri Gravity Ridge (Iasky, 1990). Bagas and Smithies (1998) interpreted the fault zone as a collisional zone, which, during subsequent extension, formed a graben between 3 and 10 km wide containing the Karara Formation of the Tarcunyah Group in the study area.

Mineralization

Recent mapping (Bagas, 1999) and exploration by Australian Platinum Mines NL since the mid-1990s has identified widely spaced copper

mineralization in the northern part of the northwestern Officer Basin, an area not previously regarded as prospective by companies involved in uranium and base metal exploration in the Rudall Complex. Mineral occurrences in the region are polymetallic and include copper associated with various concentrations of silver, gold, lead, zinc, cobalt, nickel, PGE, and rare earth elements. Details of prospects in the area are presented in Table 1, and their locations shown in Figure 2.

Copper mineralization from these prospects can be classified into three major styles. The classification adopted is not genetic, but is based on the association of mineralization with specific geological features.

Table 1. Significant copper and associated mineralization along the Camel-Tabletop graben structure

<i>Prospect</i>	<i>Significant assays</i>	<i>Metal association</i>	<i>Host rocks</i>	<i>Geological unit</i>	<i>Mineralization style</i>
BIF	0.76% Cu ^(a) 0.4% Cu ^(b) 0.5% Zn ^(b) 0.2 ppm Au ^(b)	Ag-As-Au-Cu-Mo- Pd-Pt-Zn	Felsic gneiss-schist at the contact with BIF	Rudall Complex	Shear zone hosted
Whale	1.3% Cu ^(a) 1 m at 0.22% Cu ^(b)	Au-Cu	Mafic gneiss, sandstone	Karara Formation and Rudall Complex	Unconformity associated
Gazza	1.4% Cu ^(a) 170 ppm Ag ^(a) 0.32 ppm Au ^(a) 713 ppm Co ^(a) 0.4% Ni ^(a) 9.3% Pb ^(a) 2.6% Zn ^(a)	Ag-As-Au-Co-Cu- Ni-Pb-Pd-Pt-Th-Zn	Gossanous quartz- carbonate veins hosted by chlorite schist after amphibolite	Rudall Complex	Fault hosted
Copper Hills	11% Cu ^(a) 3.5% Ag ^(a) 0.23% Au ^(a) 0.49% Pd ^(a) 0.34% Pt ^(a) 0.2% Ag ^(b) 0.2% As ^(b) 31% Cu ^(b) 531 ppm Ce ^(b) 0.5% Pb ^(b) 1.3% Zn ^(b)	Ag-As-Au-Bi-Co- Cu-Mo-Ni-Pb-Pd- Pt-Se-Th-V-Zn	Graphite-chlorite schist, carbonate rocks, and quartz veins hosted by sheared amphibolite	Rudall Complex	Shear zone hosted with marked mineralization
Leons Find	15% Cu ^(a) 5.18 ppm Au ^(a)	Au-Cu	Sheared mafic rock (basalt or high-level sill)	Karara Formation	Shear zone hosted
Copper Lake	0.2% Cu ^(a) 6000 ppm Cu ^(b)	Cu	Mudstone, and tuffaceous sandstone and siltstone	Karara Formation	Sediment-hosted stratiform
Echo	10 ppm Au ^(a) 0.2% Cu ^(a) 0.15% Co ^(a)	Au-As-Co-Cu	Quartz vein hosted in sandstone and schist	Throssell Group and Rudall Complex	Unconformity associated

NOTES: ^(a) surface rock chips; all copper assays are averages, whereas other elements are highest values

^(b) drill intersections, showing highest values

SOURCE: Assay data provided by Australian Platinum Mines NL

The three styles are:

- structurally controlled mineralization;
- unconformity-associated mineralization;
- sediment-hosted stratiform mineralization.

All these deposits show varying degrees of hydrothermal alteration. Alteration in mafic rocks in the Rudall Complex is characterized by plagioclase altered to sericite and epidote (clinozoisite), amphibole (actinolite) locally altered to iron-magnesium chlorite, and clinopyroxene altered to actinolite. Fine granular epidote also fills fractures and locally replaces the matrix.

Carbonate and chlorite alteration has commonly destroyed the primary textures of calc-silicate rocks in the area. The carbonate matrix, which also contains apatite, locally replaced tremolite, and chalcedony replaced part of the matrix. The hydrothermal alteration is indicated by the assemblage tremolite-carbonate-chlorite-apatite.

Dolerite dykes contain platy actinolite aggregates, which have replaced medium-grained clinopyroxene interlocked with microphenocrysts of plagioclase. Plagioclase is pervasively altered to sericite-epidote (hydrothermal alteration) or to microcline with granophyric textures (potassic metasomatism due to the action of residual fluids from cotectic crystallization of the dolerite). Amphibole is altered to chlorite and biotite. The matrix contains accessory amounts of fine anhedral and secondary apatite, and is cut by thin veins of plagioclase. Other accessory phases are opaque minerals (?magnetite) rimmed by titanite. These mineral associations are interpreted as hydrothermal alteration related to the emplacement of the dolerite dykes and is best developed around dyke swarms (e.g. near the Gazza prospect, Fig. 2). At least some of these dykes intruded the Karara Formation as sills and dykes (Bagas, 1999).

Hydrothermal mineralization of possible similar age has also been reported 200 km south of the Paterson Orogen near Quadrio Lake (Hocking et al., 2000). The mineralization consists of barite-

hematite stockworks with anomalous quantities of gold, arsenic, and antimony, hosted by a shale-dominated unit of probable Mesoproterozoic age in the Oldham Inlier surrounded by the Officer Basin.

Structurally controlled mineralization

Mineralization in most prospects is hosted in easterly trending faults or shear zones. The host structures are mostly dilational openings associated with the southeasterly trending Camel-Tabletop Fault Zone, which is a persistent structure that has been active at least during the Mesoproterozoic to Neoproterozoic Miles Orogeny and late Neoproterozoic Paterson Orogeny, and probably earlier (Bagas and Smithies, 1998).

At the Copper Hills polymetallic prospect (Fig. 2), structurally controlled copper mineralization is developed along a southeasterly trending curvilinear and vertical shear zone, about 2 km in length, in dolomitic carbonate and graphite-chlorite schist within amphibolite. Copper mineralization at the prospect consists of lenticular and vertical veins rich in malachite, chrysocolla, and azurite. The veins are up to 5 m thick and contain a coarse zonation, from zinc-lead-silver-rich mineralization towards the edge to silver-gold-platinum-palladium-rich mineralization in the centre. The richest mineralized zones are in dilational jogs along the shear zone, with samples assaying up to 11% Cu, 3.5% Ag, 2.3 kg/t Au, 4.9 kg/t Pd, and 3.4 kg/t Pt (Table 1). A mineral resource estimate, in accordance with the JORC (1999) code, is not yet available. However, we estimate that there may be 0.7 Mt at 1.05% Cu and 2.05 Mt at 0.37% Zn, using a cut-off grade of 0.2% for both copper and zinc. These estimates are considered uneconomic.

The mineral association at the Copper Hills prospect shows strong similarity to the assemblage at the nearby Gazza prospect, and both prospects are hosted by hydrothermally altered and sheared amphibolite in the Tabletop Terrane of the Rudall Complex (Table 1). The Gazza prospect is within the easterly trending Gazza Fault

(Fig. 2), where a 5 km-long zone contains patchy mineralization. This mineralized zone has not been tested by drilling.

At the BIF prospect (Fig. 2), copper mineralization is in shear zones that cut through banded iron-formation (metamorphosed to amphibolite facies). The prospect is on the western edge of the Camel-Tabletop Fault Zone, at the contact between metamorphosed banded iron-formation and quartz-K-feldspar-biotite schist in the Connaughton Terrane.

Unconformity-associated mineralization

The unconformable contact between the Rudall Complex and overlying rocks of the Throssell and Tarcunyah Groups is mineralized at the Echo and Whale prospects (Table 1, Fig. 2).

The Echo gold-copper-cobalt prospect has a stockwork of quartz veins containing chalcopyrite and pyrite along the contact between quartzite and conglomerate of the Throssell Group and chlorite and sericite schist in metamorphosed banded iron-formation of the Rudall Complex, which together form an inlier in the Karara Formation (Bagas, 1999).

The Whale copper prospect is on the northeastern edge of the Camel-Tabletop Fault Zone, in an alteration zone developed along the sheared unconformable contact between sandstone of the Karara Formation and tremolite gneiss of the Rudall Complex. The alteration zone is characterized by malachite staining, epidote, quartz, sericite, and chlorite, and is similar in style to the Copper Hills prospect.

Sediment-hosted stratiform mineralization

The Copper Lake copper prospect is about 7 km east of No. 23 Well, close to the northeastern edge of the Camel-Tabletop Fault Zone (Fig. 2). Disseminated chalcopyrite appears to be stratabound and in shale, mudstone, and tuffaceous siltstone and sandstone towards the lower part of the basal (predominantly conglomeratic) unit in the Karara Formation (Bagas, 1999). The mineralized sequence contains

malachite (after disseminated chalcopyrite) and can be traced for about 600 m, with rock-chip samples containing up to 6000 ppm Cu (Table 1). This mineralization could be syndepositional and could represent the only sediment-hosted stratiform mineralization in the area.

The Karara Formation in the Copper Lake area has been subdivided into a lower conglomeratic unit and an upper sandstone unit (Bagas, 1999). The conglomeratic unit is mineralized, with chalcopyrite altered to malachite, and consists of polymictic conglomerate interbedded with sandstone, siltstone, and shale. A 10–20 m-thick sheared mafic bed, with abundant malachite and azurite staining, has also been recognized towards the base of the formation in the area. This unit may be interpreted as either an altered basalt or a high-level sill. The upper nonmineralized sandstone unit consists of quartz sandstone, quartz-feldspar wacke, and minor interbeds of shale and conglomerate.

A significant characteristic of the basal conglomeratic unit of the Karara Formation is the potassic alteration represented by K-feldspar in mineralized zones, giving the rock a reddish colour, such as at the Copper Lake prospect. The zone of alteration is highlighted by high counts on the potassium channel of airborne radiometric surveys in the area. This association between mineralization and potassic alteration may be used as a tool for mineral exploration. In addition, sericitization, chloritization, and ferruginization are typically associated with fractures.

Discussion and conclusion

The northwestern Paterson Orogen has proven potential for gold (Telfer, Magnum), copper-lead-zinc (Nifty, Maroochydore), and uranium (Kintyre) mineralization. In addition, mapping by GSWA and mineral exploration companies has indicated significant prospectivity for polymetallic mineralization throughout the Paterson Orogen (Bagas et al., 1995; Bagas et al., 1999) and the northwestern Officer Basin region, including the Oldham Inlier (Hocking et al., 2000).

Most of the mineralization identified in the eastern part of the north-

western Paterson Orogen is associated with hydrothermal alteration along fractures, shear zones, and faults formed during or after the Miles Orogeny.

The recent discovery of the sediment-hosted copper mineralization in the northern part of the northwestern Officer Basin (see above) has also significantly

highlighted the prospectivity of the basal part of the Tarcunyah Group, particularly in the Camel-Tabletop Fault Zone. It is probable that this style of mineralization is related to extensional movement along the Camel-Tabletop Fault Zone during the early stages in the deposition of the c. 800 Ma Tarcunyah Group in the basal part of the northwestern Officer Basin.

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The geochemistry of the Yule Granitoid Complex, East Pilbara Granite–Greenstone Terrane; evidence for early felsic crust

by D. C. Champion¹ and R. H. Smithies²

Abstract

The middle- to late-Archaean Yule Granitoid Complex lies in the westernmost part of the East Pilbara Granite–Greenstone Terrane, and is dominated by commonly potassic, felsic, calc-alkaline granitoids, with Sr-depleted, Y-undepleted compositions, and mostly with moderate to large negative Eu anomalies. These characteristics all indicate that felsic crust was a significant component of the source. Typical Archaean tonalite–trondhjemite–granodiorite (TTG) series are not found, even amongst the very oldest (>3.4 Ga) granites. The most TTG-like granitoids are post-3270 to 2930 Ma in age, confined to the westernmost part of the complex, and share some similarities with granites found in the West Pilbara Granite–Greenstone Terrane. An abundance of post-2950 Ma granite also contrasts the Yule Granitoid Complex with complexes in the eastern part of the East Pilbara Granite–Greenstone Terrane, where such rocks are uncommon. This feature, and the presence of the c. 2945 Ma Mungaroona Granodiorite (high-Mg diorite suite) in the western part of the Yule Granitoid Complex, is probably related to the tectonic development of the adjacent Central Pilbara Tectonic Zone.

KEYWORDS: Archaean, Pilbara Craton, Yule Granitoid Complex, geochemistry

The Yule Granitoid Complex lies in the westernmost part of the East Pilbara Granite–Greenstone Terrane (Fig. 1), and is the largest outcropping granitoid complex of the Pilbara Craton. Recent studies have shown that the complex contains an extremely diverse range of rock types and has a long magmatic history of 600 million years or more. Geological and geochemical data, presented here, relating to the northern half of the exposed Yule Granitoid Complex

show that recycling of early felsic crust is a major feature of the evolution of this complex. Consequently, the suggestion that old Archaean granitoid bodies are dominated by rocks of the tonalite–trondhjemite–granodiorite (TTG) series (Martin, 1994) is not always the case.

Regional geology

The granite–greenstone terrain of the Pilbara Craton is subdivided into the East and West Pilbara Granite–Greenstone Terranes, which

are separated by the northeasterly trending Central Pilbara Tectonic Zone (Fig. 1; Hickman, 1999). The East Pilbara Granite–Greenstone Terrane consists of large ovoid granitoid–gneiss complexes partially surrounded by belts of volcanic and sedimentary rocks (greenstones). The majority of the greenstones accumulated periodically between c. 3600 to 3240 Ma, whereas significant felsic magmatism occurred episodically from c. 3660 to 2850 Ma (Nelson et al., 1999). The Central Pilbara Tectonic Zone is dominated by clastic rocks of the 3000–2950 Ma Mallina Basin that obscure the boundary between the East and West Pilbara Granite–Greenstone Terranes. The Central Pilbara Tectonic Zone was intruded by a mantle-derived high-Mg diorite suite and alkaline rocks at c. 2950 Ma, and voluminous felsic granites at c. 2935 Ma (Smithies and Champion, 1999, 2000). These granites intruded both the eastern margin of the Central Pilbara Tectonic Zone and the East Pilbara Granite–Greenstone Terrane, but decrease in both age and volume away from the contact between those two terranes. Consequently, while the majority of granites in the eastern half of the East Pilbara Granite–Greenstone Terrane are older than c. 3240 Ma, a volumetrically significant, and locally dominant, component of the Yule, Carlindi, and Pippingarra Granitoid Complexes in the western part of the terrane were intruded between c. 2945 and 2930 Ma. Younger (c. 2850 Ma) two-mica granites are also more abundant within these western complexes.

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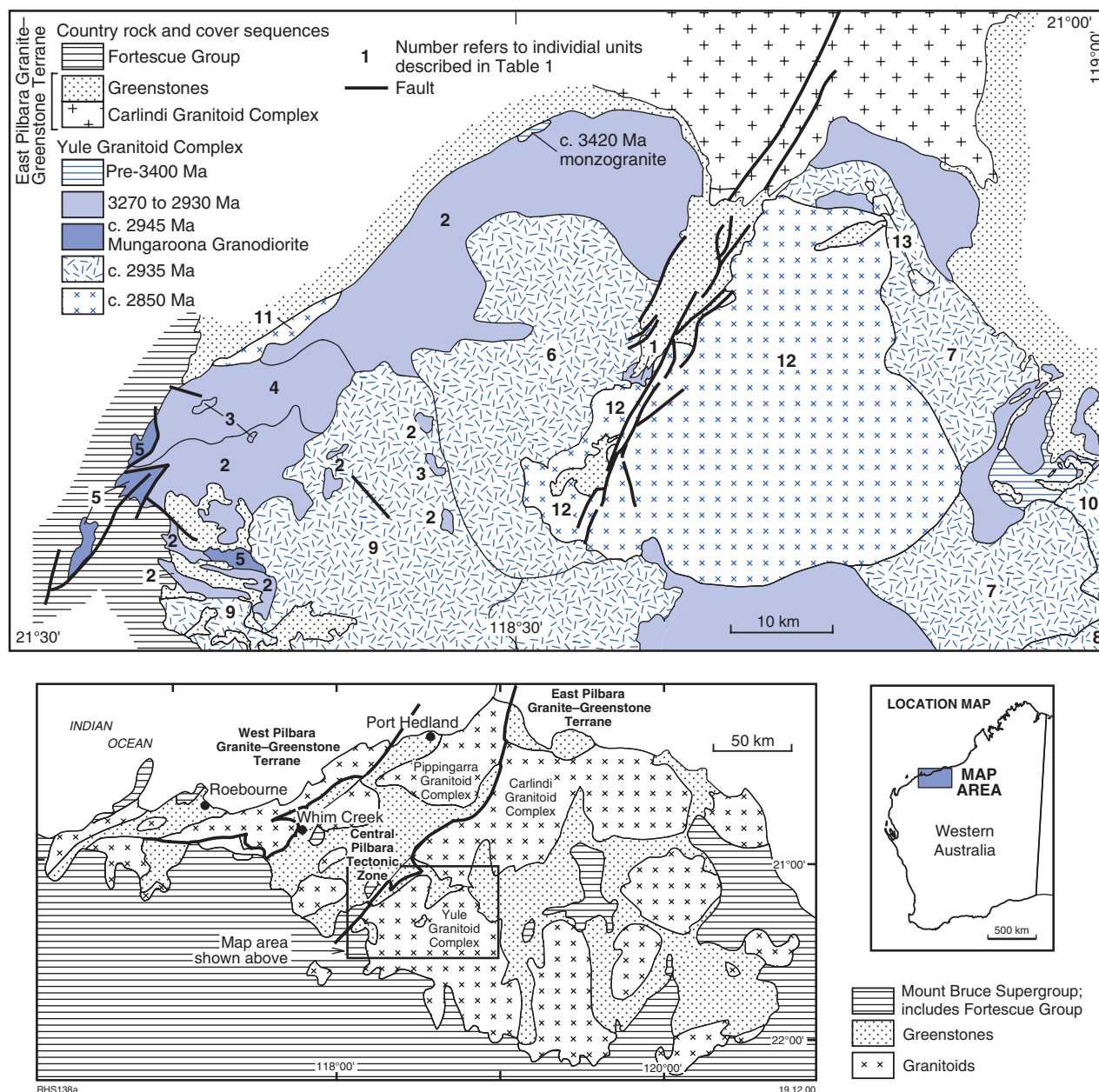


Figure 1. Distribution of granitoid units in the Yule Granitoid Complex: 1) Siffleetes Granodiorite; 2) Cheearra Monzogranite; 3) Yallingarrintha Tonalite; 4) Yandearra Granodiorite; 5) Mungaroona Granodiorite; 6) Mungarinya Monzogranite; 7) Pincunah Monzogranite; 8) Abydos Monzogranite; 9) Powdar Monzogranite; 10) Woodstock Monzogranite; 11) Pilbara Creek Monzogranite; 12) Numbana Monzogranite; 13) Gillam Monzogranite

Geology of the Yule Granitoid Complex

Figure 1 shows the geology of the northern part of the Yule Granitoid Complex. At least 18 distinct granite phases have been mapped and many of these can be further subdivided. The emplacement age of six phases has been determined by SHRIMP U-Pb (zircon) geochronology (Van Kranendonk,

1998; Nelson et al., 1999; Nelson, 2000), whereas Nd-isotopic data place age constraints on a further three phases (Champion and Smithies, unpublished data). The age ranges of the remaining phases have been inferred primarily on contact relationships and to a lesser extent on geophysical, petrographic, and structural data. When used as the sole criterion, it was noted that neither geochemistry nor structural

data provide a reliable basis for identifying individual age groups.

The oldest known intrusive phases are found at, or near, contacts with greenstone belts and include c. 3420 Ma monzogranite, the c. 3470 Ma Petroglyph Gneiss (Van Kranendonk, 1998), and other unnamed gneisses in the northeastern part of the complex. The c. 3240 Ma Kavar Granodiorite

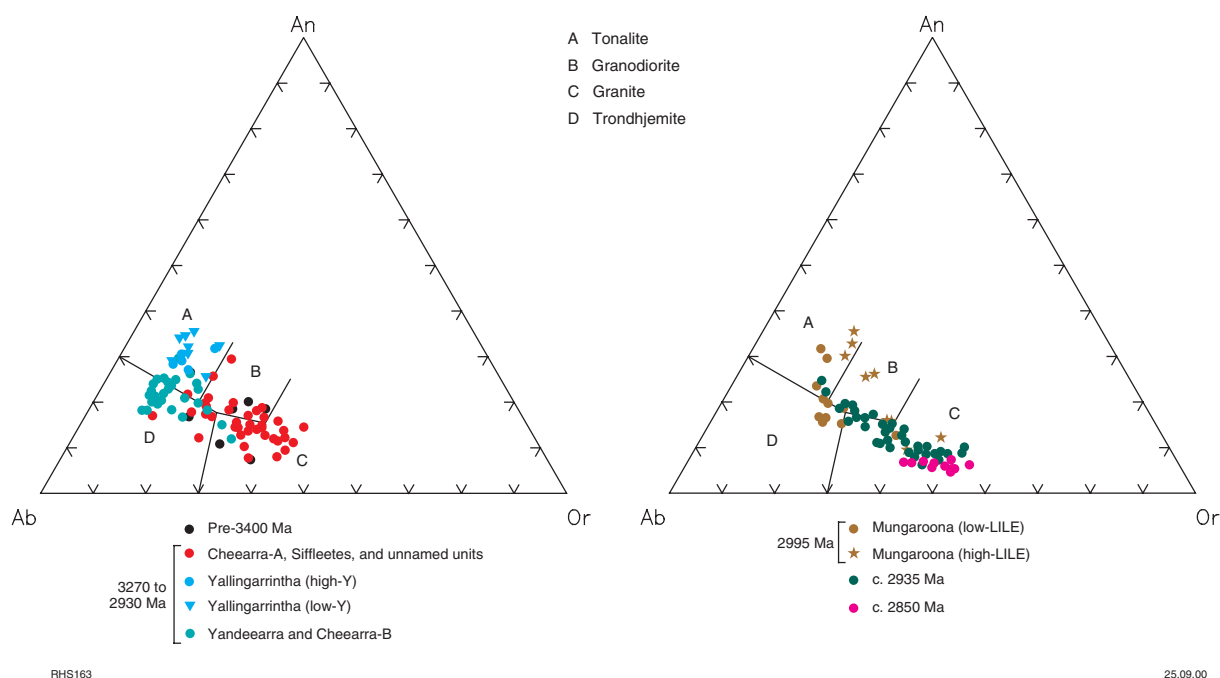


Figure 2. Normative An–Ab–Or classification diagram (Barker, 1979) for granitoids of the Yule Granitoid Complex

(Van Kranendonk, 1998) in the northeast, and the 3270 to 2945 Ma (and ?older) rocks in the western and northern parts of the complex are either in contact with the oldest phases or with the greenstones. Rocks in the southern part of the WODGINA* sheet are also probably between 3450 and 2945 Ma in age, and contain abundant greenstone enclaves, indicating that these are also marginal phases of the complex. Granites younger than c. 2945 Ma appear to form about 80% of the outcrop within the complex.

Geology and geochemistry

The granitoids of the northern part of the Yule Granitoid Complex span the range from tonalite and trondhjemite through to granite (Fig. 2). However, the great majority are calc-alkaline and monzogranitic, with the younger granites (post-2940 Ma) commonly lying at the more evolved end of this compositional range (Table 1, Fig. 2). The geochemistry of the rocks is described in terms of five groups that are defined on a basis of both

age and composition. These groups include pre-3400 Ma, 3270–2930 Ma, c. 2945 Ma, c. 2935 Ma, and c. 2850 Ma granitoids (Table 1).

Old (pre-3400 Ma) granites

This is the volumetrically smallest group of granites, and the few available geochemical data are mostly from the northeastern margin of the complex. Many of the rocks are gneissic granite, locally migmatitic, commonly with biotite-rich bands, pegmatite, and granite dykes. Compositionally, they are granodiorites to granites (65–75% SiO₂) characterized by calc-alkaline chemistry, with low Al₂O₃ (13.4 – 15.8%) and moderate to high K₂O (1.6 – 4.1%). All are Sr-depleted and Y-undepleted (Fig. 3). Samples are mostly LREE[†]-enriched, with moderate negative Eu anomalies (Fig. 4). Two samples with biotite-rich bands have elevated HREE and Y (100 and 180 ppm), higher K₂O, and lower LREE, possibly resulting from accumulation of biotite and accessory phases.

[†] REE = rare earth elements, including light REE (LREE) and heavy REE (HREE).

3270 to 2930 Ma granitoids

This group comprises medium to small plutons, some of which are clearly composite (e.g. the Cheearra Monzogranite). Many contain dykes, pods, or plutons that are either known or inferred to have intruded at 2935 or 2850 Ma. This group includes tonalite and trondhjemite, as well as granodiorite and granite (Fig. 2). They are moderate- to high-K (1 – 4.7%), Sr-depleted, Y-undepleted, LREE-enriched granitoids, mostly with moderate negative Eu anomalies (Figs 3 and 4). A porphyry phase of the Cheearra Monzogranite shares similar features, but is even more strongly depleted in Sr (and has lower Al₂O₃), with correspondingly higher Y.

The Yallingarrintha Tonalite is distinct. Compared with the other rocks of this age group, it is more mafic (61–66% SiO₂), with lower TiO₂, MgO, P₂O₅, Ba, Sr, and LREE, (Fig. 3) and has low to moderate K₂O (1.1 – 2.0%) with moderate Na₂O (3.9 – 5.0%). Two subgroups are evident, with one having significantly higher Y (70–100 ppm versus 10–35 ppm), HREE, and Nb, lower La/Lu, and much larger negative Eu anomalies (Fig. 4)

* Capitalized names refer to standard 1:100 000 map sheets.

Table 1. Simplified geochemical features of granitoid units and geochemical subgroups in the Yule Granitoid Complex

Unit	Location (number in Fig. 1)	SiO ₂ (wt%)	K ₂ O (wt%)	Na ₂ O/ K ₂ O	Eu ^(a) anomaly	Y (ppm)
Pre-3400 Ma						
all units	–	66–75	1.6 – 4.1	1.5–1.0	MO (to L)	15–40
3270–2930 Ma						
unnamed units	–	73–74	4.6 – 4.7	0.7 – 0.5	MO	11
Siffleetes	1	71–72	2.5 – 4.2	1.8 – 1.2	nd	nd
Cheearra-A	2	66–74	2.0 – 4.2	2.2 – 0.7	MI to L	15–40
Cheearra-B	2	68–73	1.1 – 1.8	4.5 – 2.5	MO to L	15–50
Cheearra-C	2	67–74	1.8 – 4.6	2.0 – 0.8	N to L	7–32
Cheearra-D	2	70–74	3.2 – 4.0	1.1 – 0.8	L	35–68
Yallingarrintha (high-Y)	3	61–66	1.2 – 2.0	3.8 – 2.1	MO	72–100
Yallingarrintha (low-Y)	3	61–66	1.1 – 2.0	4.0 – 2.0	MI to P	10–37
Yandearra	4	70–74	0.9 – 3.0	5.0 – 1.5	N to Mo	18–37
c. 2945 Ma						
Mungaroona (high-LILE)	5	54–69	1.8 – 4.7	2.0 – 0.8	MI	18–35
Mungaroona (low-LILE)	5	66–72	1.3 – 2.8	3.0 – 1.6	MI	5–26
c. 2935 Ma						
Mungarinya	6	68–74	1.8 – 5.8	1.7 – 0.5	MO to L	10–78
Pincunah	7	66–74	2.4 – 4.6	1.8 – 0.8	MO to L	10–35
Abydos	8	69.5	3.3	1.1	L	97
Powdar	9	71–74	3.4 – 5.2	1.0 – 0.6	MO to L	20–35
Woodstock	10	72–75	4.4 – 4.5	0.9 – 0.8	MO to L	9–48
c. 2850 Ma						
Pilbara Creek	11	73.5	4.5	0.9	VL	67
Numbana	12	73–76	4.6 – 5.6	0.9 – 0.5	VL	50–60
unnamed pods	–	73–75	5.1 – 5.6	0.7 – 0.6	L to VL	12–25
Gillam	13	74–75	5.1 – 5.5	0.7 – 0.6	L to VL	35–50

NOTE: (a) Size of Eu anomaly based on ratio of actual Eu value to expected value if no anomaly: positive anomaly (P) >1, no anomaly (N) = 1, minimal anomaly (MI) <1 to 0.8, moderate anomaly (MO) <0.8 to 0.5, large anomaly (L) <0.5 to 0.2, very large anomaly (VL) <0.2
nd = no data

coupled with higher and commonly constant Eu than the other. The reasons for the subgroups are not clear, particularly given the similar compositional trends. Both subgroups are Sr-depleted and Y-undepleted (Fig. 3).

The Yandearra Granodiorite is also distinctive. Compared with the rocks of this age group, this felsic unit (70–74% SiO₂) has low K₂O, Rb, and Sr; moderate to low Th, LREE, HREE, and Y; moderate to high CaO and Na₂O; and is typically Sr-depleted and Y-undepleted, with moderate negative Eu anomalies (Figs 3 and 4). However, it does include a Y-depleted subgroup that has no, or very minimal, negative Eu anomalies. Samples from this subgroup lie towards the mafic end of the group, but have lower Eu contents, suggesting a complex relationship between the two subgroups. Some samples of the Cheearra Monzogranite (foliated, porphyritic, and injection migmatite phases) also appear to have many

similarities with the Yandearra Granodiorite. Together, they form a group that has some similarities with the Archaean tonalite–trondhjemite–granodiorite series (see below).

2945 Ma Mungaroona Granodiorite

The Mungaroona Granodiorite ranges from diorite, through tonalite and granodiorite, to granite (Fig. 2). Two geochemical subgroups are present; a high-LILE* and a low-LILE subgroup. Compared with the low-LILE subgroup, the high-LILE subgroup has high K₂O, Ba, Rb, Pb, Th, and U, and is strongly LREE-enriched (La 250–450 times chondrite), with unfractionated HREE, and no or minimal negative Eu anomalies (Figs 3 and 4), despite its more mafic composition (<55 to 70% SiO₂). The mafic end-members of the high-LILE subgroup (<62%

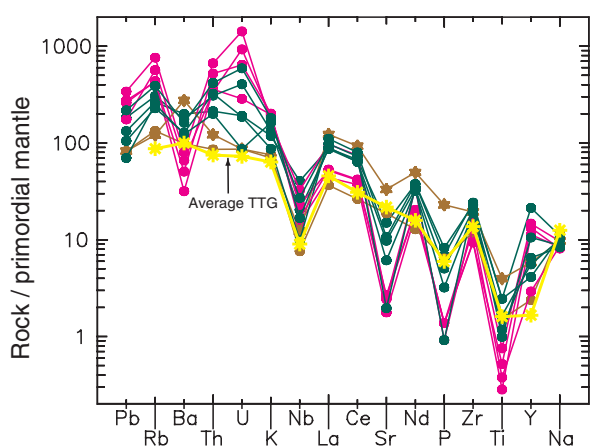
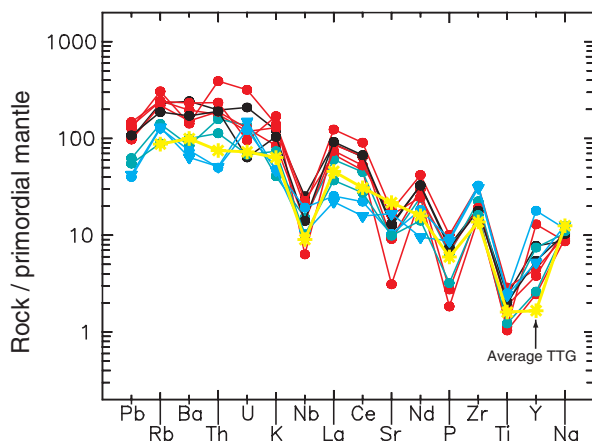
SiO₂) have high MgO (4–5%), Mg[†] (50–60), Ni (60–90 ppm) and Cr (120–200 ppm), which, coupled with the elevated LILE contents, clearly indicate that the subgroup belongs to the high-Mg diorite suite of the nearby Central Pilbara Tectonic Zone (Smithies and Champion, 1999, 2000). The low-LILE subgroup (>70 to 66% SiO₂), is moderately LREE enriched (La 60–130 times chondrite), and also has minimal to slight negative Eu anomalies (Fig. 4). Although this subgroup shares many similarities with the c. 2935 Ma granites, their lower TiO₂ and lack of significant Eu anomalies suggest that they are more like the rocks of the high-LILE subgroup of the Mungaroona Granodiorite, to which they are probably related.

2935 Ma granites

This group comprises small to large plutons (up to 300 km²) of mainly granodiorites to granites (Fig. 2). All have calc-alkaline

* LILE = large ion lithophile element

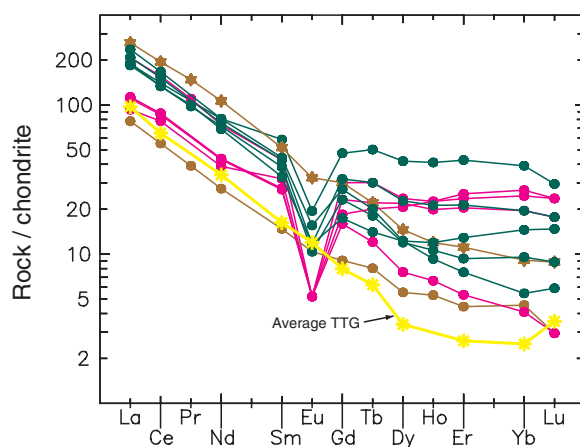
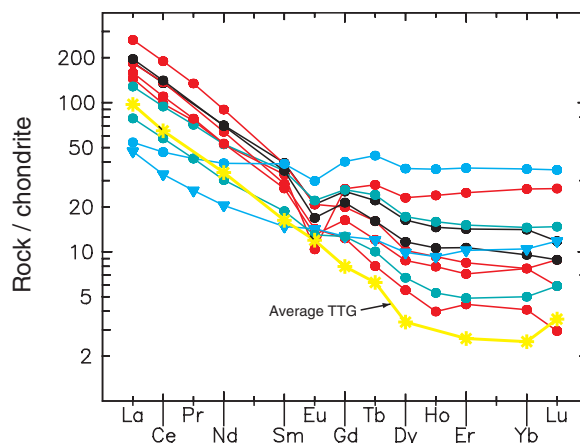
† $Mg^{\#} = Mg^{2+} / (Mg^{2+} + Fe_{Total}) \times 100$
with Fe_{Total} as Fe²⁺



RHS162

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Figure 3. Primordial mantle-normalized multi-element variation diagrams showing the compositional variation of selected granitoids of the Yule Granitoid Complex. The average TTG composition from Martin (1994) is also shown. Normalizing values are from Sun and McDonough (1989). The legend for this figure is the same as Figure 2



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Figure 4. Chondrite-normalized rare earth element diagrams showing the compositional variation of selected granitoids of the Yule Granitoid Complex. The average TTG composition from Martin (1994) is also shown. Normalizing values are from Nakamura (1974) and Evensen et al. (1978). The legend for this figure is the same as Figure 2

characteristics, with moderate to high LILEs, and are Sr-depleted and Y-undepleted, LREE-enriched, and have moderate negative Eu anomalies (Table 1). The compositional range and trends for most elements are similar for all units, with increasing K_2O , Rb, Rb/Sr, Pb, Th, U, and K_2O/Na_2O , and decreasing Al_2O_3 , Na_2O , Sr, Zn, Sc, Cr, and Ni, as silica content increases. The greatest variation between units is for the HREE and Y (Table 1, Figs 3 and 4). These rocks show extensive overlap with most of the 3270–2930 Ma granitoids, including the Siffleetes Granodiorite and the foliated, gneissic, and injection migmatite phases of the Cheearra Monzogranite.

2850 Ma granites

This group includes small pods (<1 to 10 km²) to very large bodies (~400 km²) emplaced as sheets. It also includes common to abundant pegmatites, and granite dykes intruding other granites and greenstones. The units are commonly massive and nonmagnetic, with biotite and muscovite and occasional garnet. They are typically granites (Fig. 2) that are silica rich (>73% SiO_2), with high LILE, and moderate to large negative Eu anomalies (Figs 3 and 4) and are clearly depleted in Sr and undepleted in Y. Moderate to high Rb, Rb/Sr, Rb/Ba, Ca/Sr, and K_2O/Na_2O , and low K/Rb ratios are

most consistent with crystal fractionation, but could also reflect small degrees of partial melting.

Petrogenesis and discussion

Despite the range of ages (c. 3420–2850 Ma) within the northern part of the Yule Granitoid Complex, the majority of rocks share some geochemical characteristics; they have a fairly narrow silica range (66–76% SiO_2), are calc-alkaline, have moderate to high K, are Sr-depleted and Y-undepleted, and have mostly moderate to large negative Eu anomalies (Figs 3 and 4). Champion and Smithies (1998,

1999) noted that such characteristics are typical of post-3000 Ma granites in the East Pilbara Granite–Greenstone Terrane, and indicate a source that included a significant proportion of felsic crust that partially melted at low to moderate crustal pressures within the stability field of plagioclase. Such rocks also form the older (>3400–2945 Ma) parts of the Yule Granitoid Complex, indicating that a felsic crustal source must have existed before c. 3400 Ma. This is inconsistent with the notion that the majority of middle Archaean and older granitoids worldwide belong to the TTG series (Martin, 1994). More particularly, it contrasts markedly with the granitoid complexes in the eastern part of the terrane, where pre-3000 Ma, and particularly pre-3400 Ma, calc-alkaline rocks are uncommon, but where rocks showing TTG-like compositions are abundant (Champion and Smithies, 1998).

The petrogenesis of TTGs contrasts with that of calc-alkaline rocks, with the high Al_2O_3 and Na_2O , low to moderate K_2O and LILE, and Sr-undepleted and Y-depleted compositions of the former (Fig. 3) requiring high pressure (>10 kb) melting of a mafic (basaltic) source (Martin, 1994). The only pre-2945 Ma rocks from the Yule Granitoid Complex that bear any resemblance to TTGs are all from the western part of the complex, and include the Yandearra Granodiorite, parts of the Cheearra Monzogranite, and, possibly, the Yallingarrintha Tonalite (Fig. 3). Even these differ from typical TTGs, in having commonly Sr-depleted and Y-undepleted compositions, and moderate negative Eu anomalies that are indicative of derivation at only moderate crustal pressures. This aspect, coupled with their inferred ages (post-3270–2930 Ma, Table 1), makes them most similar to TTG-like granitoids of the West Pilbara Granite–Greenstone Terrane (Smithies and Champion, 1998), and may indicate a link between the two terranes.

The other relatively mafic unit in the northern Yule Granitoid Complex is the 2945 Ma Mungaroona Granodiorite. This unit has composition features that suggest mantle derivation, and is

also confined to the western part of the complex. Its distinctive chemistry indicates that it forms part of the high-Mg diorite suite that Smithies and Champion (2000) described from the adjacent Central Pilbara Tectonic Zone. Rocks of this suite combine very mafic compositions with very high LILE and LREE and require a subduction-enriched source (Smithies and Champion, 2000).

The overwhelming abundance of post-2950 Ma granite contrasts the Yule Granitoid Complex with complexes in the eastern part of the East Pilbara Granite–Greenstone Terrane, where such rocks are uncommon. This feature, and the presence of the c. 2945 Ma Mungaroona Granodiorite (high-Mg diorite suite) in the western part of the Yule Granitoid Complex, is probably related to the tectonic development of the adjacent Central Pilbara Tectonic Zone.

Rocks of the 2945 Ma high-Mg diorite suite are concentrated within the Central Pilbara Tectonic Zone (Smithies and Champion, 2000), and Smithies and Champion (1999) argued that the thermal event responsible for the c. 2930 Ma granites was directly related to generation and emplacement of the earlier mantle-derived high-Mg diorite suite.

The 2850 Ma granites are present across the Eastern Pilbara Granite–Greenstone Terrane, but are significantly more abundant in the Yule Granitoid Complex (and the Carlindi and Pippingarra Granitoid Complexes to the north). However, they do not continue westwards into the Central Pilbara Tectonic Zone or Western Pilbara Granite–Greenstone Terrane (Smithies and Champion, 1998). The significance of these rocks and their distribution is not yet understood.

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Mesoproterozoic stratigraphy in the Oldham Inlier, Little Sandy Desert, central Western Australia

by R. M. Hocking¹, K. Grey, L. Bagas, and M. K. Stevens

Abstract

The Ward and Oldham Inliers form a basement high in the northwestern part of the Officer Basin (formerly 'Savory Basin'), and contain rocks previously included in a single unit, the Cornelia Formation. The Cornelia Formation is now divided into the steeply dipping Cornelia Sandstone, the steeply dipping shaly Quadrio Formation, and the moderately folded Oldham Sandstone. These formations have not been dated, but the Quadrio Formation and Cornelia Sandstone, although adjacent to the Oldham Sandstone, appear to be older because they dip more steeply, are relatively more tightly folded, and show a greater degree of silicification and quartz stockworking. The Quadrio Formation and Cornelia Sandstone probably correlate with the base-Mesoproterozoic Edmund Group, and the Oldham Sandstone with the ?late Mesoproterozoic Collier Group of the Bangemall Basin. However, the Quadrio Formation and Cornelia Sandstone also resemble shale and sandstone units included in the Mesoproterozoic-Neoproterozoic Throssell Group in the Paterson Orogen. The Throssell and Edmund Groups contain significant metallic mineralization of different types, and the Quadrio Formation contains barium and gold anomalies, so likely stratigraphic correlations for all three units are of economic interest.

KEYWORDS: Cornelia Sandstone, Oldham Sandstone, Quadrio Formation, Throssell Group, Bangemall Group, Officer Basin, Paterson Orogen, stratigraphy, tectonics, mineralization

Introduction

Sedimentary rocks in the Ward and Oldham Inliers (Fig. 1) in the Savory region (Little Sandy Desert) of the northwest Officer Basin were previously assigned to the Cornelia Formation ('Cornelia Sandstone' of Brakel and Leech, 1980; amended by Williams, 1992). The stratigraphic relationships and age of these rocks have been problematic since initial

mapping in the 1970s (Brakel and Leech, 1980), and were not resolved by a reassessment in the 1980s after the unconformity separating the Bangemall and 'Savory' (now Officer) Basins was discovered (Williams, 1990, 1992, 1995). The drilling of the petroleum exploration well GSWA Trainor 1 on the northern margin of the Oldham Inlier (Fig. 2) provided pertinent data (Stevens and Adamides, 1998), but did not clarify the age or relationships. Recent reconnaissance

work in the Oldham Inlier partly resolves the stratigraphic relationships of the Oldham Inlier rocks, and indicates that a substantial redefinition of the Cornelia Formation is necessary. This will help unravel the complex tectonic and stratigraphic history of the rocks in the southern Little Sandy Desert, and provide pointers for future mineral exploration.

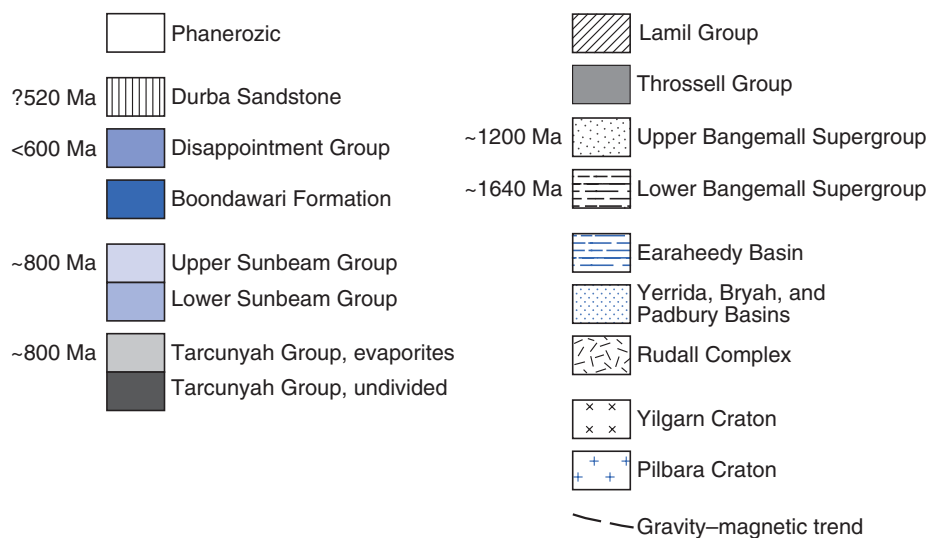
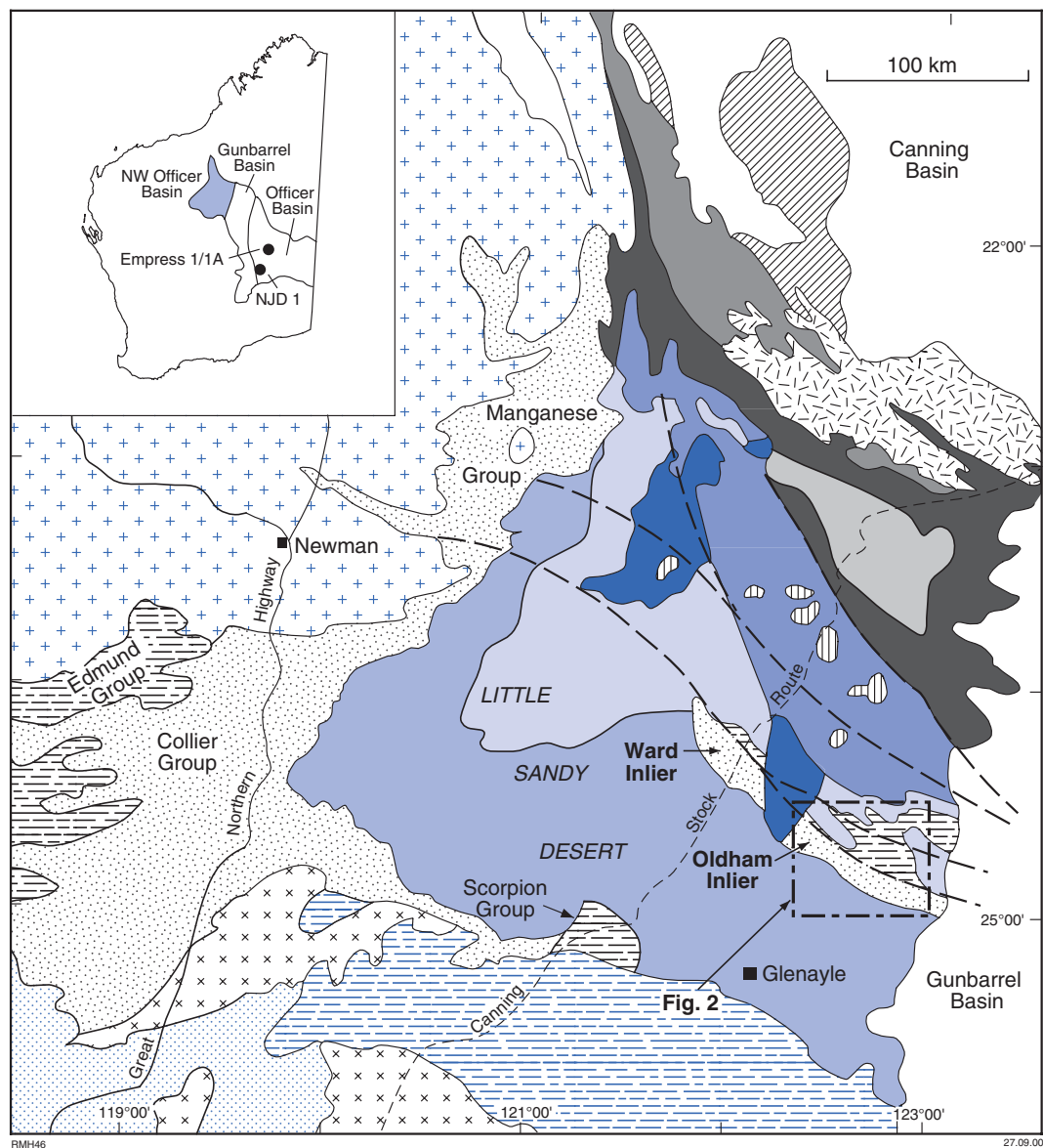
Geological setting

The Ward and Oldham Inliers in the southern Little Sandy Desert are composed of well-indurated sandstone with lenses of siltstone, shale, and conglomerate, previously referred to as the 'Cornelia Sandstone' (Brakel and Leech, 1980) or Cornelia Formation (Williams, 1992). This unit was at first thought to be older than the Collier Group (Muhling and Brakel, 1985), and then a correlative of the group (Williams, 1990, 1992). The inliers are overlapped by or faulted against the Neoproterozoic Sunbeam Group and overlying Boondawari Formation (Fig. 2; Bagas et al., 1999) of the northwest Officer Basin.

The Sunbeam Group is dominated by shallowly dipping, moderately indurated quartz sandstone, with a basal cobble conglomerate and a higher interval of stromatolitic carbonate in the Skates Hills Formation. Most clasts in the basal conglomerate are highly silicified sandstone, derived from the Cornelia Sandstone and probably the Oldham Sandstone to the south.

The Skates Hills Formation contains the *Acaciella australica* Stromatolite

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Figure 1. Regional setting of the Oldham Inlier (modified from Bagas *et al.*, 1999)

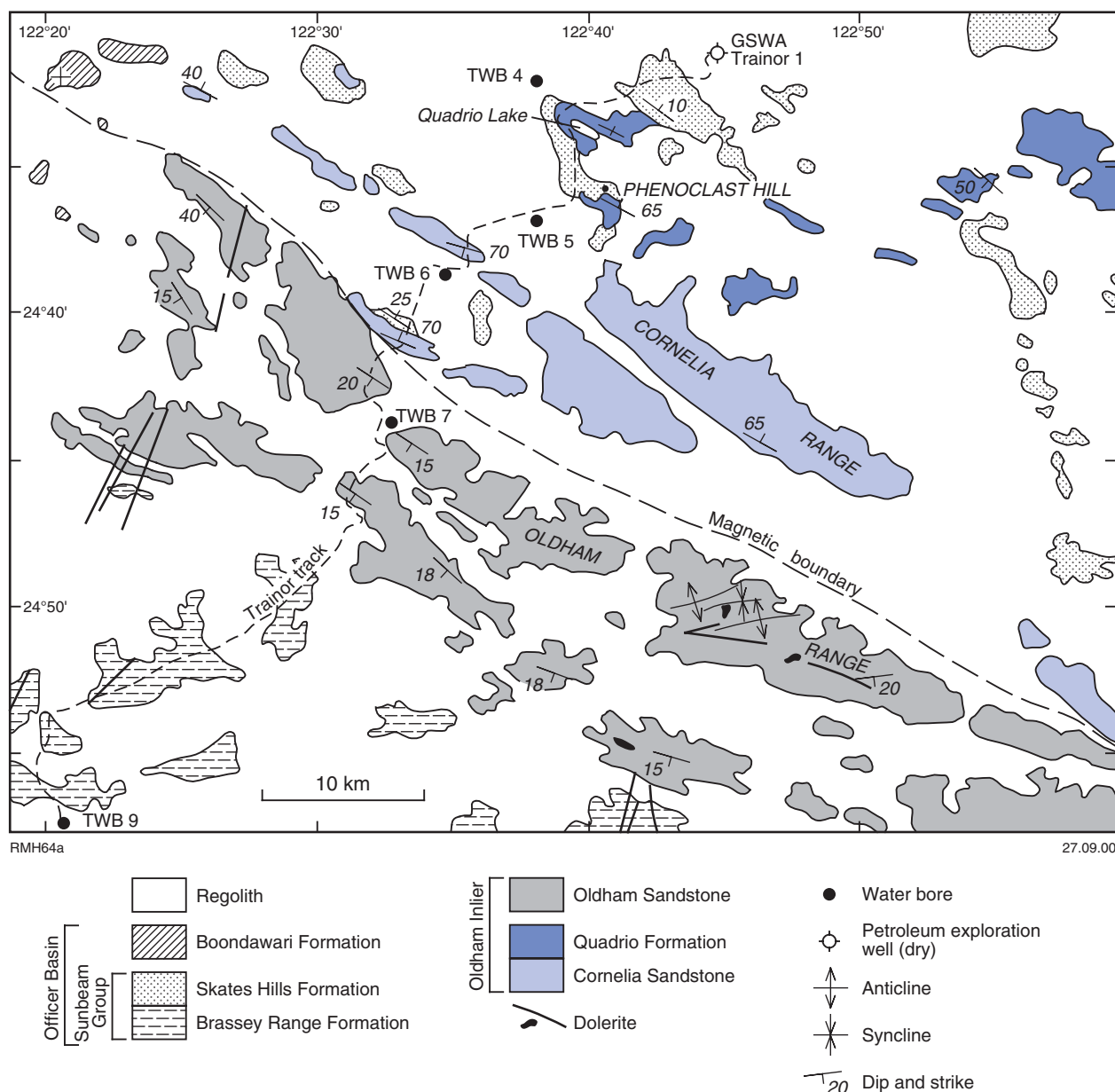


Figure 2. Outcrop geology of the Oldham Inlier (modified from Williams, 1995)

Assemblage, which can be confidently assigned to Supersequence 1 (Grey, 1995; Hill et al., 2000). Neoproterozoic palynomorphs typical of Supersequence 1 were recovered from a water bore (TWB 9, Fig. 2) in the Brassey Range Formation (Grey and Stevens, 1997). An almost identical assemblage was recovered north of the Oldham Range from TWB 6 (Grey and Stevens, 1997; Fig. 2), which was spudded into rocks then mapped as Cornelia 'Formation'. Further work indicates that at that locality, gently

dipping Neoproterozoic rocks fill a shallow successor syncline in an older steeply dipping syncline of Cornelia Sandstone.

Revised stratigraphy

Recent mapping, accompanied by Landsat and airborne magnetic image interpretation, shows that three distinct units were previously included in the Cornelia Formation. These units are here assigned to a revised Cornelia Sandstone and

two new units, the Quadrio Formation and Oldham Sandstone (Table 1). Full definitions of these units are given by Hocking et al. (2000a).

Differentiation of the Oldham and Cornelia Sandstones is based on changes in bedding orientations and a strong change in magnetic character along the northern margin of the Oldham Range (Fig. 3). The change coincides with an observed fault in sandstone, 18 km southwest of Quadrio Lake

Table 1. Stratigraphic history of the Oldham Inlier

<i>Williams (1995) and earlier stratigraphy</i>	<i>Proposed stratigraphy</i>	<i>Lithology</i>	<i>Age and correlation</i>
Cornelia Formation	Oldham Sandstone	Silicified sandstone; moderately dipping	?1.2 Ga, ?Collier Group
	Quadrio Formation	Shale, minor sandstone; subvertical	?1.6 Ga, ?Edmund Group
	Cornelia Sandstone	Intensely silicified sandstone; steeply dipping	?1.6 Ga, ?Edmund Group

(Fig. 2). Rocks in the Oldham Range to the south, defined as the Oldham Sandstone (Hocking et al., 2000a), are silicified, cross-bedded, and rippled quartz sandstone commonly dipping at about 15° to the southwest. Sandstone north of this change in magnetic character has a subdued magnetic intensity (Fig. 3), is marginally more silicified than the Oldham Sandstone, dips at much steeper angles, and has a more pronounced quartz stockwork. Therefore, the name Cornelia

Sandstone is restricted to the steeply dipping sandstone intervals north of the Oldham Range (Hocking et al., 2000a). Both formations were probably deposited on a fluvial plain, perhaps coastally situated in places as some sandstone beds are well sorted and appear to have been winnowed by waves. Either formation could be the source of many clasts in the basal conglomerate of the Skates Hills Formation at Phenoclast Hill.

The third unit, named the Quadrio Formation (Hocking et al., 2000a), outcrops in the northeastern part of the Oldham Inlier, at and north of Phenoclast Hill (Fig. 2). The Quadrio Formation is a steeply dipping, shale-dominated unit that youngs to the north. The base is obscured by the unconformably overlying Skates Hills Formation, although it appears to grade upwards from the Cornelia Sandstone at the northwestern end of the Cornelia Range (based on aerial photograph

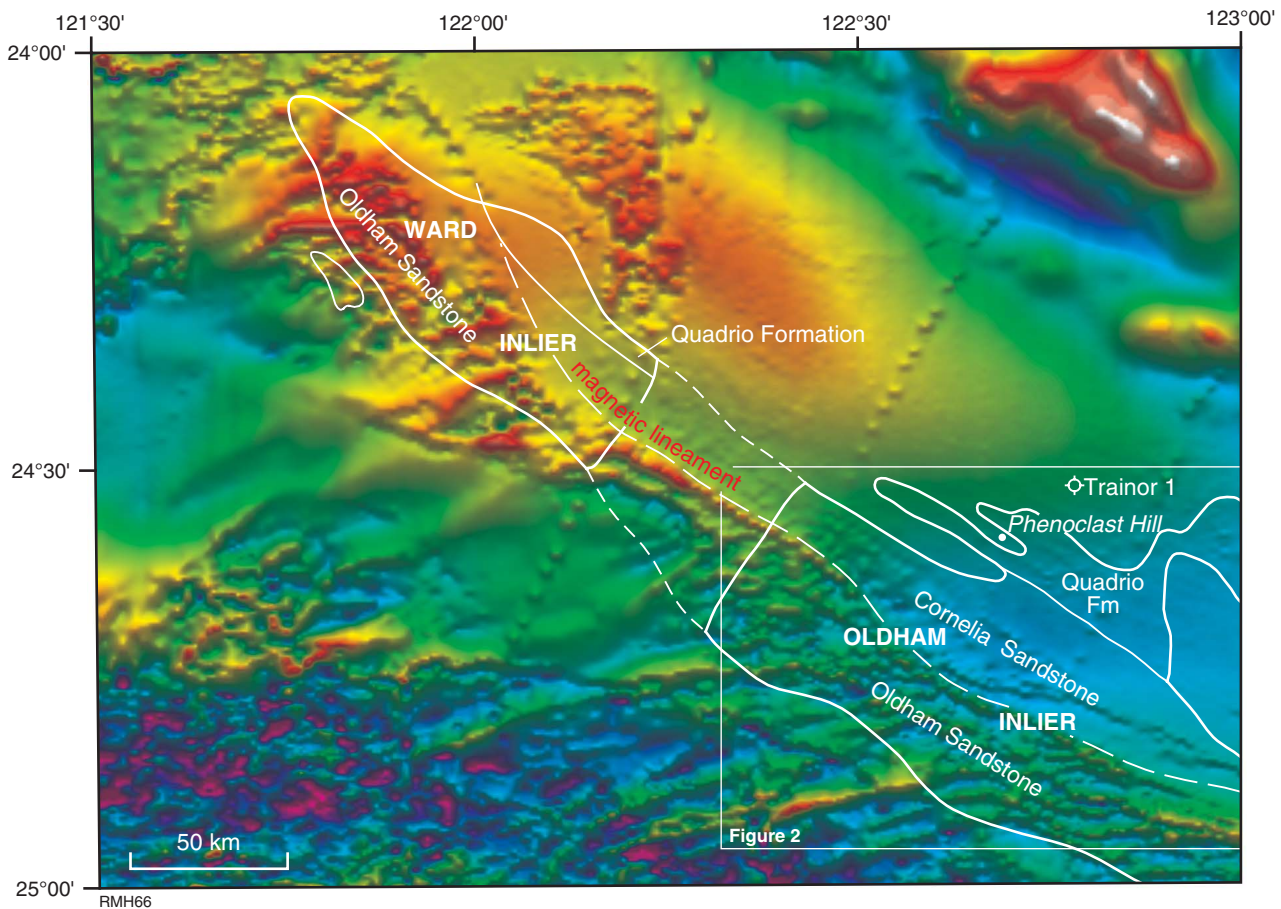


Figure 3. Total magnetic intensity image of the Oldham Inlier area

interpretation). Around Quadrio Lake it consists of ferruginized shale and siltstone that grades upwards into banded and laminated chert in a prominent ridge north of the lake. The chert is, in turn, overlain by about 100 m of recessive siltstone. Three coarsening-upward cycles grading from siltstone to rippled and hummocky cross-stratified sandstone, each 10 to 20 m thick, cap the siltstone. These are interpreted as offshore to foreshore shallowing-up cycles. They are capped by another siltstone dipping at up to 80°, which continues 3 km northeastwards to where it is overlain by the flat-lying Skates Hills Formation. The formation is interpreted as a low-energy offshore deposit, with a shallowing phase that could not be sustained. On the southern side of Quadrio Lake, epigenetic barite-hematite stockwork cutting through the Quadrio Formation contains anomalous gold values (Hocking et al., 2000b).

Trainor 1 succession

The Quadrio Formation is similar to the interval below 83 m in Trainor 1 (Stevens and Adamides, 1998), about 5 km north of the youngest exposed Quadrio Formation (Fig. 2). Rocks below 83 m in Trainor 1 dip at about 40° and are predominantly dark, well-indurated mudstone to siltstone, with thin turbiditic mass flows and slumps (Stevens and Adamides, 1998). The lithology, level of induration, and orientation in Trainor 1 are very similar to the exposed Quadrio Formation and, on this basis, the interval below 83 m in Trainor 1 is included within that formation. In both outcrop and the subsurface, this unit is dissimilar to the sandstone-dominated units in the Oldham Range (Oldham Sandstone) and Cornelia Range (Cornelia Sandstone).

Hypothetically, the Trainor 1 succession below 83 m has a maximum age of deposition of about 511 Ma (Early Cambrian), based on $^{206}\text{Pb}/^{238}\text{U}$ sensitive high-resolution ion microprobe (SHRIMP) ages of 511 ± 14 Ma, 696 ± 20 Ma, and 699 ± 20 Ma from detrital zircons at 574 m (Nelson, 1997). Even though 13 of the SHRIMP dates obtained from four zircon grains must be rejected for the Quadrio Formation to be older than about 850 Ma, an early Phanerozoic age requires a

highly complex geology for which there is no corroborating evidence. It is difficult to fit a deep-water turbiditic environment, with no evidence of fossils, into the known Phanerozoic palaeogeography (Hocking, 1994; Jackson and van de Graaff, 1981; Kennard et al., 1994). Additionally, the presence of thermally overmature Phanerozoic rocks sandwiched between thermally mature Neoproterozoic rocks is difficult to explain without invoking a highly complex system of faulting. Less than 10 km to the south, unequivocal Neoproterozoic rocks (stromatolitic carbonates of the Skates Hills Formation) overlie outcrop that can be positively assigned to the Quadrio Formation. The zircon ages, therefore, must be regarded as suspect until the dates can be verified from additional samples and a realistic model is devised to explain their anachronism.

We interpret the lower unit in Trainor 1 as part of the Quadrio Formation, which it resembles in lithology, orientation, and degree of deformation. We consider that the Trainor 1 succession and the outcropping Quadrio Formation are significantly older than the Neoproterozoic succession of the Officer Basin, which unconformably overlies them with considerable angularity.

Correlation and age

None of the three units discussed here (the Oldham Sandstone, redefined Cornelia Sandstone, and Quadrio Formation) contain any features that provide an unequivocal correlation to other Proterozoic rocks in the region (Fig. 4). The Cornelia Sandstone and (probably) the Oldham Sandstone were well indurated, folded, and eroded to form the clasts within the conglomerate in the Skates Hills Formation of Supersequence 1 age (c. 800 Ma). There is an angular unconformity of up to 80° between the Quadrio Formation and Cornelia Sandstone below, and the Skates Hills Formation and Brassey Range Formation above. The Oldham Sandstone dips uniformly at about 15° to the southwest, whereas the Cornelia Sandstone and Quadrio Formation are folded with dips typically greater than 60°. These relationships partly constrain

possible correlations. The Cornelia Sandstone and Quadrio Formation share a similar structural style, orientation, and magnetic character, and there is no indication from outcrop or Landsat imagery of a significant fault between the two. We therefore tentatively assume that they are of similar ages.

None of the three units can correlate with the Coonabildie Formation (formerly 'Kahrban Subgroup'; Williams, 1990; revised by Hocking et al., 2000a), about 50 km to the south, because recent mapping indicates that the Coonabildie Formation is the basal portion of the Sunbeam Group (c. 825 Ma; Bagas et al., 1999) and is conformable beneath the Brassey Range Formation, which is unconformable on the Oldham Sandstone. Correlation of any or all units with the Earacheedy Group (Capricorn Orogen, c. 1800 Ma; Jones et al., 2000), which outcrops 100 km to the south (Figs 1 and 4), is unlikely because the lithofacies are quite dissimilar. Probable lateral changes in the lithofacies in the Ward and Oldham Inliers do not match the regional facies patterns observed in the Earacheedy Group.

The most obvious correlation for the Oldham Sandstone is with the Collier Group, and for the Cornelia Sandstone and Quadrio Formation is with the Edmund Group (Fig. 4). The Collier Group is exposed about 100 km to the southwest (upper Bangemall Supergroup, Fig. 1), where its lithology, and degree of silicification and quartz veining are similar to the Oldham Sandstone. The Collier Group and its correlative to the north, the Manganese Group, were deformed by the Miles Orogeny of the Paterson Orogen, the maximum possible age of which is about 1150 Ma (Bagas et al., 1995). The Quadrio Formation resembles shales in the Edmund Group (?Discovery or Kiangi Creek Formations; Fig. 4), the nearest exposures of which are about 300 km to the west (lower Bangemall Supergroup, Fig. 1). Deposition of the Edmund Group began at about 1645 Ma (Martin et al., 1999). The Quadrio Formation could also correlate with the dolomitic and sandy Scorpion Group (exposed about 130 km to the southwest; Fig. 4) if the basin shallowed southward. The Scorpion Group (Hocking et al., 2000a) is a coastal-

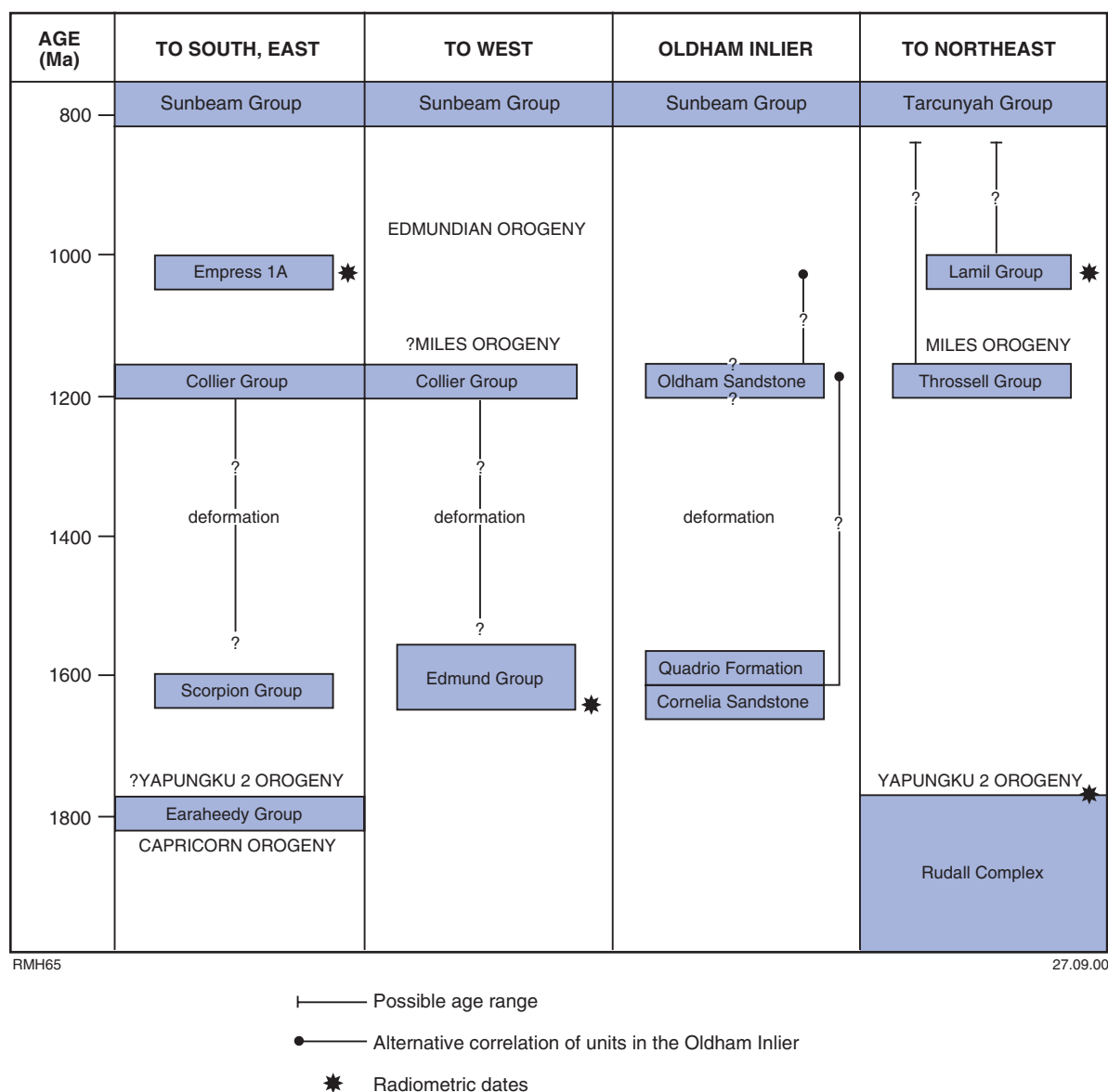


Figure 4. Regional stratigraphic relationships. Possible age ranges are indicated by bars, with units placed at the points that constrain their ages

facies, dolomite-rich succession that was previously correlated with the Edmund Group (Williams, 1990) and contains stromatolites similar to those in the lower Edmund Group.

An alternative correlation is between the Quadrio Formation and the Mesoproterozoic–Neoproterozoic Throssell Group (Fig. 4), which is exposed about 250 km northeast of the Oldham Inlier (Fig. 1; Bagas et al., 2000). The Throssell Group is a succession metamorphosed to greenschist facies (Hickman and Bagas, 1998) that consists of a basal sandy interval

(Coolbro Sandstone) overlain by carbonaceous shale, siltstone, turbidite, and carbonate units (Broadhurst Formation), and may be of similar age to the Collier Group. The Quadrio Formation resembles, both in lithology and metamorphic grade, the Broadhurst Formation, and the Cornelia Sandstone resembles the Coolbro Sandstone. If this correlation is correct, then the Throssell Group may extend at least as far as the Ward and Oldham Inliers. The southward provenance of the Coolbro Sandstone lessens the likelihood of this correlation. The position of the Oldham Sandstone in

this correlation scheme is unclear. It might relate to the interval at the base of drillhole Empress 1A (Figs 1 and 4), where pre-Supersequence 1 volcanic rocks interbedded with mudstone have a K–Ar age of 1058 ± 13 Ma (Stevens and Apak, 1999), and possibly to drillhole NJD 1 in the southern Officer Basin (Fig. 1), which also contains a similar succession at the base of the hole.

Regional implications

The recognition of three distinct units in the Oldham Inlier, all

younger than and dissimilar to the Earahedy Basin succession, and probably correlating with the Bangemall Supergroup or perhaps the Throssell Group, means that there is an extensive Mesoproterozoic basement to the northwestern Officer Basin, above possible Palaeoproterozoic rocks. The Little Sandy Desert area remained an active trough through the Mesoproterozoic and early Neoproterozoic.

The abrupt change in magnetic character and the relationship of the Cornelia and Oldham Sandstones indicate the presence of a south-facing high-angle reverse fault between the two, along the northern side of the Oldham Range. This fault is at the southern edge of the set of high-angle reverse faults that probably extend southeastward from the Rudall Complex to the Musgrave Complex (Myers and Hocking, 1998).

Accepting the correlations with the Edmund and Collier Groups implies the following events. A compressional event between about 1600 and 1200 Ma uplifted and folded the Cornelia Sandstone and Quadrio Formation. This is presumably the same event that caused uplift and erosion of the Edmund Group to the west, prior to deposition of the Collier Group. A second compressional episode after 1150 Ma (possibly related to the Miles Orogeny) thrust the Quadrio Formation and Cornelia Sandstone south-southwestward over the Oldham Formation, before deposition of the Sunbeam Group began at about 830 Ma. There is little indication of later faulting related to the c. 550 Ma Paterson and Petermann Ranges Orogenies (Bagas et al., 1995), as the Sunbeam Group is commonly subhorizontal and little faulted in the southern Little Sandy Desert. Some older structures were reactivated, as in the syncline around water bore TWB 6, where gently dipping Neoproterozoic rocks fill a shallow successor syncline in an older steeply dipping syncline of Cornelia Sandstone. The Oldham and Ward Inliers were probably emergent during the earliest stages of Supersequence 1 deposition, as the Oldham Inlier is locally overlapped by Skates Hills Formation, which belongs near the middle of Supersequence 1.

Mesoproterozoic to Neoproterozoic successions elsewhere contain significant mineralization, such as the Telfer gold deposit in the Lamil Group (Bagas, 2000), Nifty and other copper and base metal deposits in the Throssell Group (Hickman et al., 1994), manganese and copper in the Manganese Group (Williams, 1989), copper in the Camel-Tabletop Fault Zone of the Paterson Orogen (Bagas and Lubieniecki, 2000), and the Abra lead-zinc deposit in the Edmund Group (Cooper et al., 1998; Martin and Thorne, 2000). The potential for correlation between the

Oldham and Cornelia Sandstones and Quadrio Formation, and any of these mineral-bearing stratigraphic units, together with the anomalous gold values in veins cutting the Quadrio Formation, and the possibility of associated base metal mineralization (Hocking et al., 2000b) indicate the need for more-detailed evaluation of the isolated outcrops in the Ward and Oldham Inliers. In addition, the association of mineralization with barite (Hocking et al., 2000b) also raises the prospectivity of other barite occurrences in the region.

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Revised stratigraphy for the Earraheedy Group: implications for the tectonic evolution and mineral potential of the Earraheedy Basin

by J. A. Jones¹, F. Pirajno, R. M. Hocking, and K. Grey

Abstract

The Palaeoproterozoic Earraheedy Basin, which contains the Earraheedy Group, is part of the Capricorn Orogen. The basin is thought to post-date the Capricorn Orogeny (c. 1800 Ma), and was probably deformed during the second phase of the Yapungku Orogeny (1760 Ma). Revisions to Earraheedy Group stratigraphy include the introduction of the Sweetwaters Well Member of the Yelma Formation for a stromatolitic carbonate unit in the southwestern and western parts of the basin, the amalgamation of the Wandiwarra Formation and Princess Ranges Quartzite into the Chiall Formation, the introduction of the Karri Karri Member for thinly laminated shale at the base of the Chiall Formation in the north and southwest, and the recognition that the Windidda Formation is a correlative of the upper Frere Formation.

The sedimentary features in the Earraheedy Group indicate deposition in a shallow-marine to coastal environment. We suggest that the Earraheedy Group, as exposed, represents the southern portion of a passive continental margin on the northeastern edge of the Yilgarn Craton. Mineralization is related to this passive-margin environment, and subsequent deformation, associated with southwesterly directed compression. Mineral deposits include iron ore in the Frere Formation, lead–zinc sulfides and lead carbonate in the Sweetwaters Well Member, and structurally controlled gold. The tectonic setting of the Earraheedy Basin suggests that stratabound copper deposits may be present.

KEYWORDS: Earraheedy Basin, Capricorn Orogen, stratabound deposits, iron ore, copper, lead, zinc, sulphides, tectonics, models

the Earraheedy Basin forms an easterly plunging open syncline. Compressive movements from the northeast created a zone of deformation along the exposed northern margin of the Earraheedy Basin, which is named the Stanley Fold Belt.

Regional stratigraphic relationships indicate that the Earraheedy Basin is younger than the Yerrida Basin (about 2200 Ma; Woodhead and Hergt, 1997) and older than the Bangemall Basin (1650 Ma; Nelson, 1995). The basin appears to be unaffected by, and is thus probably younger than, the 1800 Ma Capricorn Orogeny, which records the collision of the Pilbara and Yilgarn Cratons (Tyler and Thorne, 1990). Alternatively, it may simply have lain east of the area affected by the orogeny, as parts of the Yerrida Basin (which is unequivocally older than the Capricorn Orogeny) are also unaffected. Poor age constraints hinder more accurate placement of the Earraheedy Basin within the regional framework. Isotopic ages for Earraheedy Group sedimentary rocks and mineralization in the basin cluster around 1800–1700 Ma. Deformation in the Stanley Fold Belt is tentatively attributed to the second phase of the Yapungku Orogeny at 1760 Ma (Smithies and Bagas, 1997), which was probably caused by the collision of the North and West Australian Cratons. If this is correct, then 1760 Ma provides a minimum age for the Earraheedy Basin. Based on stromatolite taxa, Grey (1994, p. 192) suggested that the age of the Earraheedy Group might be between 1.9 and 1.8 Ga.

Introduction

The Palaeoproterozoic Earraheedy Basin (Bunting, 1986; Pirajno et al., 1999), which contains the Earraheedy Group (Fig. 1), lies at the eastern end of the Capricorn Orogen (Tyler et al., 1998). The basement to the exposed

Earraheedy Basin is the Archaean Yilgarn Craton, and the early Palaeoproterozoic Yerrida Basin to the west. The Earraheedy Basin was probably much larger than its present-day exposure, extending farther to the southwest and the north, where it is concealed by the overlying Bangemall and Officer Basins. The preserved exposure of

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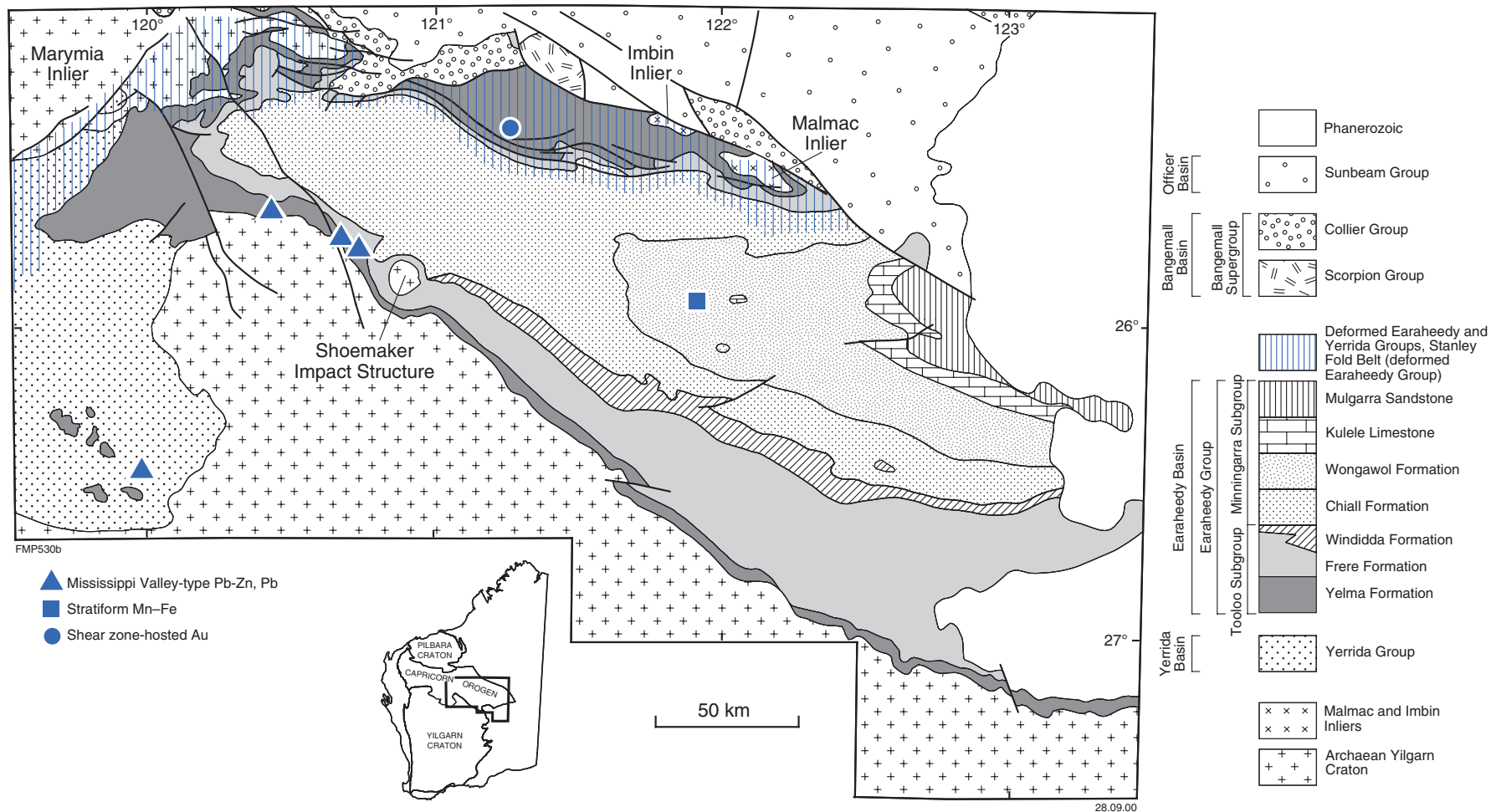


Figure 1. Simplified geological map of the Earaheedy Basin (modified from Bunting (1986) and including data from recent mapping)

Stratigraphy

The Earaaheedy Group (Fig. 2) is a 5 km-thick package of shallow-marine clastic and chemical sedimentary rocks divided into two subgroups (Hall et al., 1977). The Tooloo Subgroup consists of (from base to top) the Yelma Formation, Frere Formation, and Windidda Formation. The overlying Minningarra Subgroup consists of (from base to top) the Chiall Formation, Wongawol Formation, Kulele Limestone, and Mulgarra Sandstone.

Yelma Formation

The Yelma Formation contains shale, sandstone, and carbonate deposited in shallow-marine and locally fluvial environments. The formation is quite variable laterally and vertically in thickness and composition. The thickness ranges from 3 m in the southeastern part of KINGSTON*, to 150 m in the type area in the western part of KINGSTON (Bunting, 1986), to at least 500 m in a drillhole in the northwestern part of NABBERU. Bunting (1986) estimated a thickness of 1500 m in the western part of STANLEY, but we interpret this as structural thickening. Sandstones in the southeast are trough cross-bedded, with local asymmetric ripples and mudcracks. Stellate pseudomorphs may be after evaporite. A 100 m-thick stromatolitic carbonate facies in the southwestern part of the basin is named the Sweetwaters Well Member (Hocking et al., 2000). Stromatolites in metre-scale upward-shallowing cycles include *Asperia digitata* Grey 1984 (Grey, 1994; restricted, quiet-water environment, possibly supratidal pond), *Pilbaria deverella* Grey 1984 (moderately high energy, lagoonal environment), *Ephyalltes edingunnensis* Grey 1984 (deeper quiet-water environment), and *Murgurra nabberuensis* Grey 1984 (patch reef, moderate energy environment). Both the stromatolites and cycles are similar to those in the Duck Creek Dolomite (upper Wyloo Group; Grey, 1994). Tepee structures, crystal-mush horizons, and flat-pebble carbonate conglomerate are recognized in drillcore.

The Yelma Formation was deposited in a fluvial to possibly coastal setting in the south, and a shallow-marine to coastal environment in the north. Carbonates of the Sweetwaters Well Member formed in a saline lagoonal environment. Widespread shale (with minor sandstone) at the top of the Yelma Formation was deposited during a regional marine transgression.

Frere Formation

The Frere Formation records the onset of iron-oxide precipitation within the basin and consists of up to three major granular iron-formation intervals, separated by up to three major shale and siltstone bands, and minor carbonate. Granular iron-formation horizons consist of jasperoidal granular iron-oxide beds, typically 50 to 200 mm in thickness, and intraclastic breccia interbedded with shale and siltstone. Individual granular iron-formation beds consist of chert, iron oxides, peloids (microplaty hematite), and jasper (cryptocrystalline silica with finely disseminated hematite) in a cherty, chalcedonic or jasperoidal cement. Hematite is replaced by magnetite in iron formation deformed in the Stanley Fold Belt. Shale and siltstone units contain quartz, iron-rich chlorite, and disseminated euhedral magnetite. Along the southern basin margin, where deformation is minimal, siltstone rather than shale is present. These are parallel laminated, with minor cross-lamination. Individual lamellae are 1 to 10 mm in thickness. Laminar granular iron-formation, previously interpreted as banded iron-formation, is mylonitized granular iron-formation and iron-rich shale.

The granular iron-formation beds probably formed in the shallow waters of a continental shelf. Ferruginous peloids accreted in wave- and current-agitated iron-rich waters (Beukes and Klein, 1992), and were deposited after some reworking by mechanical processes, with variable terrigenous contamination. Cross-bedding is locally recognized in granular iron-formation units, and bedding structures commonly indicate moderate-energy conditions with intermittent still-water periods.

Interbedded shale and siltstone horizons represent subwavebase deposits in the north to possibly lagoonal deposits in the southeast.

Windidda Formation

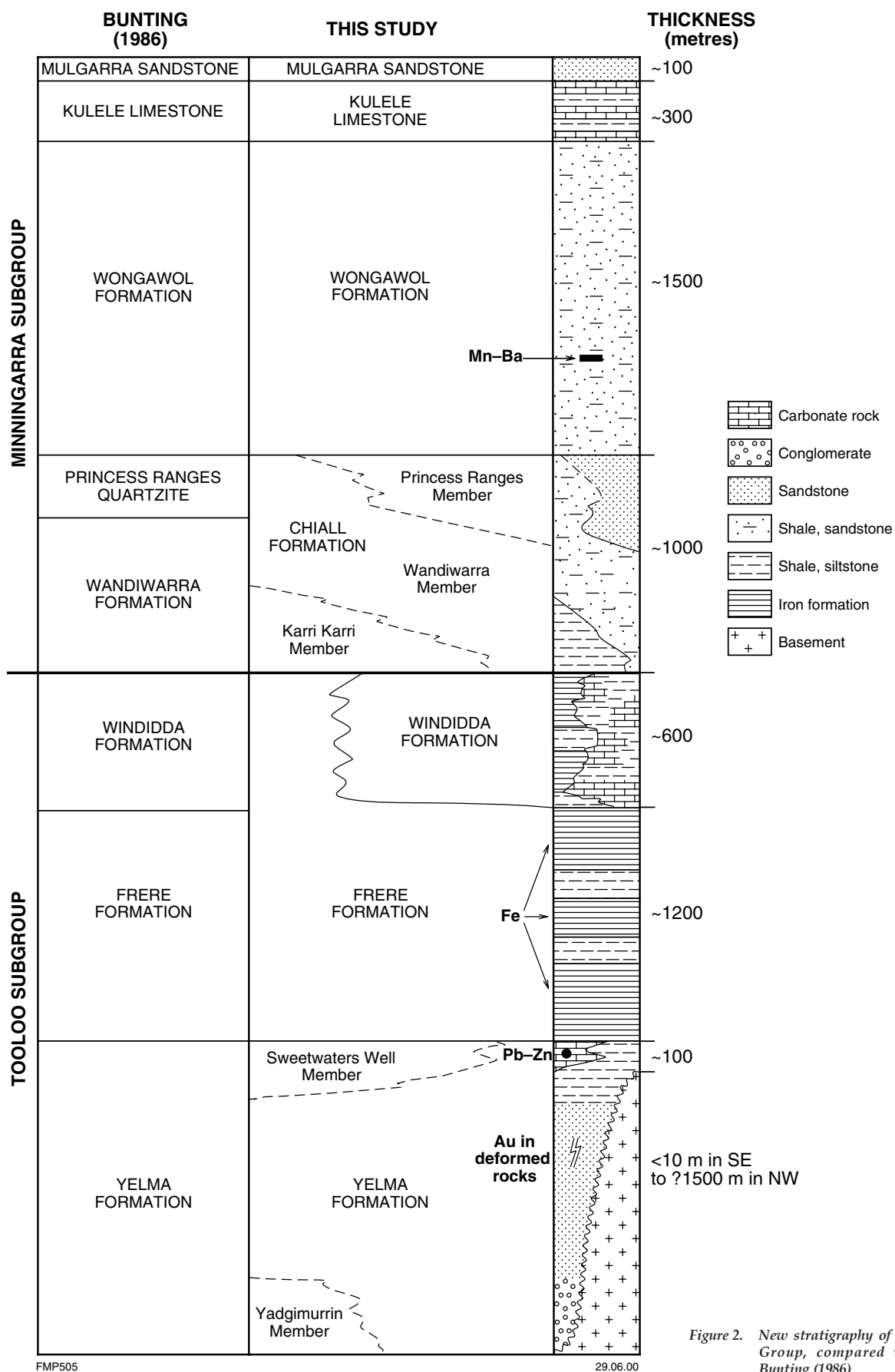
The Windidda Formation consists of shale and siltstone, locally stromatolitic carbonate, minor jasperoidal beds, and granular iron-formation and is present southeast of the Shoemaker Impact Structure. The Windidda Formation represents a carbonate shelf with coastal lagoons in the southeastern part of the basin.

Granular iron-formation persists until the top of the Windidda Formation, and chert and limestone intervals are present throughout the Frere Formation. In addition, three major granular iron-formation intervals can be differentiated in the Frere Formation in the western part of the Earaaheedy Basin, but only two in the southeastern part. The Windidda Formation is therefore reinterpreted as a correlative of the upper Frere Formation southeast of the Shoemaker Impact Structure (Hocking et al., 2000), rather than a unit that only overlies the Frere Formation (Fig. 2).

Chiall Formation

The Chiall Formation combines, as members, the former 'Wandiwarra Formation' and 'Princess Ranges Quartzite' (Hocking et al., 2000). The formation consists of shale, siltstone, and mudstone intercalated with thick sandstone beds and intraclastic breccia, and represents a change from combined chemical and clastic sedimentation to dominantly clastic deposition. The base of the formation in the south is a breccia of poorly sorted, angular carbonate clasts in a ferruginized glauconitic sandstone matrix, which led Bunting (1986) to interpret the boundary as a disconformity. This is now interpreted as a submarine hardground, recording the rapid drowning, cementation, and partial reworking of the Windidda Formation carbonate platform. Thinly laminated shale in the northern and southwestern parts of the Earaaheedy Basin (where the Windidda Formation is absent), previously assigned to the 'Wandiwarra Formation', is now referred to as the Karri Karri

* Capitalized sheets refer to standard 1:250 000 map sheets.



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Figure 2. New stratigraphy of the Earaheedy Group, compared with that of Bunting (1986)

Member (Fig. 2). The shale is interbedded with thin, fine- to medium-grained sandstone beds in the upper part of the formation. The shale and siltstone are very similar to shale and siltstone of the Frere Formation. Initially thought to be a distal facies of the Windidda Formation, the Karri Karri Member was recently recognized as a basal, distal part of the Chiall Formation (Hocking et al., 2000). Deposition of the Karri Karri Member was probably below fair-weather wavebase, based on the presence of hummocky cross-stratification, graded bedding, and mass-flow deposits. Asymmetric ripples and cross-bedding are also present. In the southeast and the upper part of the Chiall Formation, symmetric and asymmetric ripples, interference ripples, rills, washouts, and trough cross-beds indicate a shallow-water upper shoreface to foreshore setting. In the southeast, a facies consisting of shale, mudstone, siltstone to very fine grained sandstone, and calcareous mudstone is present. Wrinkle marks, symmetrical ripples, and rills within it indicate intermittent emergence.

These structures, together with palaeocurrent data, indicate a tidal environment, with periodic localized lagoonal environments in the southeast deepening northwards to a subwavebase marine shelf.

Wongawol Formation

The Wongawol Formation consists of shale, siltstone to very fine grained sandstone, intraclastic breccia, and carbonate–glauconite breccia. Bunting (1986) suggested that the formation was 1500 m thick, but low-angle faulting and folding may have exaggerated the true thickness. Asymmetrical and symmetrical ripples, rills, wrinkle marks, washouts, and mudcracks in the siltstone and very fine grained sandstone indicate a very shallow, locally emergent environment, possibly lagoonal, with periods of minimal sedimentation. Contorted bedding is common, and detached pillows of sandstone within siltstone (load structures) are also present.

Kulele Limestone and Mulgarra Sandstone

The Kulele Limestone is a cyclic platform succession consisting of

carbonate units separated by shale and sandstone (up to 300 m thick). Carbonate units are stromatolitic, oolitic, and pisolitic. Distinctive stromatolites, *Earaheedia wongawolensis* Grey 1984, consist of elongate domes, large individual domes up to 3 m high and 4 m wide, and minor columns. Compared to the Wongawol Formation, the Kulele Limestone records a slight deepening of the basin, accompanied by a drop in terrigenous influx. Metre-scale shallowing-upward cycles through most of the unit record regular minor fluctuations in sea level in a subtidal to possibly intertidal setting.

The Mulgarra Sandstone consists of sandstone, shale, and minor carbonate, with a maximum thickness of 100 m. The formation may reflect the final stage of terrigenous influx in the basin.

Mineralization

In the Earaheedy Basin, Mississippi Valley-type lead–zinc–copper sulfide deposits are present in the Sweetwaters Well Member of the Yelma Formation (Fig. 1). This mineralization is near Sweetwaters Well, where galena is hosted in the spaces between columns of *Asperia digitata*, which probably acted as local conduits for mineralizing fluids (Grey, 1984). West of the Shoemaker Impact Structure, sulfide mineralization was intersected in several drillholes. Here, the mineralized stromatolitic dolomite extends along strike for about 13 km and consists of sphalerite, galena, pyrite, and chalcopryite, largely as fracture fills, vug fills, or carbonate replacements. Petrographic and fluid inclusion studies suggest that the Shoemaker meteorite impact generated high-temperature (>300°C) fluids (Seccombe and Jiang, 1994), which may have caused the redistribution of part of the sulfide mineralization in impact-induced fractures.

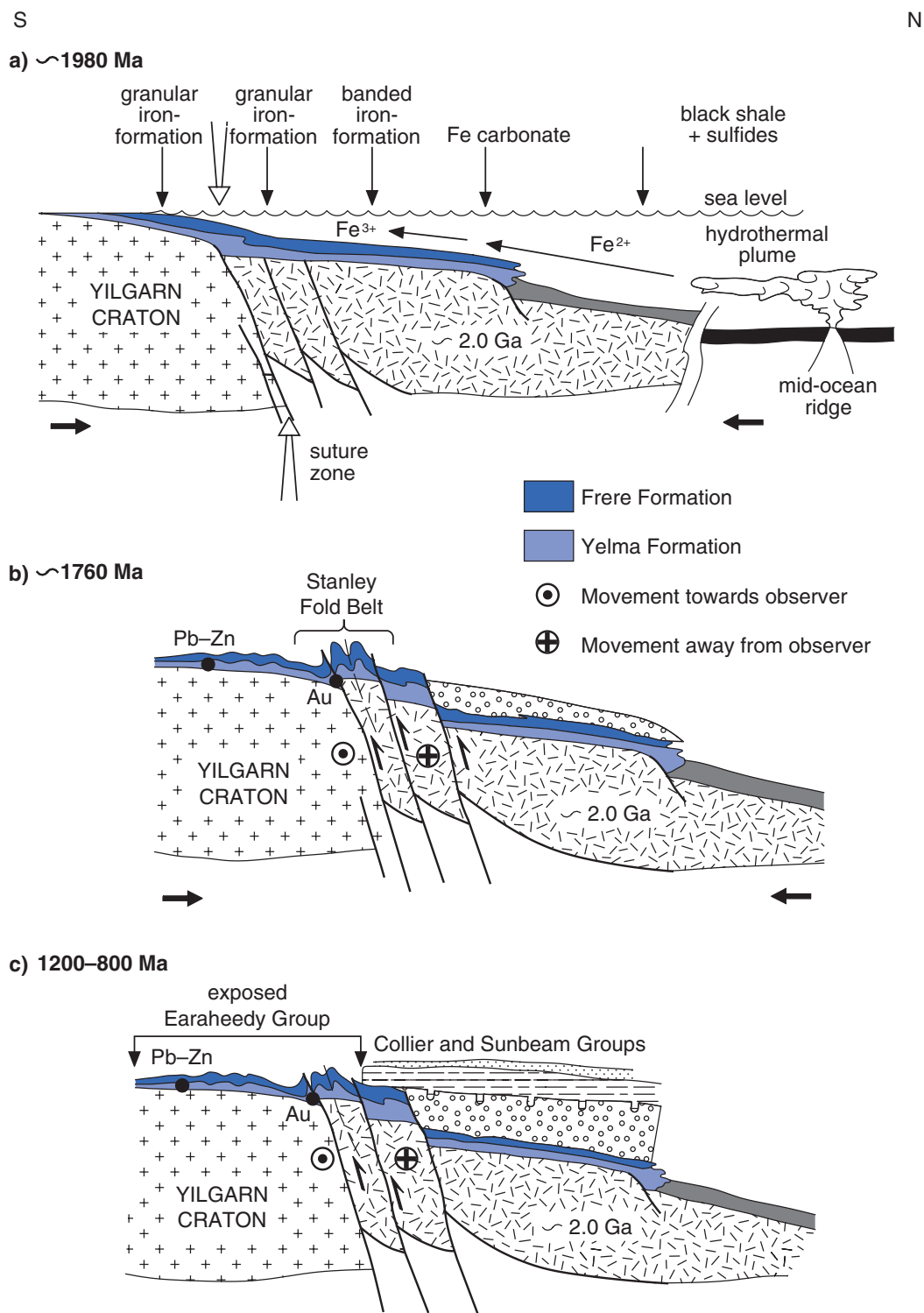
The large (>200 Mt) Magellan lead deposit is hosted by outliers of the Sweetwaters Well Member resting unconformably on the Yerrida Group to the southwest near the town of Wiluna. The Magellan mineralization consists of cerussite, plattnerite, and anglesite (Pirajno and Preston, 1998).

Minor stratiform manganese and iron oxides within the shale units of the Wongawol Formation (Pirajno and Adamides, 2000) contain anomalous abundances of copper, barium, and lead, thus enhancing the prospectivity of the Earaheedy Basin for stratabound copper of the Kupferschiefer type. Gold mineralization in the Stanley Fold Belt (the presently exposed deformed northern margin of the Earaheedy Group) is associated with mylonite and quartz veins.

Depositional model

Poor age constraints hinder our understanding of the tectonic evolution and development of the Earaheedy Basin. Any model for the evolution of the basin must account for influx of iron during the deposition of the Frere Formation, the allochemical nature of the jasperoidal and iron-oxide clasts, the coastal to shallow-marine environment for the Earaheedy Group, and the lack of evidence for contemporaneous volcanism or deformation. A proposed model for the geodynamic evolution of the Earaheedy Basin is presented in Figure 3.

The exposed Earaheedy Group is characterized throughout by deposition in a shallow-marine to coastal environment, with a shoreline to the south and southeast, and deepening towards the north. The lack of change from coastal bathymetry suggests that there was no major tectonic activity, either as abrupt hinterland uplift or basin subsidence. We envisage that the Earaheedy Basin was part of a passive continental margin (Fig. 3a) along the northeastern Yilgarn Craton. The Earaheedy Group represents the southern coastal to nearshore portion of the continental margin, where deposition occurred in response to subsidence, sediment loading, and compaction. Deposition was strongly influenced by water chemistry, sediment supply, and minor sea-level fluctuations. Sea-level fluctuations are envisaged to have been both eustatic and tectonic, with short-term eustatic changes in a greenhouse climate (Read et al., 1995) producing metre-scale cyclicity in carbonates, and longer term tectonism responsible for increases in sand deposition by



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Figure 3. Schematic illustration (not to scale) showing the depositional and tectonic model for the Earahedy Basin; note that only the Yelma and Frere Formations are shown, for the sake of clarity: a) at about 1980 Ma, iron formation is deposited on a passive continental margin (northeastern Yilgarn Craton), with the iron sourced from a spreading centre; b) at about 1760 Ma, strike-slip movements form the Stanley Fold Belt, resulting in the formation of Mississippi Valley-type lead-zinc and mesothermal gold lodes; c) between 1200 and 800 Ma, deposition of the Collier and Sunbeam Groups conceals parts of the passive continental margin; the exposed portion is the present-day Earahedy Basin

either hinterland rejuvenation or basin subsidence. We propose that the quiet low-energy conditions typifying most of the sediment fill of the basin and the suggestion of saline lagoonal environments within the Earahedy Group are consistent with deposition on an arid coastline.

The northward-deepening model for the basin is consistent with hypotheses that granular iron-formation is the shallow-water facies equivalent of deeper water, banded iron-formation (Beukes and Klein,

1992; Isley, 1995). The ultimate source of the iron, and perhaps of other metals (lead, zinc, and manganese), is interpreted to have been from a mid-ocean ridge probably located well to the north and east of the presently exposed margin of the Pilbara Craton (Fig. 3a). The lead–zinc sulfide occurrences in the Sweetwaters Well Member, west of the Shoemaker Impact Structure, and the Magellan lead carbonate and oxide deposit were probably formed during flow of basinal fluids through sandstone

aquifers. These fluids originated by dewatering of the sediments, initially through compaction, and subsequently during tectonic transport to the southwest. The structurally controlled veins in the Stanley Fold Belt are also related to the deformation of the Earahedy Group at this time (Fig. 3b). High-temperature fluids may have been generated during a thermal event related to the Shoemaker meteorite impact. The Earahedy Group is now partly concealed by rocks of the Collier Group (Fig. 3c).

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Iron–manganese oxides and glauconite-bearing rocks of the Earraheedy Group: implications for the base metal potential of the Earraheedy Basin

by F. Pirajno¹ and N. G. Adamides

Abstract

The Palaeoproterozoic Earraheedy Basin is characterized by an accumulation of clastic and chemical sedimentary rocks, Lake Superior-type granular iron-formations, and carbonates. Facies rich in glauconite are associated with the clastic sedimentary rocks. Shale units of the Karri Karri Member (Chiall Formation) host iron- and manganese-oxide mineralization. This mineralization is present as structurally controlled veins or thin beds also anomalous in copper, lead, cobalt, and barium. The association of glauconite-rich beds and stratiform iron–manganese oxides is typical of continental shelf environments. This association and the tectonic model for the Earraheedy Basin predict that stratabound sulfide deposits may be present as lateral facies-equivalents of glauconite-bearing sandstones and the iron and manganese oxides.

KEYWORDS: Earraheedy Basin, glauconite, iron, manganese, stratiform deposits, stratabound deposits, tectonics

Introduction

The Palaeoproterozoic (c. 1800 Ma) Earraheedy Basin (Bunting, 1986; Pirajno et al., 1999; Jones et al., 2000) is at the eastern end of the Capricorn Orogen, a zone of low- to high-grade metamorphic rocks, granite intrusions, and volcano-sedimentary and sedimentary basins. The Capricorn Orogen developed as result of the collision between the Archaean Pilbara and Yilgarn Cratons between 1830 and 1780 Ma (Tyler and Thorne, 1990; Tyler et al., 1998; Occhipinti et al., 1999a,b).


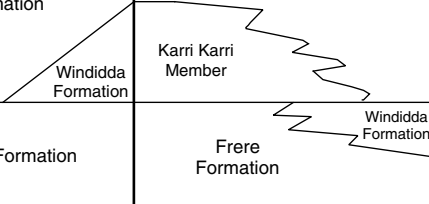

The Earraheedy Basin contains an approximately 5000 m-thick succession of clastic rocks, carbonate rocks, and iron formation of the Earraheedy Group deposited in a shallow-marine to coastal setting. The stratigraphy of the group is shown in Figure 1 and discussed in Jones et al. (2000). The basal units of the Earraheedy Group are included in the Tooloo Subgroup (Fig. 1), and have a total thickness of about 2500 m. Rock types in this subgroup are sandstone, stromatolitic dolomite (Yelma Formation), granular iron-formation interbedded with shale (Frere Formation), and finely laminated iron-rich

shale and limestone (Windidda Formation). Overlying these basal units are 2700 m of clastic and carbonate rocks of the Minningarra Subgroup, which is subdivided, from oldest to youngest, into the Chiall Formation (quartz sandstone, siltstone, and mudstone), Wongawol Formation (shale, siltstone, and fine-grained sandstone), Kulele Limestone (a platform carbonate succession with stromatolites), and Mulgarra Sandstone (a molasse-type unit, recording the final influx of terrigenous sediments).

On the basis of stratigraphic and sedimentological constraints, the Earraheedy Basin is interpreted as the shelf remnant of a passive continental margin, with the rest of the margin now buried beneath the younger Bangemall and Officer Basins (Pirajno et al., 1999; Jones et al., 2000). Compressive movements, perhaps linked to collision between the West Australian Craton and North Australian Craton at about 1760 Ma (Yapungku Orogeny; Smithies and Bagas, 1997; Tyler et al., 1998), resulted in a zone of deformation along the exposed northern margin of the Earraheedy Basin (Stanley Fold Belt; Pirajno et al., 1999).

The iron–manganese mineralization locally present in rocks of the Windidda and Wongawol Formations are discussed, and the significance of widespread glauconite in the clastic units of the Chiall and Wongawol Formations examined.

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BUNTING (1986)	REVISED STRATIGRAPHY	SUBGROUP	THICKNESS
Mulgarrar Sandstone	Mulgarrar Sandstone	Minningarra Subgroup	~100 m?
Kulele Limestone	Kulele Limestone		~300 m
Wongawol Formation	Wongawol Formation		~1500 m 
Princess Ranges Quartzite			~1000 m
Wandiwarra Formation			
Frere Formation	Frere Formation	Tooloo Subgroup	~1800 m 
Yelma Formation	Yelma Formation		<10 m in southeast to ~1500 m in west

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Figure 1. Revised stratigraphy of the Earraheedy Group, showing the position of iron-manganese mineralization (after Jones et al., 2000)

Iron-manganese mineralization in the Earraheedy Group

Iron-manganese mineralization in the Earraheedy Basin is present as structurally controlled quartz – iron oxide – manganese oxide veins hosted by steeply dipping shale units of the Karri Karri Member (Chiall Formation), and stratiform iron- and manganese-oxide bands interbedded with sandstone and siltstone of the Wongawol Formation. The distribution of these occurrences is shown in Figure 2.

The quartz – iron oxide – manganese oxide veins have easterly trends, a maximum strike length of about 100 m, and are 2 to 8 m thick. The stratiform iron-manganese oxides are spatially associated with layers of banded siliceous ironstone (jasper) and grey-green chert containing minor amounts of pyrite, chalcopyrite, and sphalerite (Bunting, 1986). The presence of sulfides suggests the establishment of temporary anoxic conditions in a

commonly oxic environment. The nature and composition of the iron and manganese oxides are not known, but it is possible that the main components are hematite and pyrolusite. The host sandstone typically contains detrital white mica, glauconite, and accessory tourmaline and zircon. The host sandstones have adhesion surfaces, symmetrical ripple marks, and small-scale cross-laminations, suggesting deposition in very shallow water and intermittently emergent conditions.

Table 1 presents chemical analyses of samples from the quartz – iron oxide – manganese oxide veins (samples GSWA 132416, 160809, 160810, and 160814) and the stratiform iron-manganese oxides (samples GSWA 160804, 160806, and 152798). These analyses show that, apart from manganese, the oxides are anomalous in copper (up to 1400 ppm), cobalt (up to 620 ppm), barium (up to 7800 ppm), and lead (up to 580 ppm). High barium values suggest the presence of barite,

whereas the high metal abundances (copper, cobalt, and lead) may be due to the fixing of these elements by the manganese oxides.

Glauconite in the Earraheedy Group

Glauconite is a micaceous mineral with the common formula $(K,Na,Ca)_{1.2-2.0}(Fe^{+3},Al,Fe^{+2},Mg)_4[Si_7AlO_{20}](OH)_{4.n}(H_2O)$. Glauconite is commonly deposited on shallow-marine continental shelves (at water depths of 50–500 m), and has a spatial association with iron and manganese formations (Kimberley, 1989; Ostwald and Bolton, 1992).

In the Earraheedy Group, glauconite is common at several stratigraphic levels and particularly well developed in sandstones of the Chiall and Wongawol Formations. In the sandstone units of these formations, glauconite forms pellets or peloids associated with clastic grains (Fig. 3). Locally, the glauconite pellets are deformed or

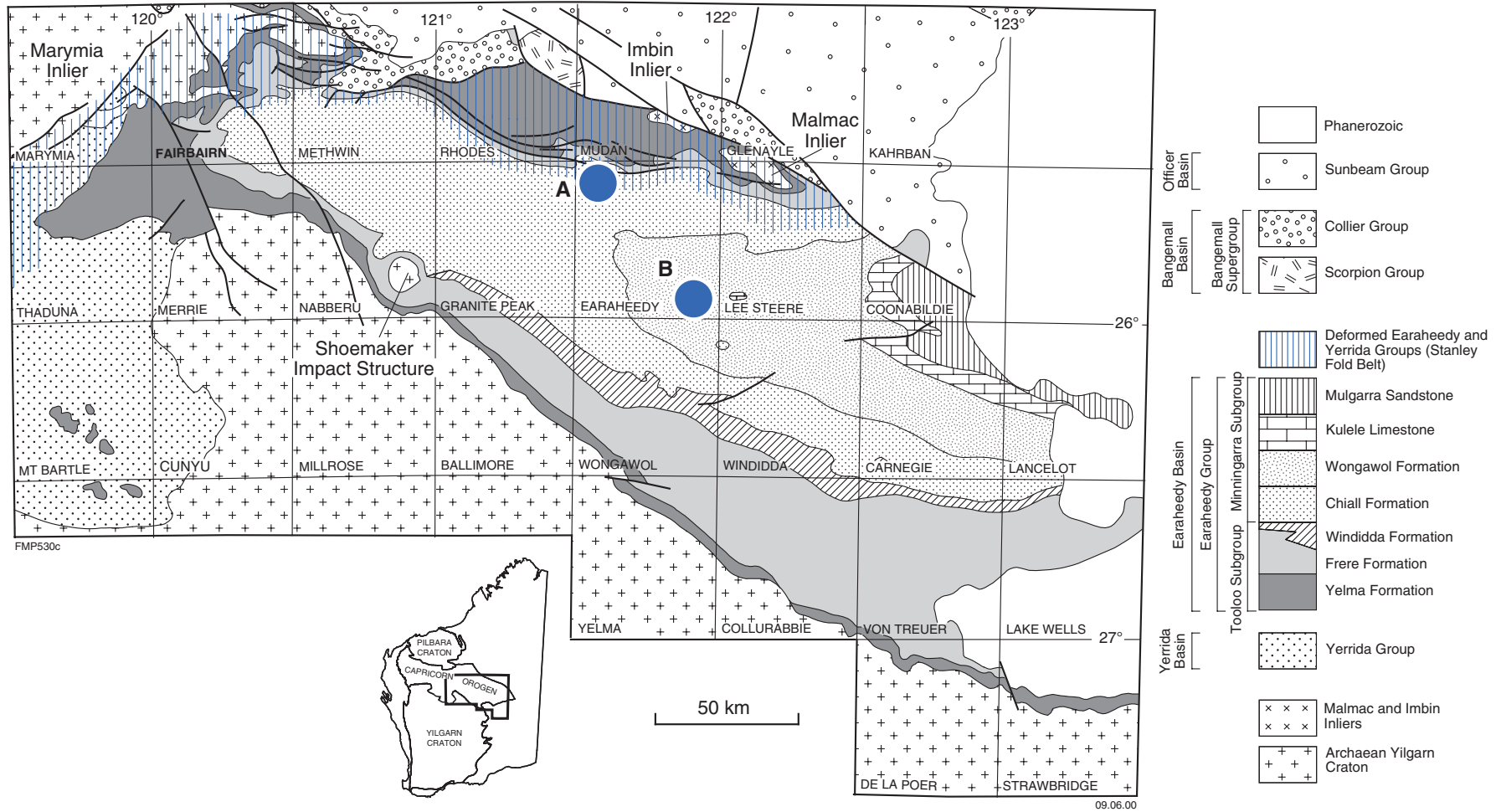


Figure 2 Simplified geological map of the Earraheedy Basin and location of manganese oxide occurrences. A indicates the area of structurally controlled quartz – iron oxide – manganese oxide, and B indicates the area of stratiform iron-manganese oxides. Capitalized names refer to standard 1:100 000 geological maps

Table 1. Analyses of manganeseiferous ironstones from the Earaheedy Basin

Elements	Detection limit	Method	GSWA 132416 ^(a) AMG 350174 ^(c)	GSWA 160809 ^(a) AMG 516677	GSWA 160810 ^(a) AMG 496693	GSWA 160814 ^(a) AMG 498718	GSWA 152798 ^(b) AMG 985306	GSWA 160804 ^(b) AMG 919244	GSWA 160806 ^(b) AMG 858255
Parts per million									
Ag	0.1	A/MS	0.1	0.2	0.3	0.5	0.2	0.3	0.3
As	0.1	A/MS	12	31	10	32	76	9	9
Au (ppb)	1	FA/MS	<1	3	<1	<1	4	x	2
Ba	0.1	A/MS	310	5 200	490	5 400	2 550	4 900	7 800
Bi	0.01	A/MS	0.15	0.14	0.28	0.27	0.03	7.8	10.4
Co	0.1	A/MS	72	265	140	620	3.8	23.5	45
Cr	2	A/OES	16	88	46	10	14	14	20
Cu	1	A/OES	116	1 400	98	98	46	340	320
Mo	0.1	A/MS	0.4	0.8	1.4	4.7	6.6	9.2	10.4
Ni	1	A/OES	15	82	60	145	13	13	23
Pb	2	A/MS	18	26	16	580	34	225	520
Pd (ppb)	1	FA/MS	na	1	x	2	2	1	2
Pt (ppb)	1	FA/MS	na	1	1	5	6	2	5
Sn	0.1	A/MS	0.7	0.8	1.4	1.2	0.3	1	1.2
Th	0.01	A/MS	na	3.4	6.6	5.4	35	6.6	9.8
U	0.1	A/MS	na	6	3.6	2.7	2.15	7.6	8.6
W	0.1	A/MS	0.8	5.6	3.6	0.8	0.5	6.8	4.2
Zn	1	A/OES	155	195	320	760	15	78	114
Mn (wt%)	1	A/OES	7.8	39	19.5	12.5	3	3	9.4
Fe (wt%)	0.01	A/OES	na	4.7	25.5	32	1.75	12.5	14.5

NOTES: (a): From the area of structurally controlled quartz – iron oxide – manganese oxide (see Figure 2)
 (b): From the area of stratiform iron–manganese oxides (see Figure 2)
 (c): Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on the EARAHEEDY 1:100 000 sheet (Adamides et al., 2000), to within 100 m

A/MS: Multi-acid digest including hydrofluoric, nitric, perchloric, and hydrochloric acids. Analysed by inductively coupled plasma mass spectrometry (ICP-MS)
 FA/MS: Lead collection fire assay using new pots. Analysed by ICP-MS
 A/OES: Multi-acid digest including hydrofluoric, nitric, perchloric, and hydrochloric acids. Analysed by inductively coupled plasma optical (atomic) emission spectrometry (ICP-OES)
 na: Not analysed
 x: Below detection limit

streaked out, or both (Bunting, 1986), perhaps indicating that they pseudomorphed mud clasts. Petrographically, the glauconite varies from colourless to light green or brown when weathered, or blue-green when fresh. Glauconite is commonly replaced by a mosaic of quartz grains, which are not in crystallographic continuity with the surrounding authigenic silica.

There is an association between glauconite and ferruginous sandstone, with alternations of glauconite-rich and ferruginous layers. Here, the peloids of the glauconite-rich layers are set in a black, fine-grained, probably manganeseiferous material.

Discussion and implications for base metal mineralization in the Earaheedy Basin

The presence of a thick succession of Lake Superior-type granular iron-

formations in the Earaheedy Basin (Goode et al., 1983), stratiform iron–manganese oxides, and glauconite-bearing sandstones suggests that deposition of these sediments occurred in a continental shelf environment.

Iron and manganese are geochemically similar and, in many instances, precipitated together, but separation can and does occur during precipitation from hydrothermal solutions, depending on Eh–pH environmental conditions. Almost complete separation of these two elements is known from the iron and manganese formation of the Transvaal Basin in South Africa (e.g. Klein and Beukes, 1992). Force and Cannon (1988) suggested that at low Eh, iron solubility is low due to the uptake of iron by sulfur ligands, precipitating sulfides. On the other hand, and under the same conditions, manganese solubility is high because there is no comparable

manganese sulfide (alabandite, MnS, is uncommon in sedimentary rocks; Force and Maynard, 1991). In oxic environments, iron and manganese also tend to precipitate separately, again in response to Eh and pH conditions, with iron oxides predominantly precipitating in deeper water (on the continental slope, at lower Eh for a given pH) and manganese oxides in shallower waters (on the continental shelf, at higher Eh for a given pH; Schissel and Aro, 1992).

Ostwald and Bolton (1992) found a genetic relationship between the glauconite-bearing sandstone and iron–manganese oxides. Glauconite tends to form in deeper offshore water, whereas manganese oxide precipitation occurs along palaeoshorelines. In addition, glauconite enhances the manganese content of the water because it removes iron from the system (Ostwald and Bolton, 1992). In other words, glauconite fixes iron in the clastic sediments, rather

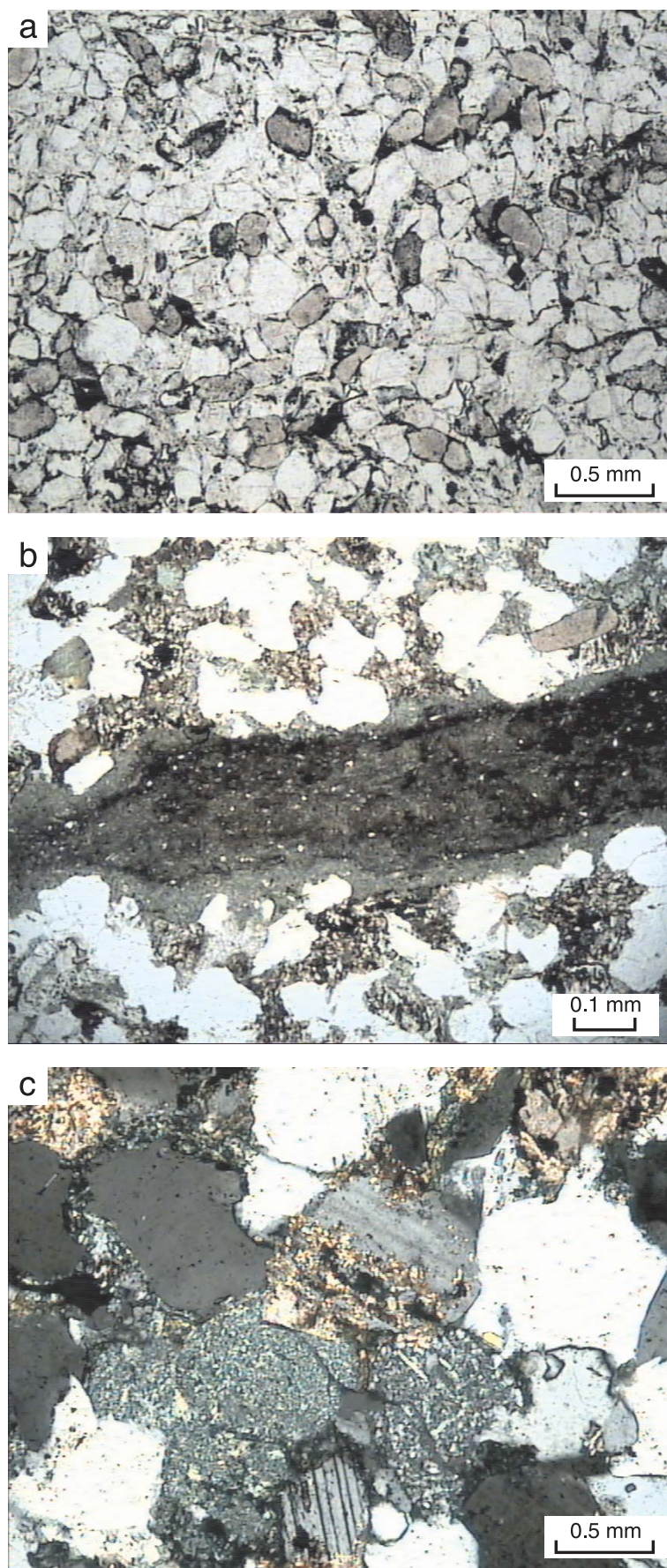


Figure 3. Modes of occurrence of glauconite in the Earaheedy Basin: a) clastic quartz, associated with abundant glauconite peloids, many of which are plastically deformed (sample GSWA 152758, crossed polars); b) mudstone clast marginally replaced by glauconite, enclosed in matrix consisting of clastic quartz, feldspar, and glauconite peloids (sample GSWA 160801, parallel polars); c) rounded glauconite peloid partially replaced by euhedral carbonate, which also replaces detrital albite (sample GSWA 160801, crossed polars)

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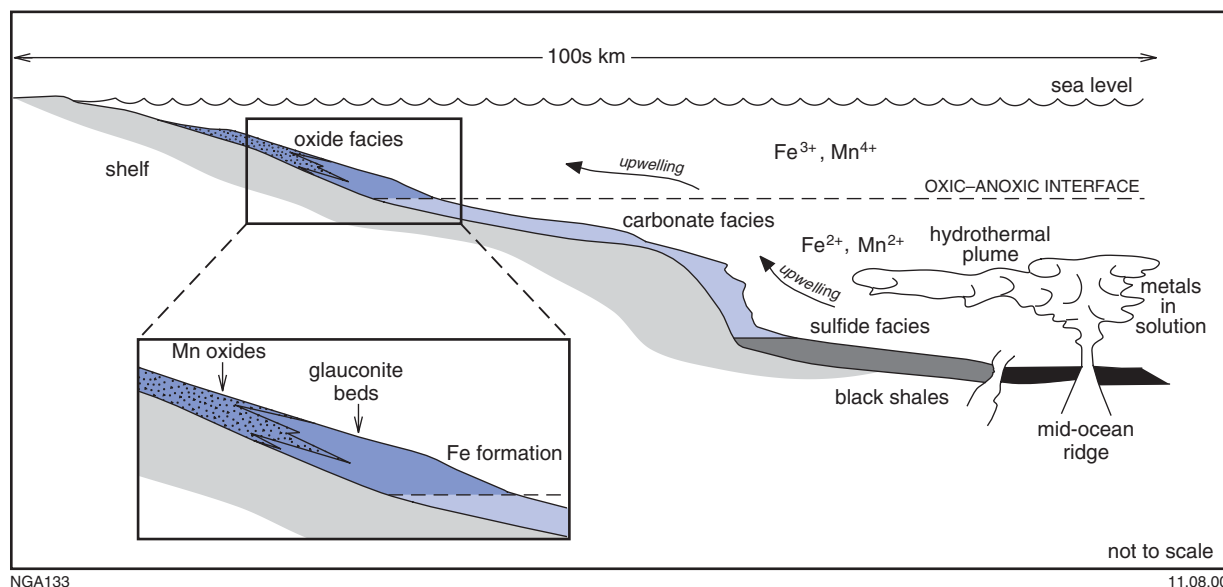


Figure 4 Depositional model of iron and manganese oxides on a continental shelf, and lateral equivalents as carbonate and sulfide facies in deeper settings (modified from Force and Cannon (1988) and Isley (1995))

similar to pyrite fixing iron in black shales. In this way, waters moving along the shelf are enriched in manganese, which is then precipitated as oxide. Anoxic conditions prevail basinward from the iron formation, iron-manganese oxides, and glauconite zones, resulting in deposition of black shales (e.g. Windidda Formation).

The origin of the vast amounts of iron and manganese required to form the observed iron and manganese formations in Proterozoic sedimentary basins is controversial, but a popular view is that subaqueous hot springs are the major source of these metals, as well as of other metals such as copper, cobalt, zinc, lead, gold, and silver (e.g. Isley, 1995). Upwelling currents transport iron and manganese in reduced form (Fe^{2+} and Mn^{2+}) from the discharge vents. Precipitation occurs just above the oxic-anoxic interface (Fig. 4), where Fe^{2+} and Mn^{2+} are oxidized to Fe^{3+} and Mn^{4+} , with separation constrained by the Eh-pH conditions mentioned above. An important facet of this model (Fig. 4) is that carbonate and sulfide facies (sulfidic shale) are the lateral and deeper water equivalents of iron- and manganese-oxide zones. Black shale-hosted sulfide deposits reported from China and Canada (Coveney et al., 1992)

formed along a transitional shelf zone, between a platform and deeper water setting. In addition, copper, lead, and zinc may exist in deltaic or lagoonal-facies sandstone, vertical or lateral to glauconite-bearing units. A similar situation is recorded from the eastern Atlantic passive continental margin of Africa, between Angola and Gabon, and in Morocco (Caia, 1976), where copper, lead, and zinc deposits are present at several localities in Lower Cretaceous sandstones.

Apart from the iron-manganese mineralization in restricted parts of the Earaheedy Basin, fringing areas of black-shale deposition, the structurally controlled quartz – iron oxide – manganese oxide are hosted by rocks of the Karri Karri Member (Windidda Formation), where they are deformed in the Stanley Fold

Belt. This suggests that tectonism led to the dewatering of the sedimentary succession and the localization of fluids along fractures and faults. If this is correct, then base metal sulfides and gold could be present in areas of the Stanley Fold Belt. This model is supported by auriferous quartz veins in mylonite zones in the Troy Creek area to the west (on the RHODES* 1:100 000 sheet; Pirajno and Hocking, 2000).

On the basis of the sedimentological character, tectonic setting, presence of iron-manganese oxides and glauconite, we suggest that the Earaheedy Basin is very prospective for stratabound sedimentary rock-hosted base metal sulfide deposits.

* Capitalized names refer to standard map sheets

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Barium–gold mineralization at Quadrio Lake, Oldham Inlier, Little Sandy Desert, Western Australia

by R. M. Hocking¹, F. Pirajno, S. Iizumi², and P. A. Morris

Abstract

Barite–hematite stockworks discovered near Quadrio Lake in the Oldham Inlier (northwestern Officer Basin) contain anomalous quantities of gold (up to 110 ppb), manganese, arsenic, and antimony. Regional geological and geophysical data suggest that this stockwork system may be part of a larger mineralized system. The mineralization is in the Quadrio Formation, a shale-dominated unit of probable Mesoproterozoic age in the Oldham Inlier, an unconformity-bounded inlier of older, deformed rocks surrounded by the virtually undeformed Officer Basin succession. This stockwork system resembles sedimentary exhalative-type deposits, where stratabound proximal sulfide and distal barite zones result from the uptake of hydrothermal fluids along fault structures. A sedimentary exhalative model is supported by Sr isotope ratios determined on samples of the Quadrio Lake barite.

KEYWORDS: Oldham Inlier, Quadrio Lake, Officer, Basin, barium, gold, sedimentary mineral deposits

Introduction

Barite–hematite veins with anomalous gold, arsenic, and antimony values extend over an area of at least 500 m by 2000 m along the south side of Quadrio Lake, near the northern end of the 'Trainor track', the access road for the GSWA Trainor 1 drillhole (Fig. 1). The locality is 400 km northeast of Wiluna in the Little Sandy Desert, in the southeastern part of the TRAINOR* 1:250 000 sheet (Williams, 1995). After the initial discovery (at MGA 465350E, 7282000N)[†], barite–hematite

stockworks were traced northwest for a further 2 km, although the mineralized area could be more extensive, as the reconnaissance visit did not attempt to determine the extent of mineralization. Hairline barite veins associated with carbonate alteration in Trainor 1 (Fig. 1; Stevens and Adamides, 1998), 10 km to the northeast, suggest a northward-waning extension of the mineralized area. In a regional context, barite is known elsewhere in the Bangemall Supergroup, adjacent to the northwest

Officer Basin (Fig. 1). The Quadrio Lake vein system is probably the first indication of sedimentary exhalative (sedex) style mineralization in this area.

Geology

Barite–hematite mineralization is hosted by rocks of the Oldham Inlier in the Savory region, a remote and poorly understood area (Fig. 1). The Oldham Inlier is overlain and overlapped by Neoproterozoic sedimentary rocks of the Sunbeam Group of the northwest Officer Basin (Fig. 1; Bagas et al., 1999). Rocks in the Oldham Inlier were previously mapped as one unit, the Cornelia Formation (Williams, 1990, 1995; Cornelia Sandstone of Brakel and Leech, 1980, and Muhling and Brakel, 1985). Recent reconnaissance work related to mapping on the NABBERU and STANLEY 1:250 000 sheets demonstrated the presence of three distinct lithologic units in the inlier (Table 1), and Hocking et al. (2000a) divided the Cornelia Sandstone into the Oldham Sandstone, the Quadrio Formation, and a redefined, more restricted Cornelia Sandstone. Barite–hematite mineralization is found in the Quadrio Formation. The ages of these units can only be inferred from regional correlations.

The Quadrio Formation is a dominantly fine grained shaly unit, with locally developed sandstone and chert intervals. Hocking et al. (2000b) extended the Quadrio Formation to the interval below 83 m in Trainor 1. However, a basal Phanerozoic age for the Trainor 1 interval (implied by U–Pb SHRIMP

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* Capitalized names refer to standard 1:250 000 sheets.

[†] Locations mentioned in the text are referenced using Map Grid of Australia (MGA) coordinates, Zone 51. All locations are quoted to the nearest 100 m.

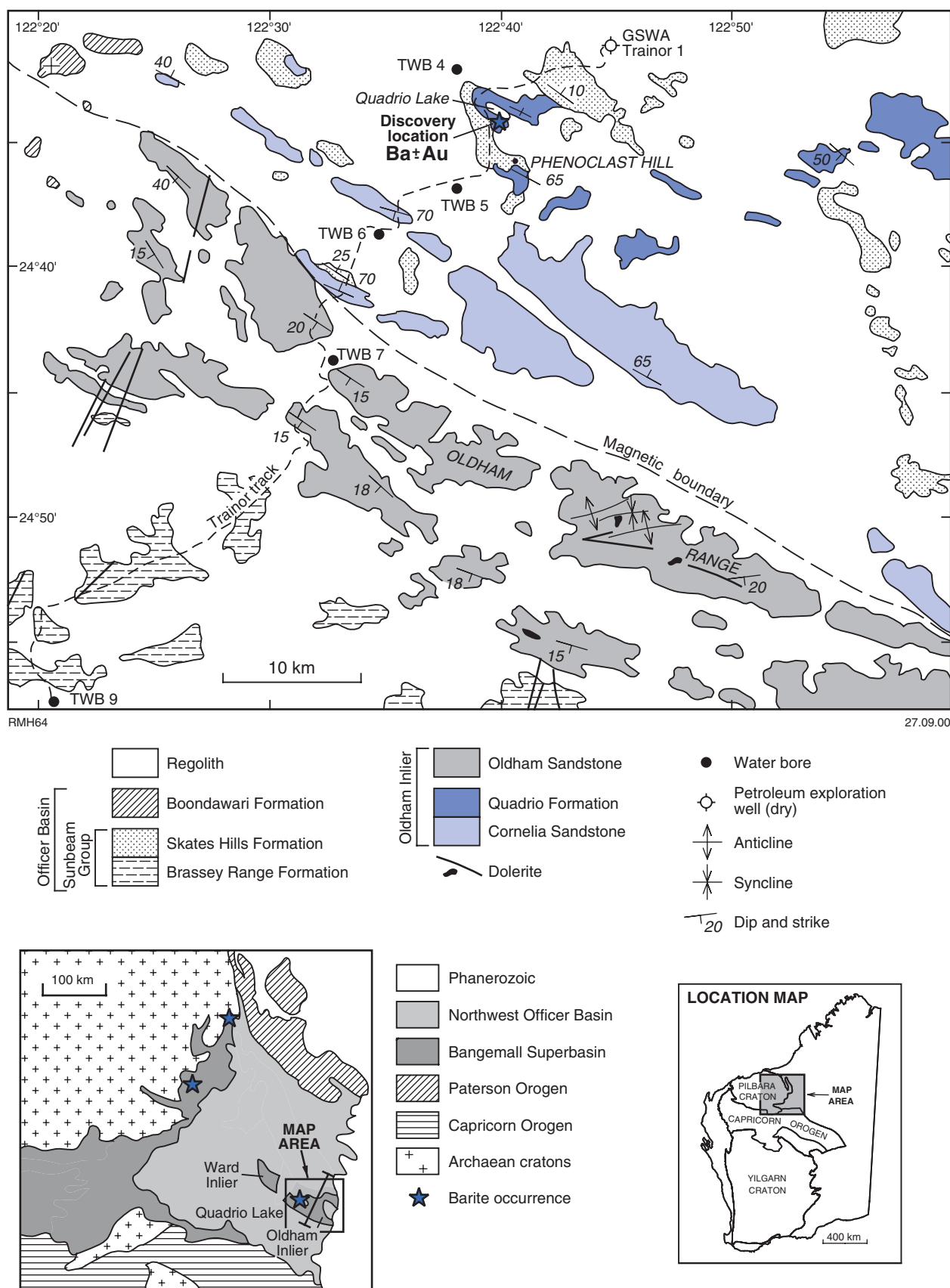


Figure 1. Geological map of the area around Quadrio Lake (based on Williams, 1995). Inset shows simplified geology of the northwestern Officer Basin (modified from Bagas et al., 1999)

Table 1. Stratigraphy of the Oldham Inlier

<i>Williams (1990, 1995), Muhling and Brakel (1985) stratigraphy</i>	<i>Hocking et al. (2000a,b) stratigraphy</i>	<i>Lithology</i>	<i>Age, correlation</i>
Cornelia Formation	Oldham Sandstone	Silicified sandstone; moderately dipping	?>1 – 1.2 Ga, ?Collier Group
	Quadrio Formation	Shale, minor sandstone; subvertical	?1.6 Ga, ?Edmund Group
	Cornelia Sandstone	Intensely silicified sandstone; steeply dipping	?1.6 Ga, ?Edmund Group

zircon ages of Nelson (1997)) is not accepted, as this would require an unreasonably complex structural model to be valid (Hocking et al., 2000b).

Both the Cornelia Sandstone and Quadrio Formation are steeply dipping, folded along west-northwest axes, and have a similar subdued magnetic character. In contrast, the Oldham Sandstone dips uniformly at about 20° southwest and has a more varied magnetic character. The Quadrio Formation and Cornelia Sandstone are tentatively considered to be of similar age, and the Oldham Sandstone is thought to be younger. The Cornelia Sandstone and Quadrio Formation probably correlate with the c. 1.6 Ga Edmund Group in the Bangemall Basin, 300 km to the west, but could also correlate with the ?c. 1.0 Ga Throssell Group, 150 km to the north (Hocking et al., 2000b). The Oldham Sandstone may correlate with the c. 1.2 Ga Collier Group in the Bangemall Basin.

There is a major change in magnetic character and structural orientation within the Oldham Inlier along the northern margin of the Oldham Range, about 15 km southwest of Quadrio Lake. This coincides with a fault northwest of the Trainor track, which marks the boundary between the Oldham and Cornelia Sandstones. Stratigraphic relationships suggest that it may be a south-directed reverse fault. No other major change in magnetic character is present between the fault and Trainor 1. On a gravity image (Geological Survey of Western Australia, 1996a), the Cornelia Sandstone occupies an intermediate 'terrace' (Hocking, 1994) between the higher density Oldham Sandstone to

the south and the lower density Quadrio Formation to the north. The first vertical derivative Bouguer gravity image (Geological Survey of Western Australia, 1996b) shows a well-defined, northwesterly trending ridge coincident with the northern side of the 'terrace'. One interpretation is that a fault separates the Quadrio Formation and Cornelia Sandstone, although none is apparent on aerial photographs. A local circular gravity low immediately south of Phenoclast Hill may represent a basement feature, or buried Mesoproterozoic-sourced salt diapirism.

Aeromagnetic imagery, Landsat/SPOT images, and mapping by

Williams (1995) of the Ward Inlier to the northwest (Fig. 1) show that its southern part appears to be Oldham Sandstone, and the northern third, Quadrio Formation. The Cornelia Sandstone may be present, but if so is less extensive than in the Oldham Inlier.

The barite-hematite vein system

The vein material is composed of barite and iron oxides (mostly hematite) that form a stockwork system trending at about 270°. The veins cut siliciclastic sedimentary rocks (mainly brown shale and siltstone), which have been



Figure 2. Barite-hematite vein system in outcrop (MGA 465350E, 7282000N)

Table 2. Selected trace element abundances of barite vein material

Sample no.	161270A	161270A (repeat)	161270B	161270C	Trainor 1 maxima
Parts per million ^(a)					
Au (ppb)	90^(b)	110	40	80	33
V	24	—	26	42	385
Mn	200	—	125	120	na
Ni	50	—	6	9	167
Cu	64	—	82	44	402
Zn	11	—	19	12	313
As	70	—	42	80	132
Mo	2.2	—	0.9	2.6	8.4
Ag	<0.1	—	<0.1	<0.1	0.86
Sn	<0.1	—	0.1	0.2	2.8
Sb	19.0	—	8.6	27.5	<0.1
Ba (%)	27.5	—	39.0	26.0	29
W	0.7	—	0.5	1.1	7.1
Pb	24	—	10	16	79

NOTES: (a) Unless otherwise indicated
(b) Abundances considered anomalous are shown in bold italics

Analyses performed by Genalysis, Perth
na not analysed

deformed into a local northwesterly plunging, upright anticline. The host rocks near the veins are silicified and contain multiple, silica-filled hairline fractures, indicative of hydraulic fracturing by high-pressure fluids. Scattered barite-

hematite veins, up to 30 cm across (Fig. 2), are present for at least 2 km to the northwest, along the margins of Quadrio Lake.

Core from the Trainor 1 drillhole, about 10 km northeast of Quadrio

Lake, contains thin barite-hematite veinlets, locally associated with pyrite, in hydrothermally altered dark-grey mudstone (Stevens and Adamides, 1998) lithologically similar to the Quadrio Formation. Hydrothermal alteration in the core predominantly consists of disseminated carbonate porphyroblasts. Maximum element abundances, using all analyses, are shown in Table 2.

Analyses of three random samples of barite-rich vein material are also shown in Table 2. These samples were taken randomly, from barite-rich material. In addition to barium, there are anomalous abundances of gold (up to 110 ppb), arsenic, and antimony.

Regional overview of stratigraphy, orogenies, and associated mineralizing events

In order to constrain an ore deposit model for the auriferous barite-hematite veins, the tectono-stratigraphic context of the region must be considered. Figure 3 shows a schematic southwest-

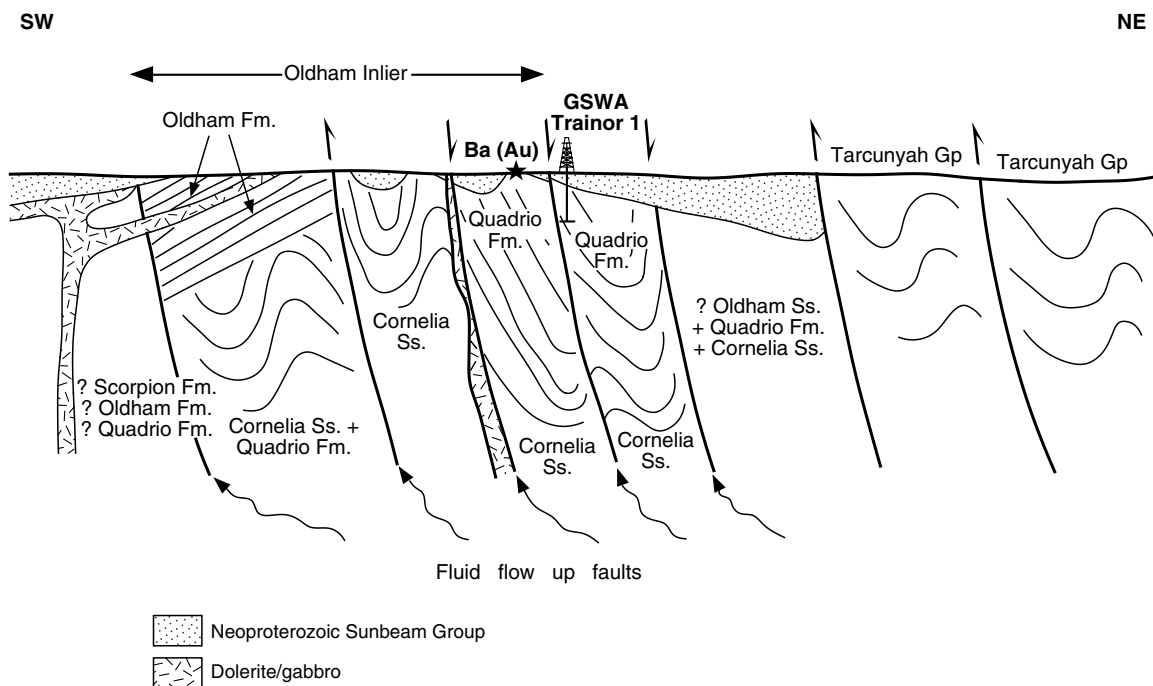


Figure 3. Schematic cross section, oriented north-northeast, across the Quadrio Lake area (not to scale; see Fig. 1 for position of section)

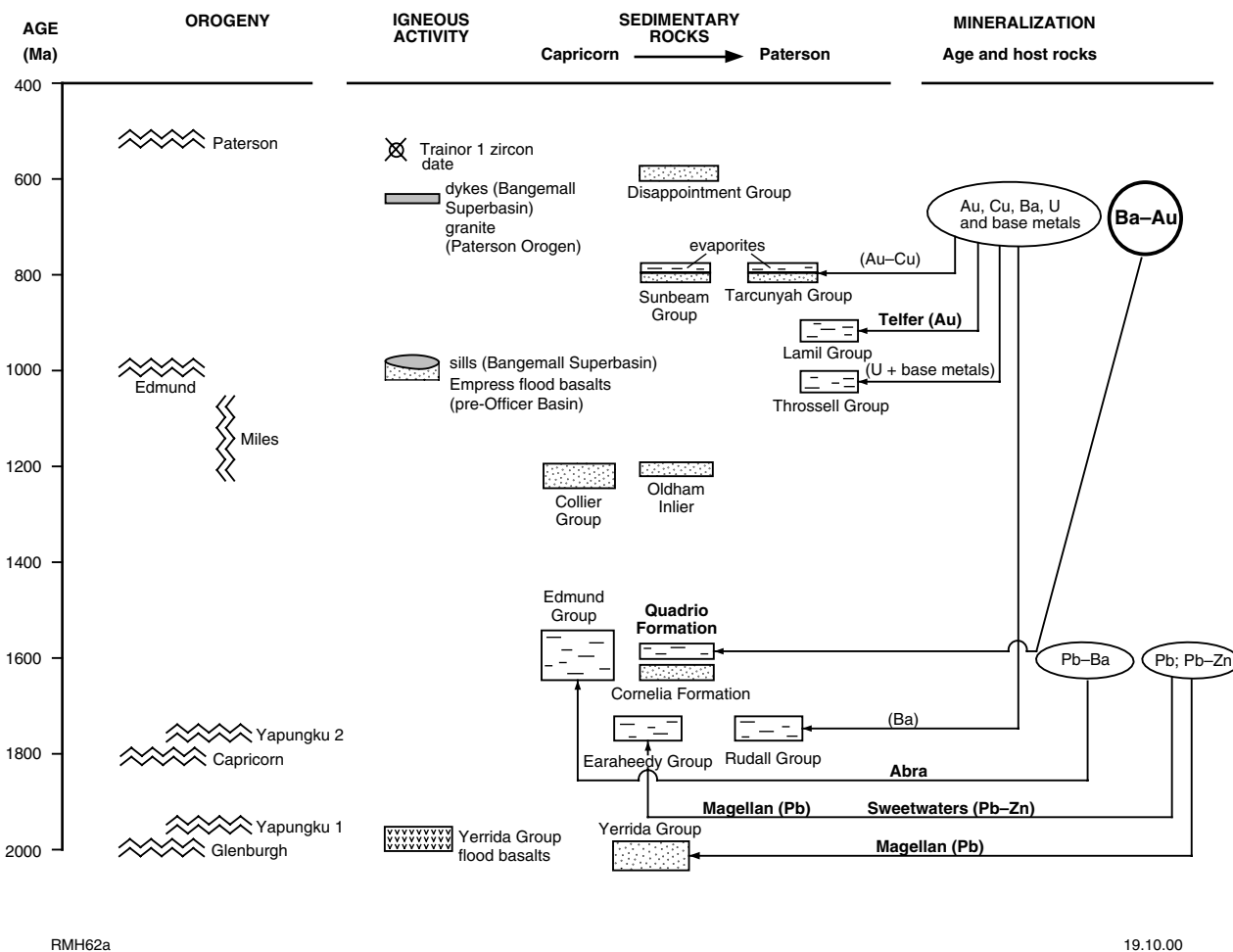


Figure 4. Chronostratigraphic correlation of Proterozoic orogenic, igneous, and mineralizing events

northeast section across the Quadrio Lake area, based on field observations, and aeromagnetic and gravity data. A series of faults that cut the folded rocks of the Oldham Inlier could have acted as conduits for mineralizing fluids.

The age of the barium mineralization (with or without gold) around Quadrio Lake is not known, but since this mineralization crosscuts deformed sedimentary rocks, it must be epigenetic. The ages of mineralizing events and orogenies in the region are shown in Figure 4. There are several groups of events, including the latest Palaeoproterozoic event (c. 1.65 Ga; e.g. Abra lead-barium, Sweetwaters lead-zinc, Magellan lead; Jones et al., 2000), and a much younger event at c. 700–600 Ma that is bracketed between the Miles and Paterson Orogenies (Tyler et al., 1998). The Telfer gold mineralization is

associated with this younger event (Rowins et al., 1997; Bagas and Lubieniecki, 2000). As the Quadrio Lake mineralization post-dates deformation of the Quadrio Formation, it is unlikely to be part of the older event (Fig. 4). Since there is no recorded mineralizing event between 1650 and 800 Ma, it is likely that the Quadrio Lake barite is part of the same event that produced the Telfer gold mineralization and other metalliferous occurrences in the Throssell and Lamil Groups (Fig. 4).

An ore deposit model

Barite deposits are commonly associated with either continental margins in foreland basins, or with intracratonic rifts (Maynard et al., 1995). The former forms barite-only deposits, with no associated lead-zinc deposits,

whereas the latter commonly represents a distal facies to stratiform lead and zinc deposits, such as those of Rammelsberg in Germany. Maynard et al. (1995) convincingly demonstrated that the use of Sr isotopes can discriminate between barite associated with stratiform–stratabound sulfide deposits in rift environments, and barren barite. They showed that $^{87}\text{Sr}/^{86}\text{Sr}$ values greater than 0.710 are only recorded from barite associated with sulfide deposits in intracratonic rift settings (e.g. Rammelsberg in Germany, Hilton in Australia). Strontium isotope ratios for the Quadrio Lake barite are presented in Table 3. Initial ratios have been calculated at 487 and 610 Ma. For both ages, $^{87}\text{Sr}/^{86}\text{Sr}$ values are greater than 0.710 and therefore we suggest that the Quadrio Lake barite belongs to an intracratonic environment. This is consistent with the recognized

Table 3. Sr isotope ratios

Sample	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2 \text{ SD}^{(a)}$	Rb (ppm)	Sr (ppm)	487 Ma	610 Ma
161270A	0.713844	0.000008	2.14	2 730	0.713824	0.713819
161270B-1	0.716063	0.000008	3.4	3 369	0.716043	0.716038
161270B-2	0.716067	0.000008	3.4	3 369	0.716047	0.716042

NOTES: (a) Standard deviation

Sr isotope analysis carried out at Shimane University, Matsue, Japan, following procedures discussed by Iizumi et al. (1994). Rb and Sr concentrations determined by ICP-MS at Genalysis Laboratory Services (Perth), following procedures discussed in Morris (2000)

intracratonic setting of the region since the Mesoproterozoic, and with the anoxic depositional setting implied by the host rocks (shale and siltstone). An anoxic depositional environment in parts of the host intracratonic basin is

conducive to the later deposition of sulfides.

The tectonic setting of the area (an intracontinental basin) is conducive to sedex deposits. A proposed ore deposit model is presented in

Figure 5, based on the sedex-style sulfide deposits described by Goodfellow et al. (1993). In our model, the mineralization can extend for hundreds of metres to tens of kilometres from feeder channels. The three main facies comprise a vent complex, proximal stratabound sulfide ore, and distal stratabound sulfate and oxide ore (Fig. 5). A halo of hydrothermal alteration (albite, chlorite, carbonate, and silica) surrounds the feeder channel. The sulfide, oxide, and sulfate mineralization replaced the pre-existing lithologies on a 'lit-par-lit' style.

The feeder channels are probably controlled by structural breaks, such as fault or shear zones. The major fault 15 km south of Quadrio Lake could be one of these structures. Alternatively, if the gravity 'terrace'

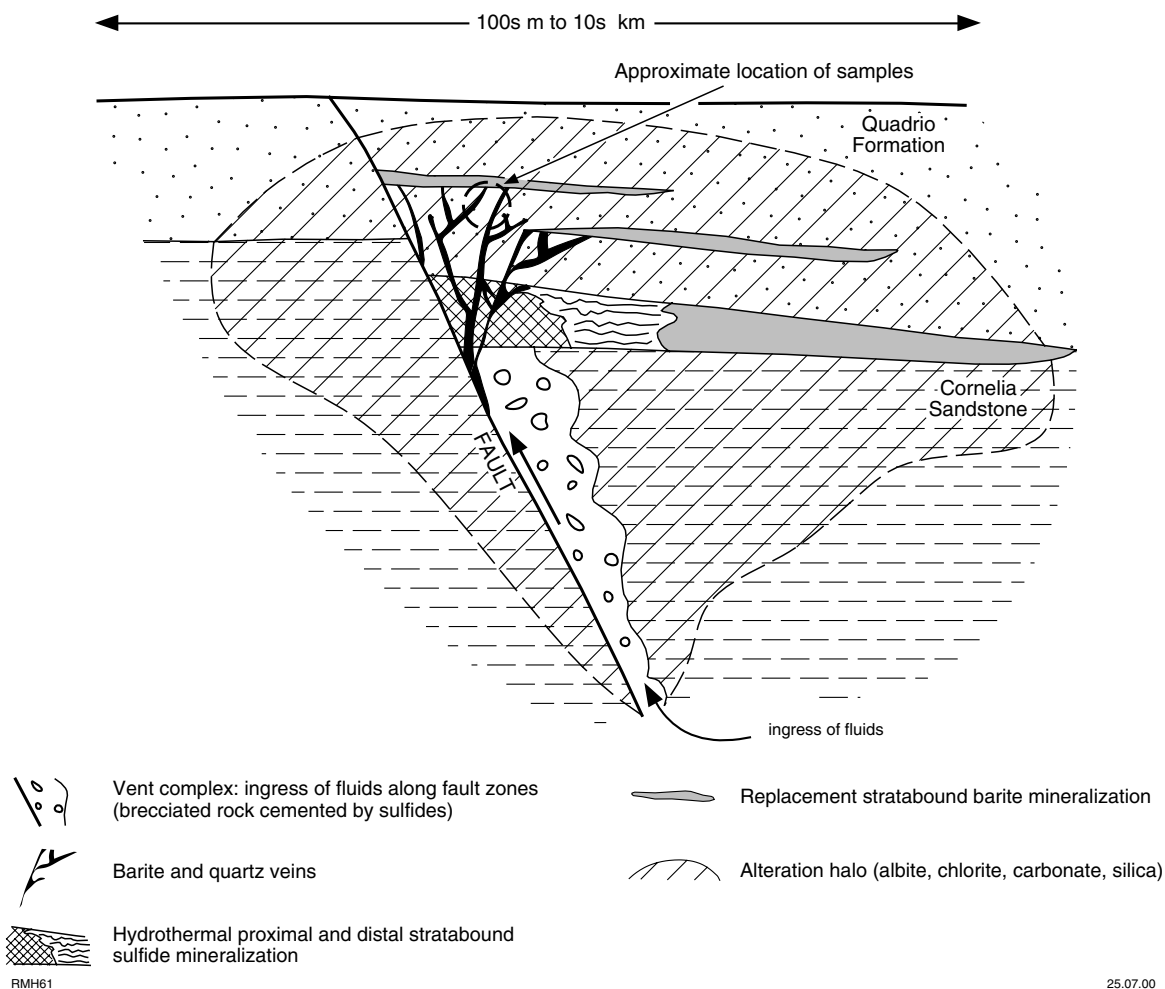


Figure 5. Ore deposit model, showing vent, replacement-style proximal sulfide, and distal oxide-sulfate facies

on which the Cornelia Sandstone lies is also a fault terrace, then the northern edge (immediately south of Phenoclast Hill) could be the controlling structure. A typical feeder channel is a vent complex, characterized by brecciated material cemented by sulfides. Sedimentary rocks lie above the feeder and form a stratabound–stratiform massive sulfide zone. In the general model, layers and stockworks of barite are present distal to the sulfide zone. The Quadrio Lake stockwork may be in this distal zone. It may be significant that silica alteration is present around the barite veins, whereas carbonate alteration is present in the barite–sulfide mineralization detected in the Trainor core (Stevens and Adamides, 1998).

The model is simplistic because of the poor knowledge of the geology, stratigraphy, and structure of the

region. Other possible models include a mineralized system centred on a buried intrusion, which is possible because of the gravity low immediately south of Phenoclast Hill. Such options can only be assessed when more is known about the geology of the Oldham Inlier and adjacent areas.

Further exploration should be directed towards sedimentary horizons that are indicative of an anoxic environment, particularly at their intersection with major structures.

Conclusions

The Quadrio Lake area and surrounding region has potential for sedex-type base metal mineralization. The discovery of barite with anomalous gold in the Oldham Inlier raises the

prospectivity of these other occurrences. The challenge for the explorationist is to be able to locate sulfide mineralization that may be linked to the barite–hematite vein system. The presence of anomalous amounts of gold, arsenic, and antimony in barite suggests that hydrothermal fluids carried gold and other metals in solution, which precipitated primarily in sites closer to the venting structures. The ‘spent’ solutions always carry trace amounts of the main solutes, which in this case probably included gold, arsenic, and antimony.

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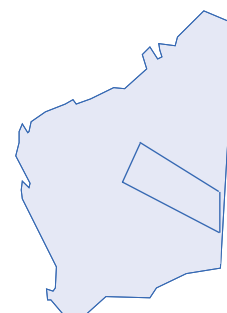
Program 3

Subprogram 3102

MINERAL AND PETROLEUM RESOURCE STUDIES

Interior Basins petroleum initiatives project

Objective: *To encourage the level of onshore oil and gas exploration in Western Australia by undertaking studies of its sedimentary basins and their hydrocarbon prospectivity. The onshore sedimentary basins of Western Australia, such as the Canning and Officer Basins, are considered by many geoscientists to be highly prospective for oil and gas, yet remain underexplored.*



Highlights and activities 1999–2000

The main activities during 1999–2000 were the compilation of the Yowalga and Lennis area prospectivity Reports, the Vines 1 well completion Record and compilation of data for other Reports in progress. These manuscripts contain details of significant improvements in the understanding of potential Neoproterozoic petroleum systems of the Officer Basin. Additional field-work in the Gibson area is underway and will contribute to future revisions of the RUNTON 1:250 000 geological map. Improved understanding of the stratigraphy of this remote region of the Officer Basin will also contribute to the selection of a drilling locality for a scheduled 2000 m stratigraphic test in the Gibson area of the Officer Basin.

Vines 1 (Fig. 1) was spudded on 4 July 1999 and reached a total depth of 2017.5 m on 28 August 1999. The drillhole was continuously cored from 44.5 to 2017.5 m. While coring at a depth of 1483 m, the analogue total-gas detection system indicated a 25-times background increase. The driller reported this gas show to the well-site geologist and the cored interval was recovered for inspection. Core over the interval of the gas show has no visible porosity,

but two fracture systems are present. The major fracture system is a subvertical set of fractures that are filled with calcite and other carbonate minerals. A second fracture system consists of syndepositional compaction features including faults and slumps. The well-site geologist reported that core from the interval of the gas show could be heard to degas overnight. Wireline logs did not indicate any significant hydrocarbons or porosity over the interval of the gas show, and no attempts were made to recover fluid from the well. Analysis of cores, cuttings, and logs from Vines 1 will provide new data for the reservoir, source rock, and biostratigraphic interpretation of the Officer Basin. These analyses are ongoing and publication of the results is planned for the 2001 calendar year. These data will be used, along with outcrop studies, for correlation with previous wells drilled in the basin, and to extend the depositional model for organic facies in the Officer Basin. This model will be applied to other areas of the Officer Basin in the search for additional stratigraphic coring locations that will prove the source facies for hydrocarbon generation, migration, and entrapment.

During 1999–2000, five papers authored or co-authored by the Interior Basins team were published or presented to conferences in

Australia and overseas. These papers were as follows:

- 'A sequence stratigraphic depositional model of Neoproterozoic strata, Yowalga area, Officer Basin, Western Australia', which was presented at the 2000 Australian Petroleum Production and Exploration Association (APPEA) Conference and published in the APPEA Journal
- 'Hydrocarbons of the Western Australian Officer Basin' which was presented at the 2000 Sprigg Symposium: Frontier Basins, Frontier Ideas, and the extended abstract was published in the Geological Society of Australia Abstracts
- 'A palaeomagnetic study of two deep drill-holes in the Officer Basin: no evidence for a high latitude position for Australia in the Neoproterozoic' was presented at the Nordic Palaeomagnetic Symposium and published in the conference proceedings
- 'Mid-Neoproterozoic biostratigraphy and isotope stratigraphy in Australia' was published in Precambrian Research
- 'Neoproterozoic glaciogene successions, western Officer Basin, Western Australia', was

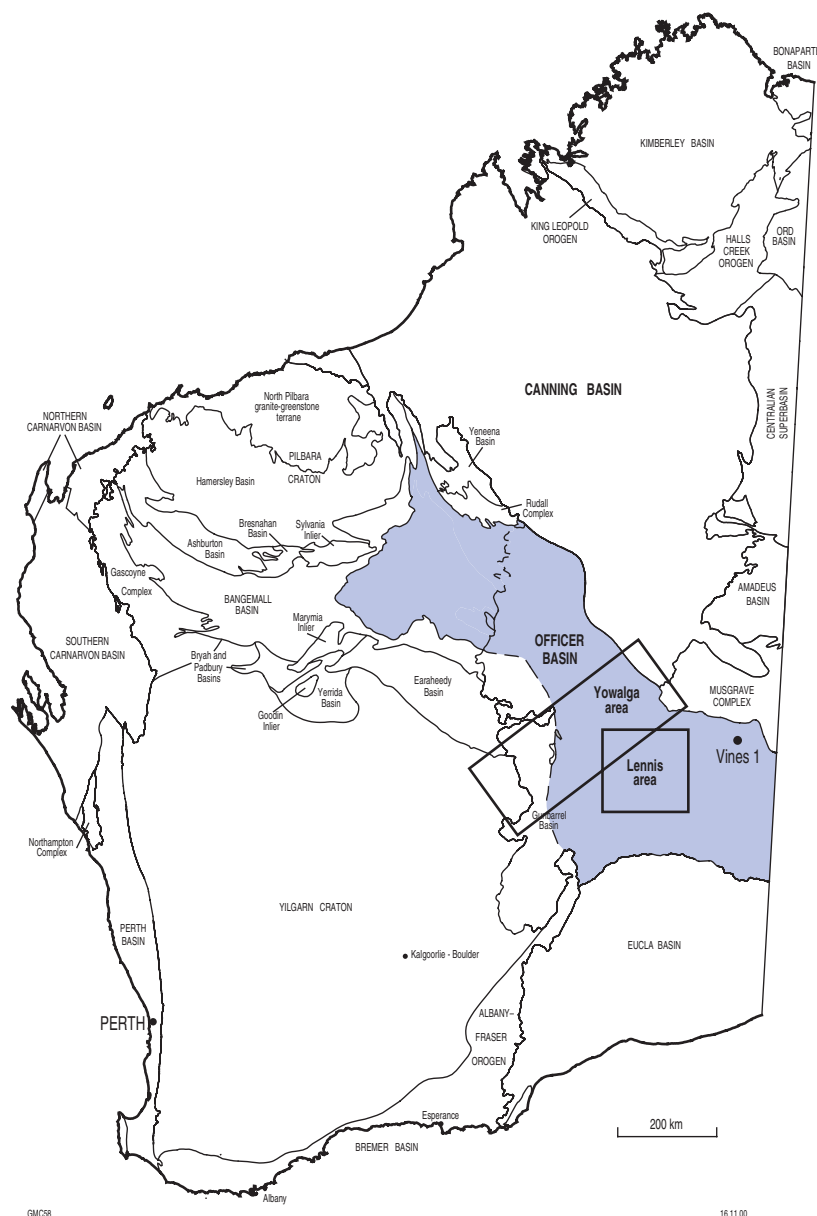


Figure 1. Location of the Interior Basins petroleum initiatives project

published in the GSWA Annual Review 1998–99.

1999–2000 publications and products

Report 76: 'Basin development and petroleum exploration potential of the Yowalga area, Officer Basin, Western Australia'.

Future work

A Report will be published on the basin development and exploration potential of the Lennis area.

Compilation of analytical data, core descriptions, and geophysical logs, together with preliminary interpretations will be published in the Vines 1 well completion report.

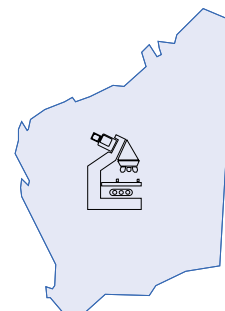
Following completion of fieldwork in the Gibson area, Reports on the exploration potential of the Gibson and Waigen areas will be published. Additional planned publications are: 'A review of the stratigraphy of the Officer Basin, Western Australia', and a Report on 'Hydrocarbons and petroleum systems of the Officer Basin, Western Australia'. In order

to promote the work of GSWA, and in particular the results of the petroleum initiatives project, external publications and presentations for the APPEA Conference and the American Association of Petroleum Geologists (AAPG) Conference are in preparation.

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Biostratigraphy and palaeontological services

Objective: *To provide biostratigraphic, palaeoenvironmental, palaeobiological, and palaeontological information that allows precise interpretation of correlations, age, environment, and processes in the evaluation of the State's hydrocarbon and mineral potential.*



Highlights and activities 1999–2000

Studies of c. 3.45 Ga Archaean stromatolites in the Warrawoona Group of the eastern Pilbara region (with Professor Hans Hofmann of Montreal and McGill Universities) generated huge international interest. Descriptions of the stromatolites were published in the Geological Society of America Bulletin in August 1999. The following month, a slab containing the 'egg-carton stromatolites' was presented to the Western Australian Museum for display in the new 'Diamonds to Dinosaurs' gallery. On the same day, the ABC television program Quantum featured the excursion organized by GSWA to allow international experts to examine the fossils *in situ* before they were collected. Detailed studies of the morphology, organic geochemistry, and microfossil potential are now underway, having been stimulated in part by the search for similar structures on Mars.

The discovery attracted wide coverage in both the Australian and international media. Pages describing the stromatolites and their implications were posted on the DME web site (www.dme.wa.gov.au/ancientfossils). A flood of requests for information followed the publicity and ranged from scientists wanting to carry out further investigations, to children preparing school projects. The 'egg-carton stromatolites' will feature again on television next year in a documentary series on the evolution of planet Earth being made by TVE (Spanish National Television).

Biostratigraphic correlation in the western Officer Basin (in support of the Interior Basins petroleum initiative program) remains the

principal focus of GSWA palaeontological studies, and involves the use of both stromatolites and palynomorphs. After the success of Empress 1 and 1A, which contained abundant palynomorphs, the Vines 1 drillcore was disappointing from a palaeontological viewpoint. Only a limited palynoflora is present, and much of it is reworked. No stromatolites were identified. However, comparison with samples from Nicholson 2, a drillhole in the South Australian part of the Officer Basin, suggests that most of the assemblage is a Sturtian equivalent.

Progress continued on other aspects of Precambrian biostratigraphy. Contributions were made to publications on the Yerrida and Earraheedy Basins, and the Ward and Oldham Inliers. A manuscript describing modifications to palynological preparation techniques to improve acritarch yields was completed.

The ongoing task of cataloguing and maintaining the fossil collection continued, with major effort being put into obtaining accurate map references for samples before they can be entered into GSWA's corporate database system. A start has been made by capturing sample data from Palaeontological Reports dating back to the 1960s. The stromatolite collection, containing more than 1000 samples, was reorganized and storage data upgraded. Work has started on the Phanerozoic non-type collection.

A wide range of information about fossils, biostratigraphy, and correlation was provided to both internal and external clients. Over 150 external requests for information required extensive information gathering. Requests most frequently relate to stromatolite identification,

biostratigraphic dating of Proterozoic successions, loans of fossil material, and access to various fossil localities. Information was also requested about diatoms, acritarch preparation techniques, stromatolites as tourist souvenirs and their role in ecotourism, stromatolite characteristics that can be recognized by remote sensing, atmospheric oxygenation through microbial activity, Neoproterozoic glaciations and the 'Snowball Earth' hypothesis, and precipitation textures in the late Archaean. Parts of the collection were made available for examination or sampling by visitors from both Australia and overseas.

Output this year was either as publications, or in the form of data used by other geologists in preparing their products. Four conference presentations (on Neoproterozoic palaeomagnetism, Mesoproterozoic and Neoproterozoic stratigraphic revisions, Warrawoona Group stromatolites, and Officer Basin petroleum potential) contained input from the Biostratigraphy and palaeontological services section. Altogether nine papers or publications containing significant contributions from the section were published, a further four are in press, and three are in an advanced stage of preparation. These included:

- Report 57: 'Geology and petroleum exploration potential of the central and southern Perth Basin'
- a reappraisal of Neoproterozoic successions in the northwestern Officer Basin (in the GSWA Annual Review for 1998–99)
- Neoproterozoic glaciogenic successions of the Officer Basin (in the GSWA Annual Review for 1998–99)

- the origin of 3.45 Ga stromatolites from the Warrawoona Group (in Bulletin of the Geological Society of America)
- evaporite–stromatolite associations in the c. 2.3 Ga old Bubble Well Formation of the Yerrida Group (in Geology)
- a palaeomagnetic study of Empress 1 and 1A and Trainor 1, Officer Basin, and their significance for palaeolatitude (in Proceedings of the Nordic Palaeomagnetic Symposium, Aarhus Geoscience)
- mid-Neoproterozoic biostratigraphy and isotope stratigraphy in Australia (in Precambrian Research)
- Ediacarian sedimentology and hydrocarbon biomarkers in the Ungoolya Group of the Officer Basin, Australia (in Precambrian Research).

1999–2000 publications and products

Record 1999/10: 'A modified palynological preparation technique for the extraction of large Neoproterozoic acanthomorph acritarchs and other acid-insoluble microfossils';

Index to and scanned images of internal Palaeontological Reports issued between 1962 and 1996 (issued on CD).

Future work

The main emphasis in 2000–01 will be on the completion of a lithostratigraphic revision of the western Officer Basin, a monograph on Neoproterozoic stromatolite biostratigraphy, and a report on the palynology of Vines 1. Capture of data for PALAEOBASE will also have a high priority.

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Western Margin petroleum initiative project

Objective: To encourage and orient petroleum exploration of the onshore Carnarvon and Perth Basins with the production of original geoscientific reports on the hydrocarbon potential of those areas by integrating newly acquired GSWA data and industry open-file data.

Highlights and activities 1999–2000

The main activities during the year were the preparation of reports and external papers on the Southern Carnarvon Basin and the Peedamullah Shelf (Fig. 2). Continued studies of the Woodleigh impact structure were mostly analytical and petrological in nature.

A number of significant products were released as publications during the year. Papers published this year were on reservoir quality in the Merlinleigh Sub-basin (AAPG), and the Woodleigh structure (Earth and Planetary Science Letters). A paper with AGSO on probable biogenic gas within the Peedamullah Shelf is being completed for the PESA Journal.

The review of offshore petroleum exploration wells in the Abrolhos

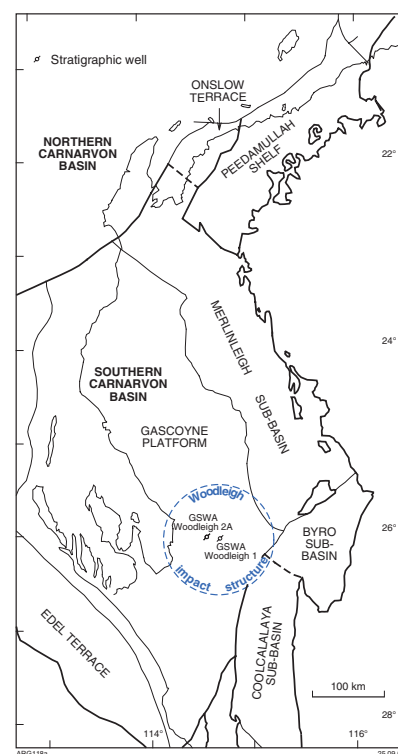
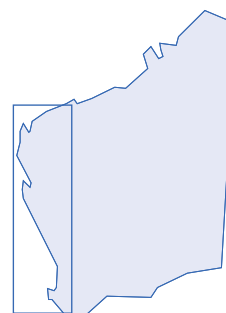
Sub-basin completed in 1999 is to be released next financial year as a Report. This study is centred on post-mortems of the nine wells in the region.

Promotional booths containing displays of major products from the Western Margin and Interior Basins project teams were prepared for the 2000 APPEA Conference (Brisbane), GSWA 2000 open day, and the 2000 AAPG Conference (New Orleans).

1999–2000 publications and products

Report 57: 'Geology and petroleum potential of the central and southern Perth Basin'.

Figure 2. The northern part of the Western Margin petroleum initiatives project area, showing the location of the Woodleigh structure



Future work

A Report on the petroleum geology of the Peedamullah Shelf and a Record on the Southern Carnarvon Basin will be released.

Due for completion in 2000–01 are reports and papers on the Woodleigh structure, prospects and leads in the northern onshore Perth Basin, and the hydrocarbon potential of the Coolcalalaya

Sub-basin. Work on a Bulletin on the evolution and petroleum potential of the Southern Carnarvon Basin, synthesizing previously published GSWA reports and some new regional interpretations of offshore data, is to commence early in 2001. A number of external papers on the Woodleigh structure and the Lower Permian of the Carnarvon Basin are planned to highlight the potential of the region.

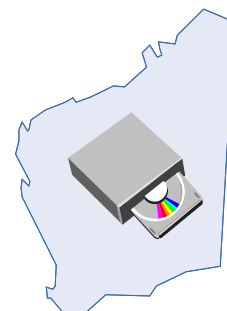
New data to be acquired during 2000–01 will be analyses of existing core, mainly from Woodleigh 1 and 2A, and deepening of Water and Rivers Commission artesian bores along the coast in the Southern Carnarvon Basin.

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Resource assessment and geoscientific advice

Resource studies and MINEDEX database

Objectives: To maintain a detailed inventory of the State's identified mineral resources, monitor mining and exploration activities, and provide advice on mineral resources, mineral exploration, and potential for mine development. To promote development of industrial minerals in Western Australia by the systematic documentation of industrial mineral occurrences and production of reports on industrial mineral commodities, and to provide advice concerning industrial mineral resources to industry, government, and the public. All these functions are supported through MINEDEX, the Department's mines and mineral deposits information database.



Highlights and activities 1999–2000

In 1999–2000, ongoing data capture into DME's mines and mineral deposits information (MINEDEX) database formed a significant part of the function of this section, together with advice to a wide range of customers. MINESTAT, the production module of MINEDEX, was implemented, with inclusion of substantial historical production. An updated non-confidential digital dataset from MINEDEX, including information on mineral resources and mine locations, commodities, ownership, and development status, was released to the public to accompany Record 2000/13. The coverage of historic mine sites is far more extensive than previous data extracts from MINEDEX and, for the first time, historic (pre-1985) gold production data are available in digital format. The released data contain selected information on 17 561 sites (about 6000 previously).

This supplements the 'Western Australia atlas of mineral deposits and petroleum fields 1999', which is one of the most popular publications of the Geological Survey of Western Australia.

A position paper overviewing exploration and development in Western Australia during 1998–99 was prepared, and the updated map 'Iron ore deposits of the Pilbara region' was released. Quarterly updates of mineral exploration activity in Western Australia were produced during the year. Mineral exploration (excluding petroleum) has been steadily declining in Australia and Western Australia since the record highs in mid-1997. Exploration activity (generally) is now 25% lower than for one year previously, and 43% lower than for the peak activity of 1996–97. Gold exploration expenditure in Western Australia has suffered the most, with a 30% decline during the last year and a 57% decline over the last

three years. Gold exploration activity is now at levels last experienced in 1993.

MINEDEX is also used as an inventory of mineral resources. Gold resources (measured and indicated) increased for the seventh year in succession, despite continued high levels of production. Recent discoveries of major deposits such as Coyote, Thunderbox, and Belleisle (St Ives) and a move to near-mine exploration suggest that gold resources may increase further next year, despite the recent severe cutbacks in exploration. However, the drop in gold exploration, particularly in areas away from existing mines, is a concern for longer-term maintenance of current gold resources.

The boom in nickel exploration during the last five years is now reflected in the sustained dramatic increase in the measured and indicated resources during the last

four years — with resources increasing from only 7.70 Mt of contained nickel in 1994 to 20.23 Mt at the end of 1999. Most of the increase has been in resources of lateritic nickel deposits. Resources of diamonds have remained steady after a large upgrade of resources in March 1999, rather than any new discoveries. Bauxite resources remain unchanged. Resources of high-grade iron ore have declined slightly for the second year in succession.

A report on the geology and mineral resources of the Mid West region was completed and will be released as Record 2000/14 early next financial year. The report formed part of the joint Federal–State–industry regional minerals study looking at possible development and infrastructure scenarios within the region for the next ten years. Another report, on the Southern Cross – Esperance region, was prepared for the Department of Resources Development. A similar report on the Gascoyne region (Record 2000/7) was prepared as part of the Gascoyne–Murchison Strategy, which is a five-year, \$45 million, rural development and adjustment initiative operating in the Gascoyne–Murchison pastoral rangelands. All

reports were accompanied by new solid geology interpretations at 1:500 000 scale (plotted at 1:1 000 000 scale).

For industrial minerals, the main projects completed during 1999–2000 included preparation of one draft Mineral Resources Bulletin, one Record, and one miscellaneous publication, as well as contributing to the regional minerals studies (Gascoyne, Mid West, and Southern Cross – Esperance). A summary paper of recent developments and highlights, 'Industrial minerals in Western Australia: the situation in 2000', was prepared and released as Record 2000/3.

Greater recognition of the industrial mineral potential of Western Australia was achieved with an international conference on industrial minerals held in Perth where several papers were presented by GSWA. International publicity of limestone and lime sand resources of Western Australia was achieved with publication of an article in *Industrial Minerals* magazine.

Geological investigations on speciality clays and common clays

(attapulgitite, bentonite–saponite, and brick–tile clays) in Western Australia were completed during 1999–2000 and a draft Mineral Resources Bulletin prepared. Fieldwork commenced on the next project in this series, that is, on high-grade silica and silica sand resources of Western Australia.

1999–2000 publications and products

Record 2000/3: 'Industrial minerals in Western Australia: the situation in 2000';

Record 2000/7: 'Geology and mineral resources of the Gascoyne Region';

Record 2000/13: 'Mines and mineral deposits of Western Australia: digital extract from MINEDEX – an explanatory note';

Iron ore deposits of the Pilbara region (1:500 000).

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Geoscientific advice relating to exploration

Objectives: *To monitor and assess exploration performance on mineral tenements and provide geological advice needed for the administration of, and proposed changes to, the Mining Act and Offshore Minerals Act.*



Highlights and activities 1999–2000

Most mineral tenements are held for exploration or prospecting rather than productive mining. Advice on these exploration activities, as gauged from statutory mineral exploration reports and discussions with tenement operators, assists the Department to administer tenements in an efficient and equitable manner, and to ensure that the State is effectively explored.

Exploration performance on 1446 mineral tenements (Table 1) was

reviewed during 1999–2000 (773 in 1998–99) as part of the assessment of applications for exemption from expenditure conditions, applications for extension of term of exploration licences, applications for retention licences, applications for special prospecting licences, and applications for Ministerial consent to dealings in exploration licences during their first year of tenure.

The number of applications for exemption from expenditure received by the Department has increased by about 7% to 5883 during 1999–2000, but referral of

such applications to the Geological Survey for geological advice has increased to 22% of the total applications (from about 14% in 1998–99). This is mainly due to two reasons: a relative increase in applications under Section 102(2)(e) and (f) (i.e., that the tenement contains a deposit that is currently subeconomic, or contains ore required for future operations), and secondly that more exemption applications are being recommended for refusal. The latter results in the lodgment of submissions that often contain work programs requiring assessment. The

Table 1. Tenement reviews

Geological advice provided	Number of tenements				
	1995–96	1996–97	1997–98	1998–99	1999–2000
Expenditure exemption	3 004	458	821	580	1 287
Extension of term of Exploration Licences	353	186	27	48	82
Dealings in first-year Exploration Licences	36	58	21	27	7
Iron-ore authorization (Exploration Licences)	na	6	13	9	22
Iron-ore drop offs (Exploration Licences)	na	13	10	27	22
Retention Licence applications	na	na	5	3	3
Special Prospecting Licence applications	na	na	11	14	1
Other	na	na	48	65	22
Total	3 393	721	956	773	1 446

NOTE: na = not available

number of exemption applications refused has increased to 7% of the total in 1999–2000 (3% in 1998–99).

The increase in referrals of applications for extension of term for exploration licences is due to

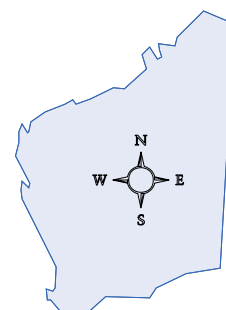
more applications being received where previous conditions of the licences were not met. In these cases, extensions of term may still be granted if reasons acceptable under Regulation 23AB can be demonstrated (i.e. significant

mineralization has been discovered, or new geological concepts are being applied).

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Regional mineralization mapping

Objectives: To enhance perceived prospectivity for precious metals, base metals, ferro-alloys, and diamonds, and to encourage mineral exploration within the State, particularly in areas where there has been limited sustained exploration activity, by undertaking studies that synthesize and integrate open-file statutory data with existing geological, mineral occurrence, geophysical, geochemical, and remote-sensing data. Products of this work are data packages comprising hard-copy reports and maps, together with GIS-compatible databases on CD-ROMs.



Highlights and activities 1999–2000

During the year, two data packages were published (one on the west Pilbara and the other on the east Kimberley). Compilation of databases and digitizing of spatial data continued for the east Pilbara. Work commenced on updating CD-ROMs of three earlier projects (Bangemall, southwest Western Australia, and the north Eastern Goldfields) using data from the latest WAMEX releases since 1998 (Fig. 3).

Each data package contains a Report that synthesizes information on the

mineral prospectivity of an area, a CD, and a 1:500 000 map that shows mineral occurrences, mineralization styles, commodity groups, and geology. The CD-ROM in each package contains the following datasets available in Arc Explorer format: WAMIN (spatial and attribute database of mineral occurrences); EXACT (spatial and attribute database of mineral exploration activities); MINEDEX (extract of the Departmental database with mine sites and mineral resources); TENGRAPH (extract of the Departmental database with mining tenements and holders);

geology (solid and regolith); Landsat images; aeromagnetic data; radiometric data; gravity data; and topographic and cultural features.

1999–2000 publications and products

Report 70: 'Mineral occurrences and exploration potential of the west Pilbara';

Report 74: 'Mineral occurrences and exploration potential of the east Kimberley'.

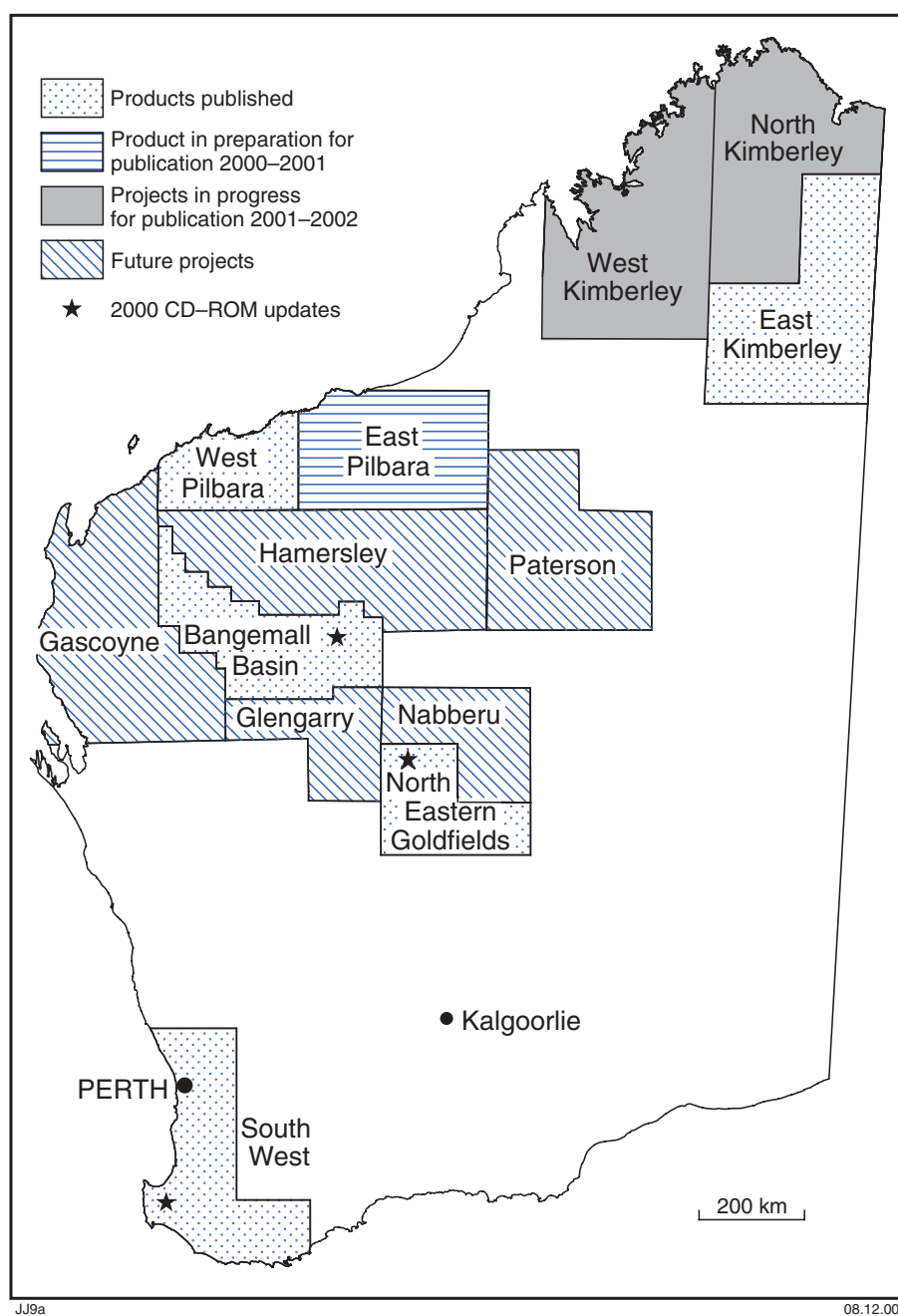


Figure 3. Progress of regional mineralization mapping projects

Future work

The data package for the east Pilbara area (in the form of a Report, a CD, and map) is planned for release in mid-2001. Compilation and digitizing of spatial data will continue for mineral occurrences and mineral exploration activities for the west and north Kimberley areas, and it is planned to release

data packages for these two areas during 2001–02.

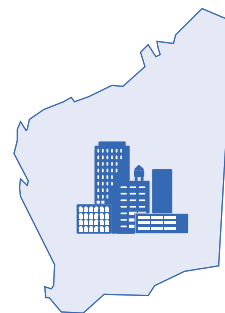
Compilation and digitizing of additional spatial data will be completed for updates of mineral occurrences and mineral exploration activities for three areas: the Bangemall, the southwestern region of Western Australia, and the north Eastern Goldfields. The

new digital data will be released on three updated CD-ROMs in the second half of 2000–01.

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Urban and development areas geological mapping

Objectives: To undertake detailed geological mapping and resource delineation in areas of the State that are likely to see significant development, and in which landuse planning would benefit from the availability of digital and hard-copy geoscience datasets. Also to provide high-quality and timely information and advice to Government, industry, and the general public on the regolith, landforms, mineral occurrences and resources, solid geology, and geohazards, both onshore and in shallow near-shore areas.



Highlights and activities 1999–2000

The project commenced in 1998, and field mapping has been completed for the GERALDTON, HOWATHARRA, and COWARAMUP 1:50 000 map sheets (Fig. 4). Consultation continued with the local shires, Government Departments such as CALM and AgWest, and with other potential map users such as primary producers and land developers. The regolith–landform mapping system was combined with an appraisal of potential for extracting basic raw materials to form the basis of the published maps and reports.

Mapping involved the systematic collection of surface and near-surface material properties, and landform properties and patterns. Field data were added to the WAROX database, which continued to be tested in both the field and office. Map compilation in the field used 1-m resolution orthophotographs, resulting in significant improvements to spatial integrity. ArcView GIS software was used by the mapping geologists as the primary map-compilation tool, and the process of digital compilation was continually refined through the year.

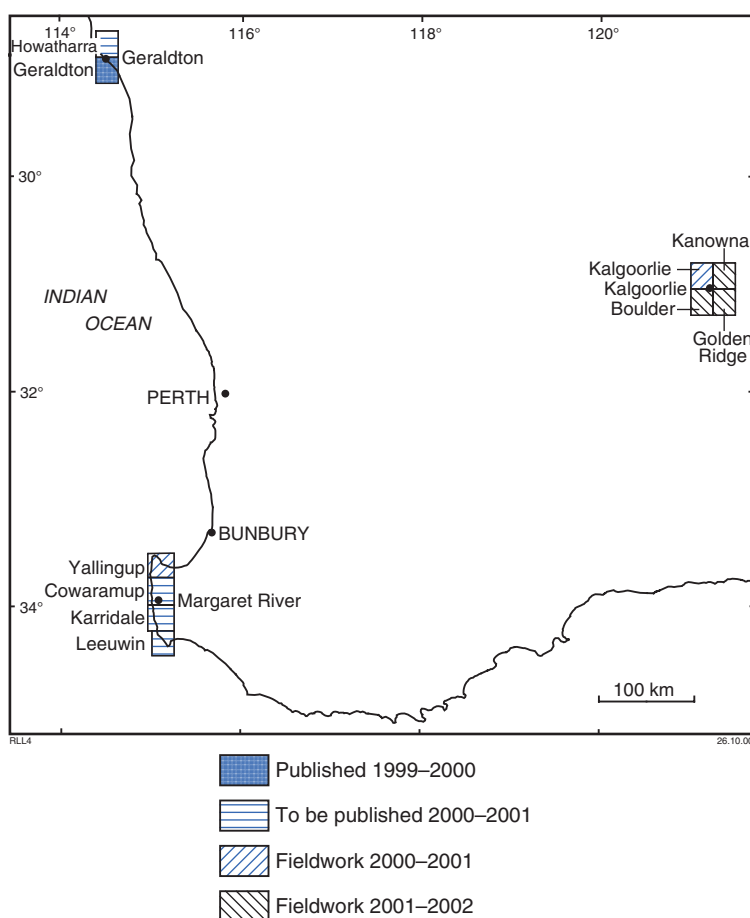


Figure 4. Progress of urban and development areas geological mapping

1999–2000 publications and products

Record 2000/17: 'Regolith–landform resources of the Geraldton 1:50 000 sheet' (including map and CD-ROM).

Future work

Now that the form of the new product has been established, work will continue on publications for

COWARAMUP and HOWATHARRA. KARRIDALE and LEEUWIN will also be published in 2000–01 following completion of fieldwork. Digital remastering and revisionary fieldwork will be completed on YALLINGUP in early 2001, resulting in completion of a Cape-to-Cape dataset for this part of the South West Region.

An orientation survey is planned for the Kalgoorlie area in late 2000, and

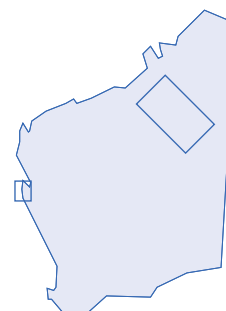
systematic mapping is scheduled to begin in early 2001. High priority will be given to fieldwork for KALGOORLIE, followed by the BOULDER, KANOWNA, and GOLDEN RIDGE 1:50 000 sheets.

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Subprogram 3103 REGIONAL GEOSCIENCE MAPPING

Lennard Shelf and Shark Bay project

Objectives: To prepare comprehensive accounts and maps of the Devonian reef complexes of the northern Canning Basin and their associated terrigenous clastic deposits and of the geology and mineral resources of the Shark Bay World Heritage Area.



Highlights and activities 1999–2000

Mapping and section measuring in the Devonian outcrop belt of the Lennard Shelf, with associated biostratigraphic, sedimentological, and subsurface studies, has been in progress for the present project since 1992, the objective being to increase geological understanding of the Devonian reefal succession and the associated terrigenous conglomerates.

The Devonian rocks are regarded as highly prospective for both

zinc–lead mineralization and petroleum. The reef complexes form one of the classic features of world geology, and the results of the project will be of widespread interest to geoscientists and the general public.

1999–2000 publications and products

Report 58: 'Subsurface facies analysis of Devonian reef complexes, Lennard Shelf, Canning Basin, Western Australia'.

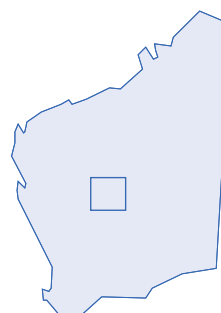
Future work

A manuscript on exhalative mineralization associated with stromatolites will be completed shortly, and work will continue on the preparation of other papers and a Bulletin dealing with the geology of the reef complexes.

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Glengarry project (Bryah, Padbury, and Yerrida Basins)

Objective: To increase geoscientific knowledge of the Bryah, Padbury and Yerrida Palaeoproterozoic basins and to gain a greater understanding of the evolution of the Capricorn Orogen. This is to be achieved through the collection, synthesis, and dissemination of geological information and the production of geological maps and supporting publications. These products integrate field and laboratory studies, including mapping, petrology, geochemistry, geochronology, remote sensing, and metallogeny.



Highlights and activities 1999–2000

The Palaeoproterozoic Bryah, Padbury, and Yerrida Basins in Western Australia are part of the eastern Capricorn Orogen. These basins record periods of sedimentation and magmatism

along the northern margin of the Archaean Yilgarn Craton. Each basin is characterized by distinct stratigraphy, igneous activity, structural and metamorphic history, and mineral deposit types. The oldest of these basins, the Yerrida Basin (c. 2200 Ma), is floored by rocks of the Archaean Yilgarn

Craton. An important feature of this basin is the presence of evaporites and continental flood basalts. The c. 2000 Ma Bryah Basin developed on the northern margin of the Yilgarn Craton during back-arc sea-floor spreading and rifting, the result of which was the emplacement of voluminous mafic and ultramafic

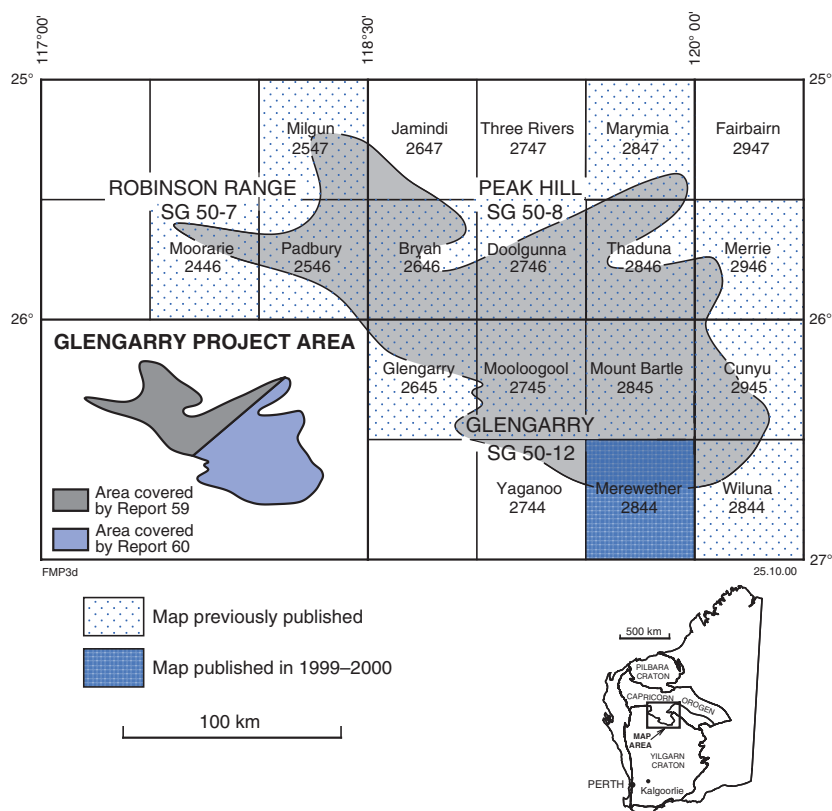


Figure 5. Progress of geological mapping in the Glengarry project area

volcanic rocks. During the waning stages of the Bryah Basin, this mafic to ultramafic volcanism gave way to deposition of clastic and chemical sedimentary rocks. At a later stage, the Padbury Basin developed as a retro-arc foreland basin on top of the Bryah Basin, in a fold-and-thrust belt. This resulted from either the collision of the Pilbara and Yilgarn Cratons (Capricorn Orogeny), or the c. 2000 Ma westward collision of the southern part of the Gascoyne Complex and the Yilgarn Craton (Glenburgh Orogeny). During the Capricorn Orogeny, the Bryah Group was thrust to the southeast, over the Yerrida Group.

Important mineral deposits are contained in the Yerrida, Bryah, and Padbury Basins. In the Yerrida Basin, a large Pb-carbonate deposit (Magellan) is present and good potential for black shale-hosted Ba, Cu, Zn, and Pd exists. The Pb-carbonate deposit is hosted by the

upper units of the Juderina Formation and the lower unit of the unconformably overlying Earraheedy Group. The Bryah and Padbury Basins contain orogenic gold, copper-gold volcanogenic massive sulfides, manganese, and iron ore. The origin of the gold mineralization is probably related to tectono-thermal activity during the Capricorn Orogeny at c. 1800 Ma.

During the year GSWA's work focused on compiling Reports 59 (Bryah–Padbury) and 60 (Yerrida) and Explanatory Notes for MILGUN. Geochemical and petrographic studies continued on the volcanic rocks of the Narracoota and Killara Formations in an attempt to unravel the role of volcanism in the geodynamic evolution of the Bryah and Yerrida Basins. Sampling of sedimentary successions of the Bryah and Yerrida Groups was carried out for the purpose of constraining the depositional age.

1999–2000 publications and products

Report 59: 'Geology and mineralization of the Palaeoproterozoic Bryah and Padbury Basins, Western Australia';

Report 60: 'Geology and mineralization of the Palaeoproterozoic Yerrida Basin, Western Australia';

MILGUN 1:100 000 Explanatory Notes;

MEREWETHER 1:100 000 geological map.

Future work

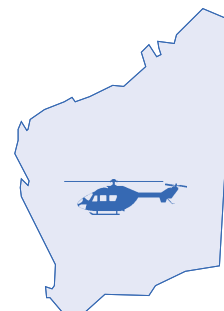
Work for the Glengarry project is almost complete (Fig. 5). Additional work is planned to improve our understanding of the geology and geodynamic evolution of Capricorn Orogen's Palaeoproterozoic basins. Work is also being conducted, in collaboration with Curtin University, on dating of detrital zircons and muscovites from the sedimentary successions, to constrain their age and to establish sediment contributions from the Yilgarn Craton and other sources. This includes field sampling for U–Pb and baddelyite SHRIMP dating of igneous and sedimentary rocks, and provenance studies in the Bryah and Yerrida Basins. This work is part of a joint research program with geoscientists from the University of Western Australia and Curtin University of Technology.

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Regional regolith and geochemical mapping

Objectives: To ascertain the distribution and composition of surface material (regolith) over parts of Western Australia, and to provide these data as maps and digital datafiles as regional-scale, baseline information for the mineral exploration industry.



Highlights and activities 1999–2000

Maps and Explanatory Notes were published for the Fraser Range region (in conjunction with AGSO), AJANA, KINGSTON, and STANLEY at 1:250 000 scale in 1999–2000 (Fig. 6), and gravity was measured at each sampling site. Regolith sampling and gravity capture was carried out on WINNING POOL – MINILYA, and regolith samples were subsequently analysed.

The interpretation of regolith chemistry on parts of KINGSTON and STANLEY was enhanced by the availability of gravity data collected during the sampling program, and the second-generation regional mapping being carried out on these map sheets. The GSWA regolith classification scheme continues to prove its worth, particularly in highlighting provenance differences in areas of sand-dominated regolith, such as is found in the northern part of STANLEY and over granitoid rocks on KINGSTON. A presentation dealing with the relationship of chemistry and regolith type in sand-dominated areas on the AJANA map sheet featured at the GSWA 2000 open day in March 1999. A talk on aspects of the GSWA regional regolith and geochemical mapping program was presented at the AMF conference 'Improving the Chances of Exploration Success'.

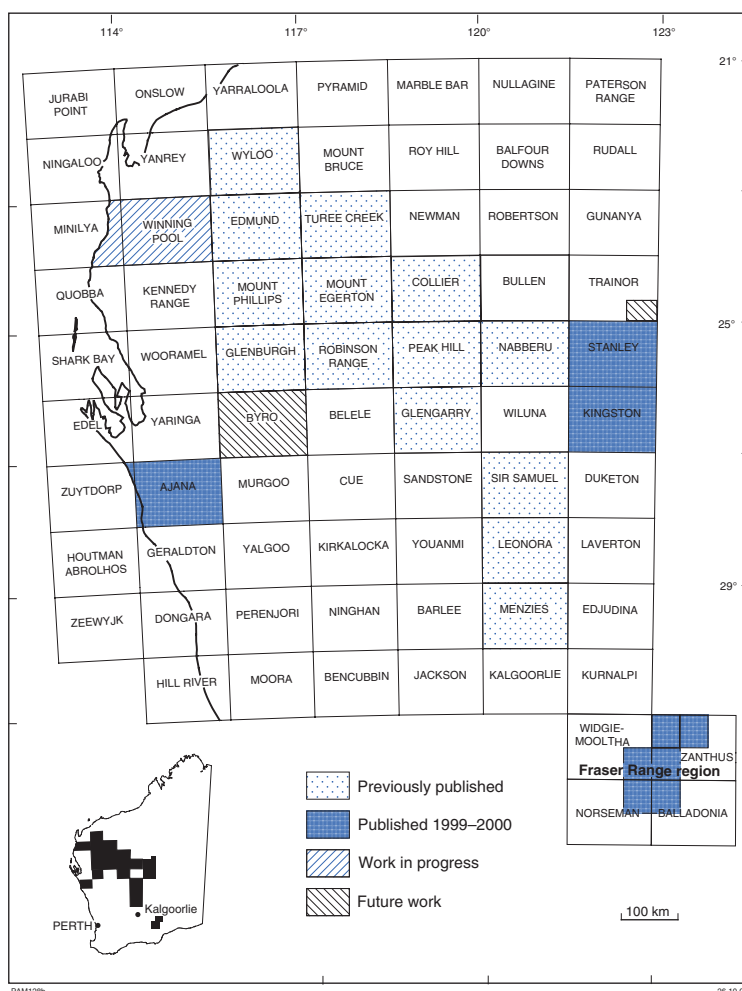


Figure 6. Summary of progress of the regional regolith and geochemical mapping program

1999–2000 publications and products

Explanatory Notes, maps, and digital data for: AJANA, KINGSTON, STANLEY, and the Fraser Range region;

Record 2000/11: 'Composition of Geological Survey of Western Australia geochemical reference materials'.

Future work

During 2000–01, GSWA will release maps and Explanatory Notes for WINNING POOL – MINILYA and BYRO.

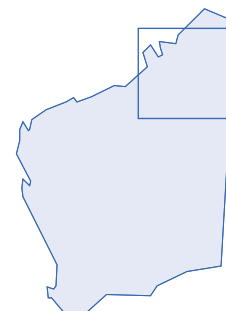
Regolith sampling will be carried out on the BYRO 1:250 000 sheet in August 2000. Maps and Explanatory Notes from this area are to be published by July 2001. Regolith mapping and sampling over an area of barite-hosted mineralization in

the Officer Basin (NICHOLLS 1:100 000 map sheet) will be carried out in October 2000, and a program of developing seamless regolith maps and accompanying geochemical databases (based on published products from the GSWA regional regolith and geochemical mapping program) will commence.

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King Leopold and Halls Creek Orogens project

Objective: To increase geological knowledge of the King Leopold and Halls Creek Orogens by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochronology, geophysics, geochemistry, sedimentology, palaeontology, remote sensing, and metallogeny.



Highlights and activities 1999–2000

During 1999–2000, a 1:500 000 geological map of the Halls Creek Orogen was completed, together with an accompanying simplified geology map and a reference. The LISSADELL 1:250 000 Explanatory Notes were also completed (Fig. 7). Significant progress was made on completing the first draft of Bulletin 143 on the geology of the King Leopold and Halls Creek Orogens. AGSO published the HALLS CREEK 1:100 000 geological map and Explanatory Notes.

A paper on the geochemistry and tectonic setting of basalts from the Halls Creek Group and the Tickalara Metamorphics was published in the Australian Journal of Earth Sciences. A paper on the geochronology and geochemistry of granites in the Hooper Complex of the King Leopold Orogen and the Western zone of the Lamboo Complex of the Halls Creek Orogen appeared in Precambrian Research. Two papers on further aspects of the geology and geochronology of the Halls Creek Orogen were submitted to the Journal of the Geological Society of London.

1999–2000 publications and products

LISSADELL 1:250 000 Explanatory Notes;

Geological map of the Halls Creek Orogen, East Kimberley region;

Simplified geology of the Halls Creek Orogen, East Kimberley region.

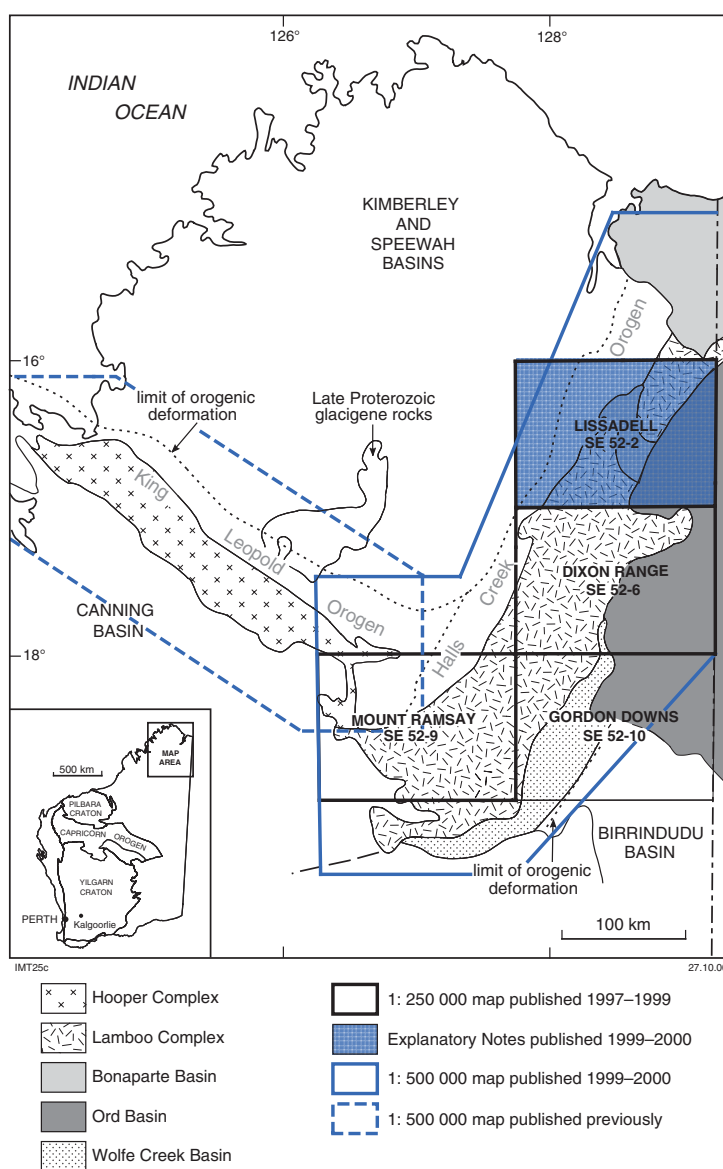


Figure 7. Progress of geological mapping across the King Leopold and Halls Creek Orogens

Future work

During 2000–01, work will continue on the Bulletin on the

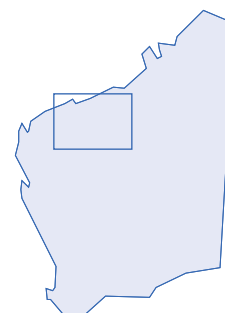
geology of the King Leopold and Halls Creek Orogens. AGSO will release a Bulletin on the layered mafic–ultramafic

intrusions of the Halls Creek Orogen.

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Pilbara Craton project

Objective: To increase geoscientific knowledge of the Pilbara Craton by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.



Highlights and activities 1999–2000

In 1999–2000, geological mapping was completed on the COOYA POOYA, WALLARINGA, and SPLIT ROCK 1:100 000 maps, and commenced on the WHITE SPRINGS, EASTERN CREEK, and CARLINDIE 1:100 000 maps (Fig. 8). This is an NGMA project with AGSO, who contributed to the 1999–2000 mapping on WALLARINGA and MARBLE BAR. Results of the project were the subject of public presentations at the GSWA 2000 open day in March.

A new tectono-stratigraphic subdivision of the granite–greenstone terrains of the north Pilbara was presented in a poster presentation at GSWA 2000. All 3660–2800 Ma granitoids and greenstones underlying the late Archaean Hamersley Basin succession belong to the North Pilbara Terrain, and this consists of, from northwest to southeast, the West Pilbara Granite–Greenstone Terrane, the Central Pilbara Tectonic Zone, the East Pilbara Granite–Greenstone Terrane, the Mosquito Creek Basin, and the Kurrana Terrane. These divisions are explained in publications currently in preparation.

AGSO published an Atlas of the North Pilbara (AGSO Record 2000/4) presenting and interpreting geological, geophysical, and radiometric data obtained under the mapping accord project with GSWA. Contributions to a special issue of Economic Geology, devoted entirely to the geology and mineralization of

pre-2800 Ma Archaean terrains in Western Australia, were substantially completed. SHRIMP geochronology continued to support the mapping program.

A GSWA excursion to Archaean stromatolite localities in the east Pilbara was attended by international authorities on stromatolites and disciplines related to the early evolution of life. Following the excursion, which was filmed and subsequently televised by the ABC Quantum program, GSWA donated some of the best preserved stromatolites to the Western Australian Museum.

1999–2000 publications and products

NORTH SHAW 1:100 000 Explanatory Notes;

COORAGOORA 1:100 000 Explanatory Notes;

ROEBOURNE 1:100 000 map sheet;

PINDERI HILLS 1:100 000 map sheet;

WARRAWAGINE 1:100 000 map sheet;

ROEBOURNE 1:250 000 map sheet;

Record 2000/4: 'Archaean geology of the Muccan region, East Pilbara Granite–Greenstone, Western Australia – a field guide';

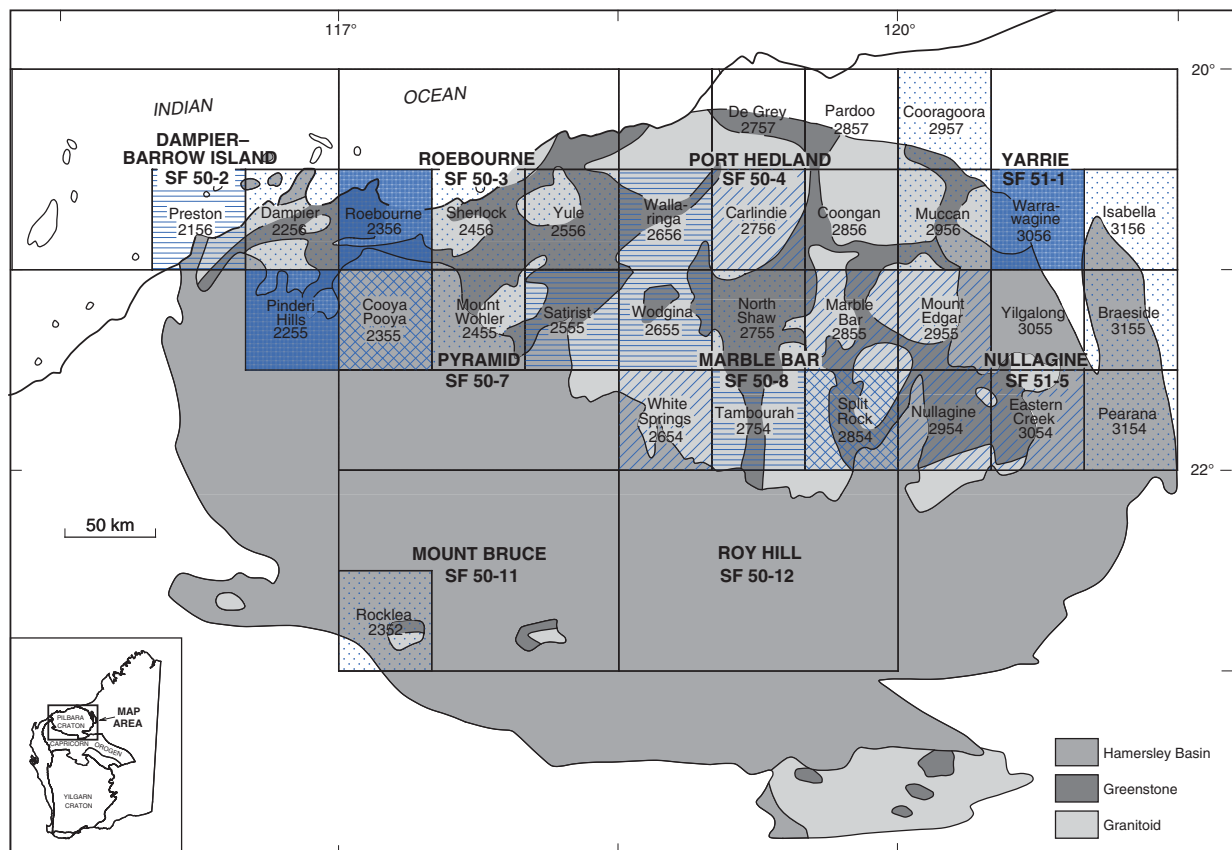
Record 2000/5: 'Archaean geology of the North Shaw region, East Pilbara Granite–Greenstone Terrane, Western Australia – a field guide';

Record 2000/9: 'Archaean geology of the West Pilbara Granite–Greenstone Terrane, Western Australia – a field guide'.

Future work

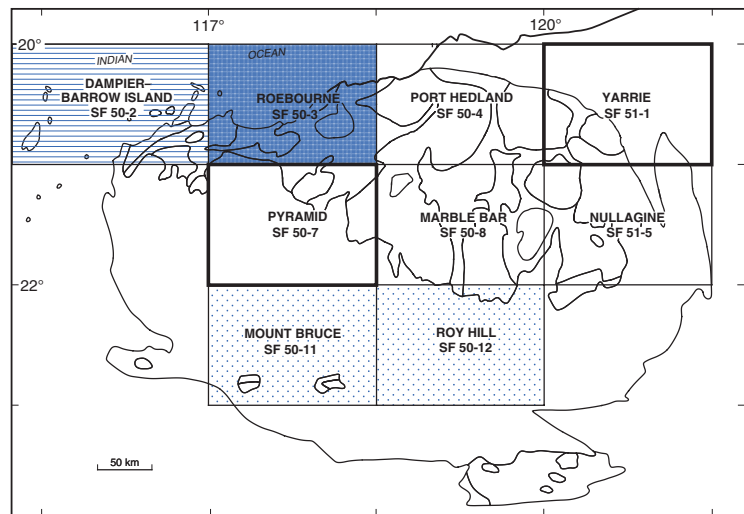
The 2000–01 year will see the completion of the TAMBOURAH, SATIRIST, PRESTON, WODGINA, and WALLARINGA 1:100 000 maps, and the DAMPIER – BARROW ISLAND 1:250 000 map. Fieldwork will be completed for the MOUNT EDGAR, WHITE SPRINGS, and EASTERN CREEK 1:100 000 maps, and on the PYRAMID 1:250 000 sheet area. Recent 1:100 000 mapping will be used to complete the compilation of a new YARRIE 1:250 000 map, which will be published in the 2001–02 year. Field guides for two excursions to the east and west Pilbara will be written for the Fourth International Archaean Symposium, to be held in Perth in 2001.

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a)

- Map previously published
- Map published 1999–2000
- Map to be published 2000–2001
- Fieldwork completed
- Fieldwork 2000–2001
- Compilation 2000–2001

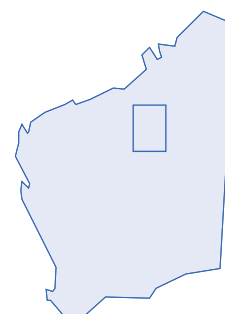


b)

Figure 8. Progress of regional mapping in the Pilbara Craton

Paterson Orogen project

Objective: To increase geoscientific knowledge of the Paterson Orogen by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.



Highlights and activities 1999–2000

Completion of geological mapping on the PATERSON 1:100 000 sheet area in July 1999 completed the current program of field activities in the Paterson Orogen (Fig. 9). Subsequent office work during the year involved compilation of the PATERSON 1:100 000 map, and completion of Explanatory Notes for the PATERSON and POISONBUSH 1:100 000 maps and for the RUDALL 1:250 000 map. A paper on copper mineralization along the Camel-Tabletop Fault Zone was written, and is presented in this Annual Review.

1999–2000 publications and products

THROSSELL 1:100 000 Explanatory Notes;

POISONBUSH 1:100 000 Explanatory Notes;

BLANCHE–CRONIN 1:100 000 Explanatory Notes;

RUDALL 1:250 000 Explanatory Notes;

PATERSON 1:100 000 map sheet.

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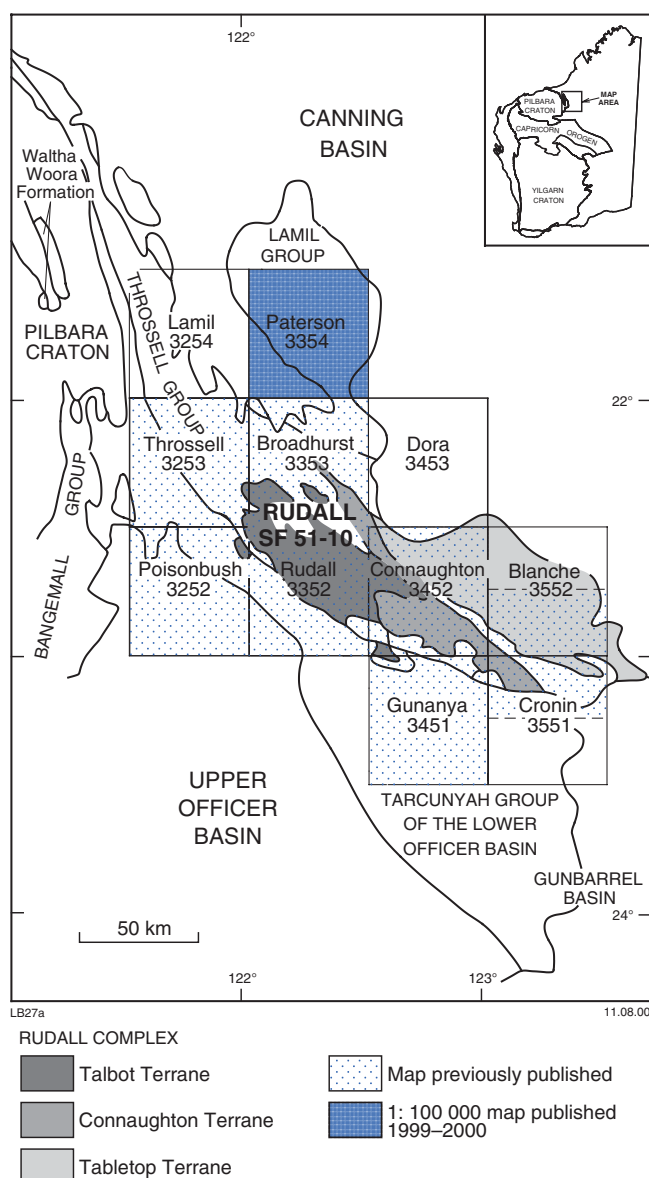
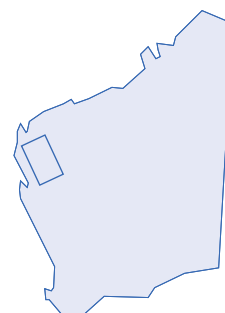


Figure 9. Location of the mapping program in the Paterson Orogen

Southern Gascoyne Complex project

Objective: To increase geological knowledge of the southern Gascoyne Complex by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.



1999–2000 highlights and activities

During the 1999 field season remapping of Palaeoproterozoic rocks on the DAURIE CREEK and CARRANDIBBY 1:100 000 map sheets was completed (Fig. 10). Remapping on the northern part of the YALBRA 1:100 000 map sheet was completed in conjunction with two Honours students (based at Curtin University of Technology and the University of Western Australia) from the Tectonics Special Research Centre. Mapping of rocks north of the Dalgety Fault on DAURIE CREEK and GLENBURGH was carried out by Professor C. Passchier of the University of Mainz, Germany, following on from previous work on the Errabiddy Shear Zone, to the south. For the 2000 field season remapping of the Palaeoproterozoic rocks on the CANDOLLE 1:100 000 map sheet has commenced in conjunction with two Honours students (based at Curtin University of Technology) from the Tectonics Special Research Centre.

Compilation for a 2nd edition ROBINSON RANGE 1:250 000 map sheet was completed, with the exception of the GOULD 1:100 000 map sheet area, which is still to be finalized. Writing of Explanatory Notes for the GLENBURGH 1:100 000 map sheet commenced. S. A. Occhipinti contributed toward a poster on 'Palaeoproterozoic kinematics in the southern Capricorn Orogen, Western Australia', to be presented at the 15th Australian Geological Convention in July 2000.

Sampling for whole-rock geochemical analysis and geochronology was carried out in the 1999 field season. New SHRIMP U–Pb zircon isotopic ages have been obtained from several samples. A maximum age of c. 1800 Ma from a quartzite from the Mount James

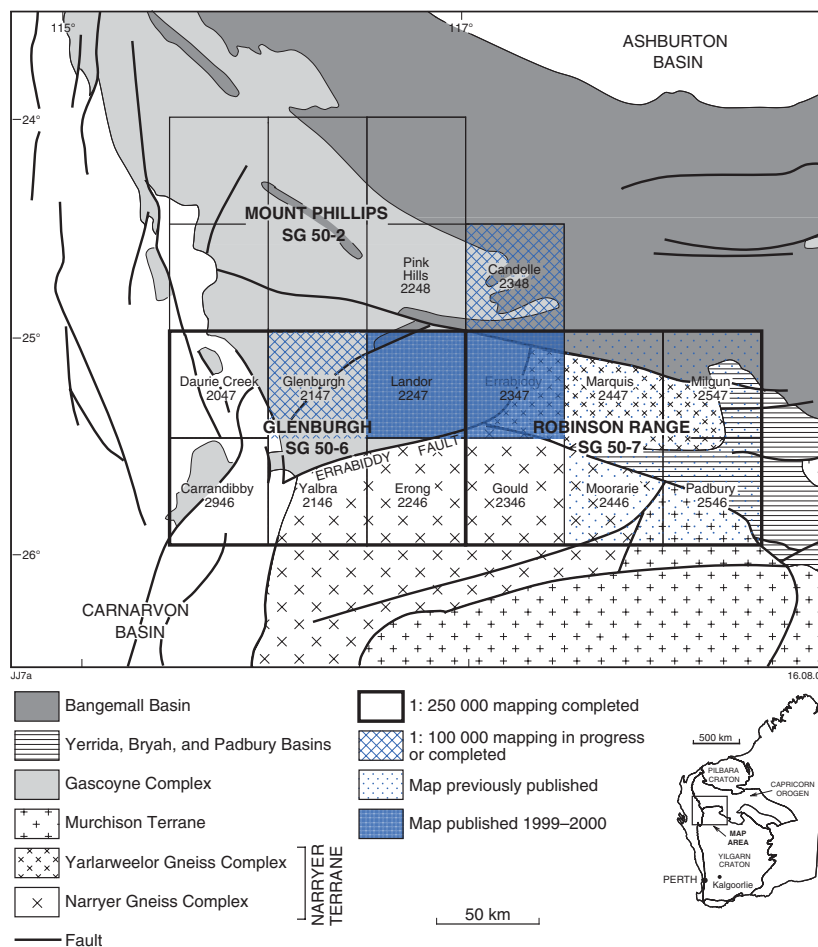


Figure 10. Progress of geological mapping for the Southern Gascoyne Complex project

Formation represents the first geochronological control on that unit. A previously unrecognized metasedimentary unit, the Coordewandy Formation, outcrops beneath the Mount James Formation in the Errabiddy Shear Zone on YALBRA. It is intruded by probable c. 1800 Ma pegmatite veins.

Preliminary results from geochronological sampling in the Carrandibby Inlier show that it is

probably an extension of the Palaeoproterozoic rocks of the southern Gascoyne Complex, and is not part of the Yilgarn Craton. A paper on 'The nature of c. 2.0 Ga crust along the southern margin of the Gascoyne Complex' by S. Sheppard, S. A. Occhipinti, I. M. Tyler, and D. R. Nelson was published in the GSWA Annual Review for 1998–99. Three papers were presented at a symposium held at Curtin University of Technology

in September 1999 on 'Two billion years of tectonics and mineralisation'; S. A. Occhipinti presented a paper 'Deformation and metamorphism during the c. 2000 Ma Glenburgh Orogeny and c. 1800 Ma Capricorn Orogeny'; S. Sheppard presented a paper 'Granites of the southern Capricorn Orogen, Western Australia'; and I. M. Tyler presented a paper 'Palaeoproterozoic orogeny in Western Australia'.

1999–2000 publications and products

ERRABIDDY and LANDOR 1:100 000 Explanatory Notes (combined);

ERRABIDDY 1:100 000 map sheet;

LANDOR 1:100 000 map sheet.

Future work

During 2000–01, fieldwork on the Palaeoproterozoic rocks of the CANDOLLE 1:100 000 map sheet will be completed. Compilation of the 2nd edition ROBINSON RANGE 1:250 000 map sheet will be finalized, and compilation for the 2nd edition GLENBURGH 1:250 000 map sheet will commence. The map and Explanatory Notes for the GLENBURGH 1:100 000 map sheet will be published, and work on manuscripts for Explanatory Notes for the ROBINSON RANGE and GLENBURGH 1:250 000 map sheets will commence.

GSWA staff will also compile a guide for an excursion to the Narryer Terrane and southern Gascoyne Complex, as part of the

4th International Archaean Symposium to be held in Perth in September 2001.

Geochemical and geochronological sampling will continue to accompany the mapping program.

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Bangemall Basin project

Objective: To increase the knowledge of the Bangemall Basin through the application of specialist field and laboratory studies, including biostratigraphy, geochemistry, geochronology, petrology, remote sensing, sedimentology, and stratigraphy. This information is to be disseminated through the production of geoscientific maps and supporting publications.

The Mesoproterozoic Bangemall Basin is a major geological unit that contains Western Australia's largest stratabound Pb–Cu–Ba deposit. This, combined with the basin's age and geological setting, makes it one of the most prospective areas in Australia for large, blind, sediment-hosted base-metal orebodies. The Bangemall Basin also has a history of minor gold and phosphate production.

Highlights and activities 1999–2000

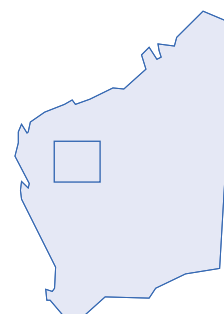
Fieldwork on the northwestern part of the Bangemall Basin during 1999–2000 has involved detailed mapping in the MAROONAH, MANGAROON, and EDMUND 1:100 000 map sheet areas (Fig. 11). The principal sandstone

units were sampled for provenance studies and palaeocurrent data was collected. Office-based activities have included the compilation of geological data for MAROONAH, MANGAROON, and part of EDMUND, analysis of field data, and further acquisition of aerial photography.

As a result of recent mapping of Bangemall Basin rocks on MAROONAH and MANGAROON, the thin, locally developed basal siliciclastic unit, the Yilgatherra Member, has been raised to formation status. Facies distribution and thickness in the Yilgatherra Formation and the overlying Irregularly Formation are strongly controlled by the synsedimentary Talga Fault on ELLIOTT CREEK and EDMUND, together with other smaller, northwesterly trending faults on MAROONAH and MANGAROON. In

addition, highly variable palaeocurrent directions in the Yilgatherra Formation suggest that basement inliers were topographic highs at the time of deposition.

North of the Talga Fault, the Irregularly Formation consists primarily of peritidal dolostone and sandstone with minor siltstone. South of this fault, the formation thickens considerably and is dominated by thick subtidal cycles of intraclast breccia and dololite, with rare stromatolites. This facies passes southward into interbedded dololite, dolomitic siltstone, and sandstone. Further south, the upper Irregularly Formation is characterized by interbedded shallow-marine sandstone and stromatolitic dolostone, whereas fluvial to shallow-marine siliciclastic facies dominate the succession around the eastern margin of MANGAROON.



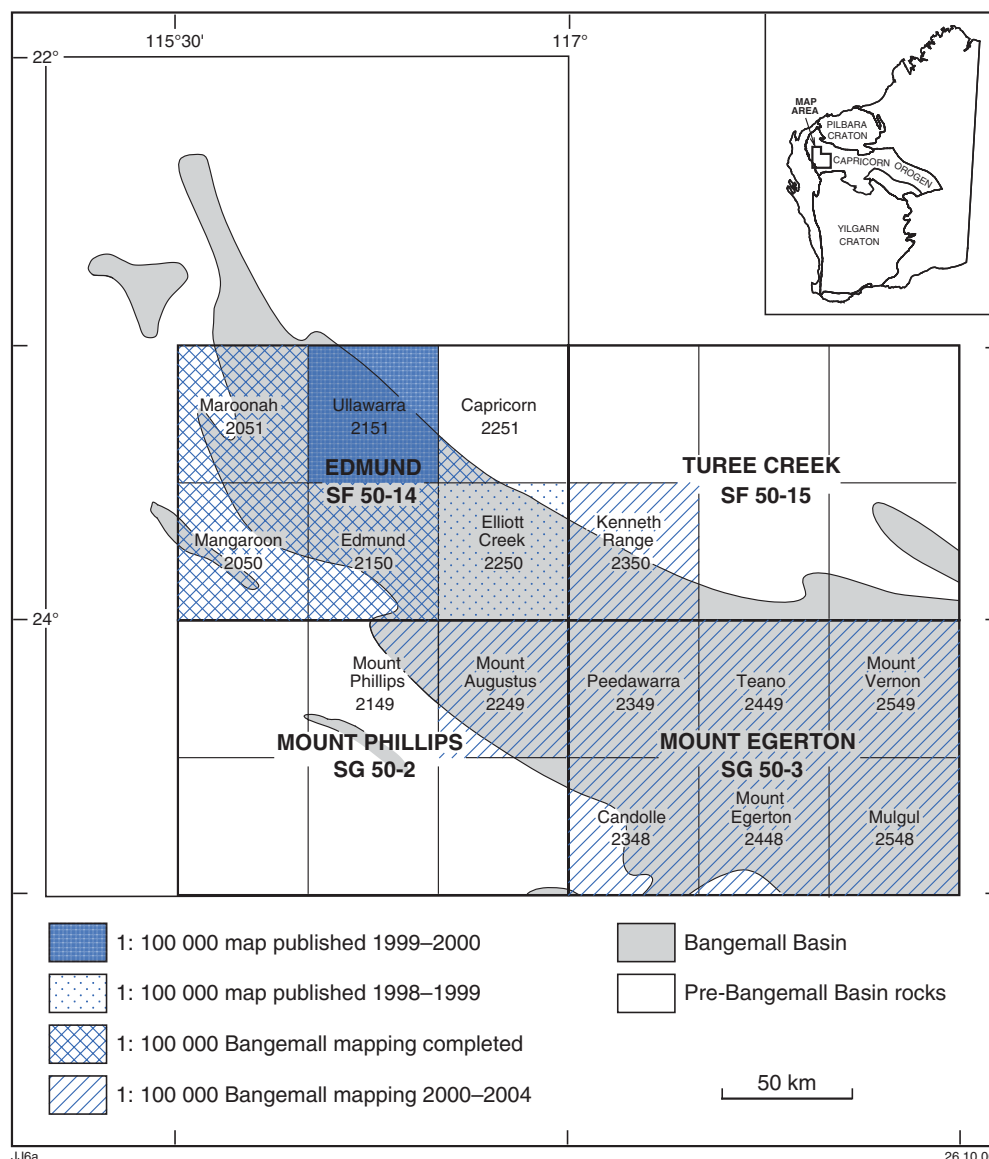


Figure 11. Progress of geological mapping for the Bangemall Basin project

A paper entitled 'A provisional revised stratigraphy for the Bangemall Group on the Edmund 1:250 000 sheet' was published in the GSWA Annual Review for 1998–99.

1999–2000 publications and products

ULLAWARRA 1:100 000 preliminary release map sheet.

Future work

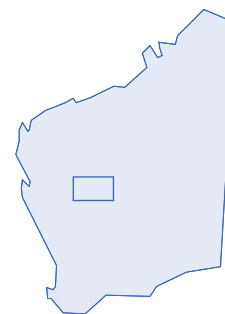
Mapping of Bangemall Group rocks on KENNETH RANGE is to be completed during the 2000–01 field season and work on CANDOLLE will commence during this period. Principal objectives are to test and implement the revised stratigraphy in the southwestern and northeastern parts of the basin, to identify and sample suitable horizons for U–Pb

zircon geochronology, provenance studies, and geochemistry, and to further examine the relationship between the Edmund and Collier Groups.

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Earaheedy Basin project

Objective: To increase geoscientific knowledge of the Earaheedy Basin, one of the Capricorn Orogen's Proterozoic tectonic units, through the collection, synthesis, and dissemination of geological information. This is to be achieved through the production of geological maps and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochemistry, geochronology, remote sensing, and metallogeny.



Highlights and activities 1999–2000

The Palaeoproterozoic Earaheedy Basin in Western Australia, which contains the Earaheedy Group, lies at the eastern end of the Capricorn Orogen. Recent geological mapping has led to a revision of the stratigraphy, the development of a new model for basin evolution, and a better understanding of the potential for mineralization.

The Earaheedy Basin is interpreted to have been much larger than its present-day exposure, extending further to the southwest and to the north, where it is masked by the overlying Bangemall and Officer Basins. Regional stratigraphic relationships indicate that the Earaheedy Basin is younger than 2200 Ma and older than 1650 Ma, and it appears to be unaffected by the 1800 Ma Capricorn Orogeny. Poor age constraints hinder more accurate placement of the basin within the regional framework. Isotopic ages for Earaheedy Group sedimentary rocks and mineralization cluster around 1700–1800 Ma.

In addition to the potential for iron ore of the Frere Formation, known mineralization in the Earaheedy Basin includes Mississippi Valley-type Pb–Zn–Cu deposits in the Sweetwaters Well Member, near the Shoemaker Impact Structure, and the large (>200 Mt) Magellan Pb deposit, which is hosted by outliers of the Yelma Formation on the Yerrida Basin. Minor stratiform Mn and Fe oxides are present within the shale units of the Windidda Formation. These stratiform oxides contain anomalous abundances of Cu, Ba, and Pb, thus enhancing the prospectivity of the Earaheedy Basin for stratabound Cu of the Kupferschiefer type. Gold mineralization is present in the Stanley Fold

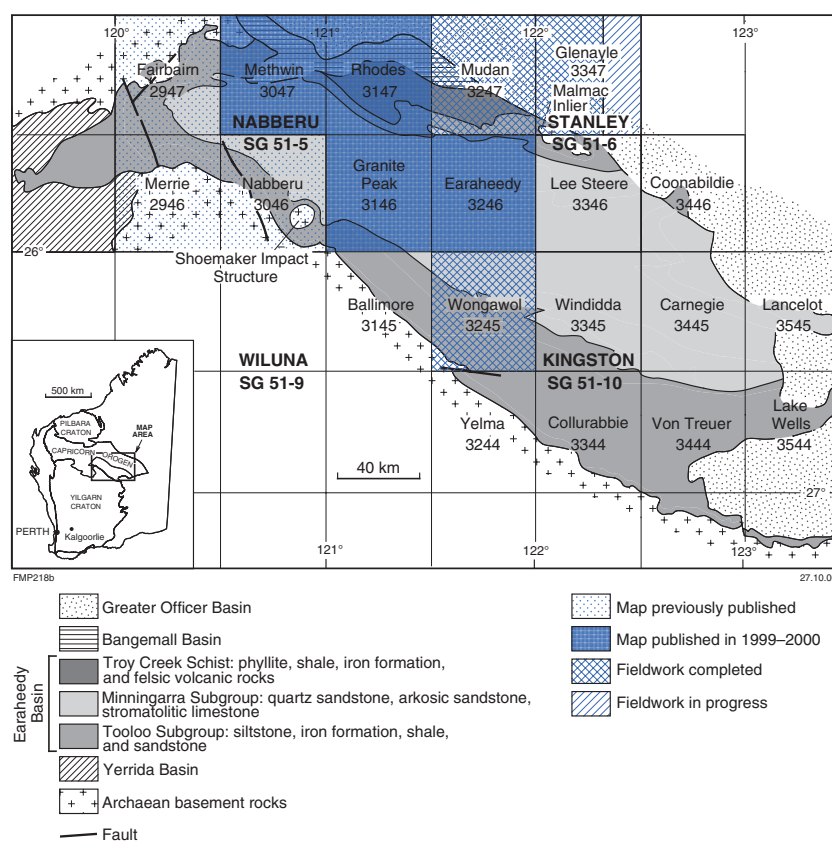


Figure 12. Progress of geological mapping for the Earaheedy Basin project

Belt (a zone of deformation along the presently exposed northern margin of the Earaheedy Group), where it is associated with mylonite and quartz veins.

The Earaheedy project also includes mapping and the study of rocks from adjacent tectonic units such as the Bangemall (Mesoproterozoic) and Officer (Neoproterozoic) Basins, and mafic igneous rocks (Glenayle Dolerite). The latter intrude units of the Officer Basin (Sunbeam Group) and may be part of a large igneous province with potential for Ni and

platinum-group elements mineralization.

The GSWA's work continued throughout the year and included geological mapping, and geochemical and mineralization studies of Earaheedy Group and Glenayle Dolerite rocks. During the year, field geological mapping was completed for MUDAN and WONGAWOL and was commenced for the GLENAYLE 1:100 000 map sheet (Fig. 12). To date, the results of these studies have resulted in the above-mentioned revision of

the lithostratigraphy of the Earraheedy Group, which has been detailed in a GSWA Record and in a paper presented at the 15th Australian Geological Convention in Sydney.

1999–2000 publications and products

MERRIE 1:100 000 Explanatory Notes;
RHODES 1:100 000 map sheet;
EARAHEEDY 1:100 000 map sheet;
GRANITE PEAK 1:100 000 map sheet;
METHWIN 1:100 000 map sheet.

Future work

Work planned for 2000–01 includes field mapping for the LEE STEERE and GLENAYLE 1:100 000 map sheets, compilation of the 2nd edition 1:250 000 geological map of NABBERU and a start to the mapping of the WINDIDDA 1:100 000 map sheet. There will be a continuation of studies of the basin tectonics and associated mineralization, and Explanatory Notes for FAIRBAIRN, EARAHEEDY, METHWIN, NABBERU, GRANITE PEAK, and RHODES will be written. A Report and solid geology map of the Shoemaker Impact Structure will be finalized,

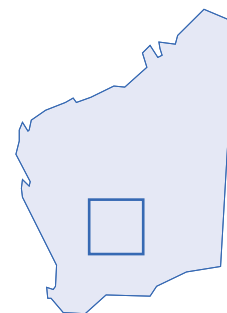
and there will be a field sampling program for U–Pb and baddelyite SHRIMP dating of igneous and sedimentary rocks in and adjacent to the Earraheedy Basin.

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East Yilgarn terrane custodianship

Objectives: *To increase geoscientific knowledge of the East Yilgarn Terrane by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps, GIS-based seamless geological databases, and supporting publications that integrate field and laboratory studies, including mapping, petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.*



The East Yilgarn terrane custodianship covers the eastern two-thirds of the Yilgarn Craton and contains the economically significant Eastern Goldfields and Southern Cross provinces (Fig. 13). The Yilgarn Craton, with its extensive areas of Archaean granitoid and linear to arcuate greenstone belts, hosts numerous world-class gold and nickel deposits. The custodianship includes the Kalgoorlie regional office, the J. H. (Joe) Lord Core Library, and the Eastern Goldfields and Central Yilgarn (Southern Cross) field mapping projects. This section reports on GSWA activities in the Eastern Goldfields. Details of the Central Yilgarn (Southern Cross) project are reported separately below.

Highlights and activities 1999–2000

Construction of the J. H. (Joe) Lord Core Library took place in 1999–2000 and is located at the corner of

Broadwood and Hunter Streets, West Kalgoorlie. This facility will provide one of the most advanced systems of drillcore storage in Australia. The internal storage facility is sufficient for 15–20 years and will provide industry with state-of-the-art access to valuable drillcore from the minerals industry.

Attached to the storage facility is the new regional office for the GSWA, which is the operational base for staff engaged in fieldwork activities in the Eastern Goldfields, and for some of the staff involved in the Southern Cross and Earraheedy Basin regional mapping projects.

The Kalgoorlie office has continued to provide advice to the general public, mining companies, and others on the geology of the East Yilgarn, and to provide access to the WAMEX open-file database, GSWA publications, including an increasing volume of digital data, and past mining tenement plans.

Good cooperative relationships have continued to be maintained with the Western Australian School of Mines (WASM) and AGSO staff working in the Yilgarn. The Kalgoorlie office has also been involved with the local branch of the Australasian Institute of Mining and Metallurgy (AusIMM). Staff participated in the organization of the very successful conference on nickel laterites in the Eastern Goldfields (New Generation Nickel Laterites in the Eastern Goldfields), as well as workshops on the 1999 Kalgoorlie seismic lines and the JORC Code for Reporting of Mineral Resources and Ore Reserves. As with previous years, the Kalgoorlie office provided logistical support in the Australian Mineral Industries Research Association Limited (AMIRA) Yilgarn granitoid study (AMIRA Project P482).

In October 1999, a combined GSWA and AGSO open day was again held in Kalgoorlie. Despite the downturn in exploration activity, about 90 people attended to view posters

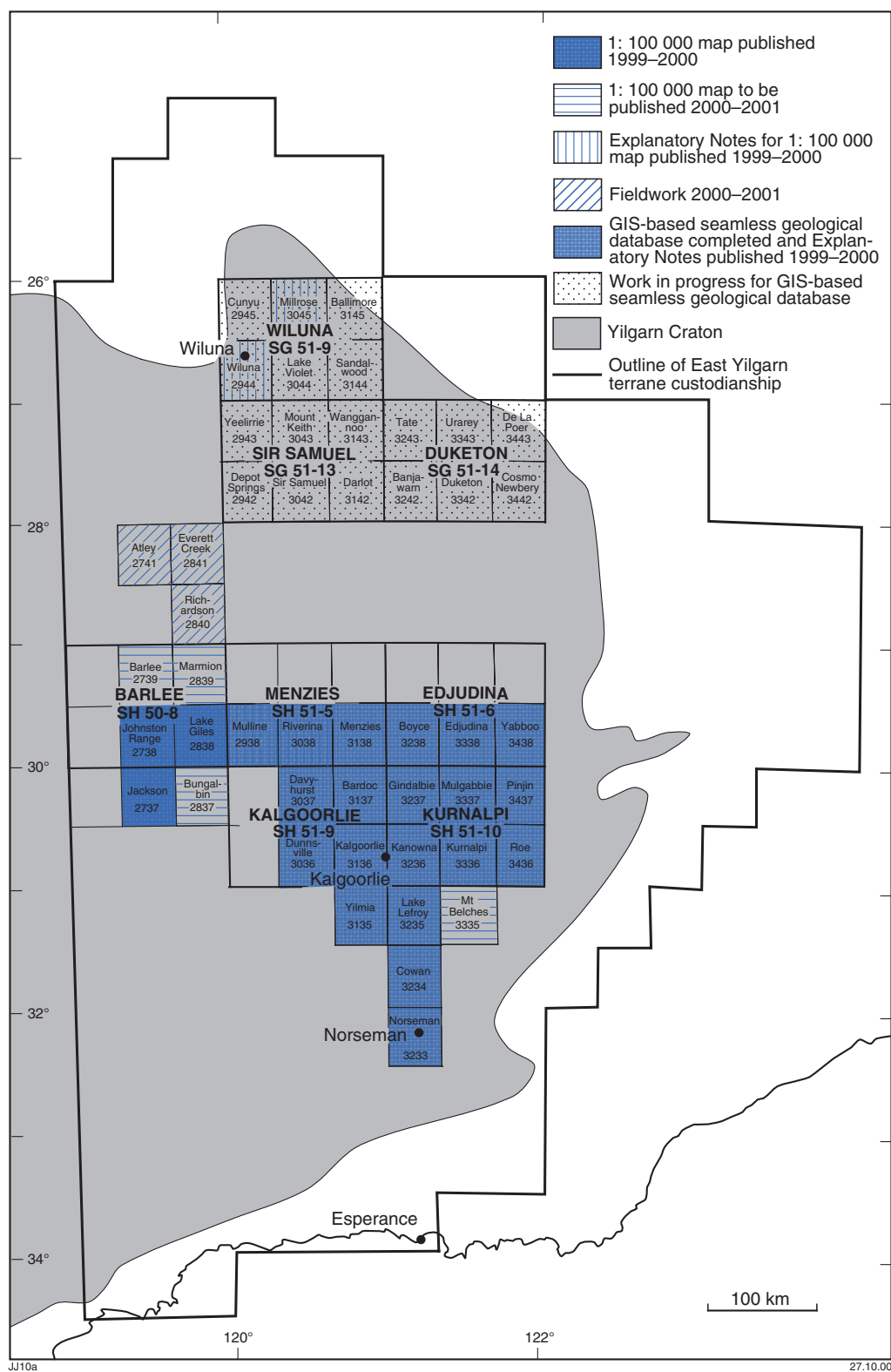


Figure 13. Progress of geological mapping in the east Yilgarn region and progress towards the GIS-based 'seamless' digital database

illustrating the recent activities of GSWA and AGSO.

During the year, the first phase of the development of the GIS-based seamless digital geoscience database for the East Yilgarn terrane custodianship was completed. This initial phase covers an area from Menzies to Norseman and incorporates seamless digital coverage of twenty 1:100 000 geological outcrop maps. The themes included in the database are 1:100 000 outcrop geology and structures, mineral location and resource data (MINDEX), tenement and geographic information (TENGRAPH), recent Landsat images (January–February 1998), aeromagnetic coverage (1.6 km line spacing) and 1:250 000 interpretative geology. The data is supplied in a number of computer formats, including ARC/INFO, ArcView and MapInfo.

An exciting new service, which was a spin-off from the development of the seamless digital geoscience database, was the creation of a 'map-on-demand' facility to produce hard-copy maps of any part of the area covered by the database. This 'map-on-demand' facility is available in the GSWA Kalgoorlie office and in Mineral House, Perth.

The second phase of the GIS-based seamless digital geoscience database has been compiled for release in 2000–01. This phase covers the north Eastern Goldfields and includes the following eighteen 1:100 000 geological map sheets: CUNYU, MILLROSE, BALLIMORE, WILUNA, LAKE VIOLET, SANDALWOOD, YEELIRRIE, MOUNT KEITH, WANGGANNOO, TATE, URAREY, DE LA POER, DEPOT SPRINGS, SIR SAMUEL, DARLOT, BANJAWARN, DUKETON, and COSMO NEWBERY.

1999–2000 publications and products

WILUNA 1:100 000 Explanatory Notes;

MILLROSE 1:100 000 Explanatory Notes;

MULLINE and RIVERINA 1:100 000 Explanatory Notes (combined);

WILUNA 1:250 000 map sheet.

Future work

Development of the East Yilgarn Geoscience Database will continue in 2000–01. Fieldwork will commence for the third phase of the GIS-based seamless digital geoscience database. This phase covers the Leonora to Laverton region and includes the following

eighteen 1:100 000 geological maps: MUNJEROO, WILDARA, WEEBO, NAMBI, MOUNT VARDEN, MCMILLAN, MOUNT ALEXANDER, WILBAH, LEONORA, MINERIE, LAVERTON, BURTVILLE, MOUNT MASON, BALLARD, MELITA, YERILLA, LAKE CAREY, and MOUNT CELIA.

Explanatory Notes for the DUKETON and WILUNA 1:250 000 maps and for the MOUNT BELCHES 1:100 000 map will be completed.

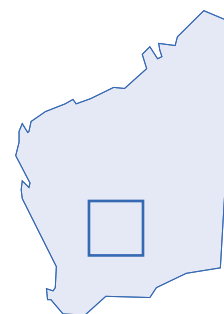
Work on the mineralization in the Eastern Goldfields will result in a Record on felsic volcanism and associated mineralization in the Gordons area, northeast of Kalgoorlie, and the compilation of a mineral occurrence dataset for the WOOLGANGIE and YILMIA 1:100 000 map sheets.

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Central Yilgarn (Southern Cross) project

Objective: *To increase geoscientific knowledge of the central part of the Yilgarn Craton by the collection, synthesis, and dissemination of geological information, particularly through the production of systematic geological maps and supporting publications that integrate field and laboratory studies, including petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.*



Highlights and activities 1999–2000

The central Yilgarn 1:100 000-scale field mapping program began in the Marda-Diemals area, the geographic centre of the Yilgarn Craton, in late 1997. In 1999–2000, fieldwork and compilation of the BUNGALBIN, BARLEE,

and MARMION 1:100 000 sheets was completed, and field mapping on the RICHARDSON 1:100 000 sheet began. Further fieldwork was carried out on the MENZIES 1:250 000 sheet, and this sheet will be compiled in the coming year (Fig. 14).

Other activities and results during 1999–2000 included publication of

four new SHRIMP U–Pb isotopic ages, collection of samples for a further 21 samples for SHRIMP analysis, and preparation of a paper describing the structural evolution of the region. A composite dataset providing total aeromagnetic coverage of the YOUANMI 1:250 000 sheet was

acquired for use in field mapping programs, and for public-domain release.

Structural mapping on major shear zones has confirmed the broad conclusions of the structural model presented in the 1998–99 GSWA Annual Review. However, new geochronological data on the Marda Complex, associated granitoids, and the Diemals Formation, when combined with detailed mapping of relationships, have raised some issues with respect to the exact sequence of deformation events. These questions are being addressed as part of the ongoing mapping program. Also of interest is the apparent occurrence of a widespread granitoid emplacement event at c. 2690 Ma, 20–30 Ma before the main period of granitoid emplacement in the Kalgoorlie region to the east. The c. 2690 Ma granitoid emplacement pre-dates the major movement on the regional-scale shear zones.

Dr Angela Riganti presented a paper titled 'Late Archaean volcanism and sedimentation in the central Yilgarn Craton' at the GSWA 2000 open day, and an extended abstract by A. Riganti, S. F. Chen, S. Wyche, and J. E. Greenfield was published in GSWA Record 2000/8: 'Geological data for WA explorers in the new millennium'.

Publications and products 1999–2000

JOHNSTON RANGE 1:100 000 map sheet;

JACKSON 1:100 000 map sheet;

LAKE GILES 1:100 000 map sheet.

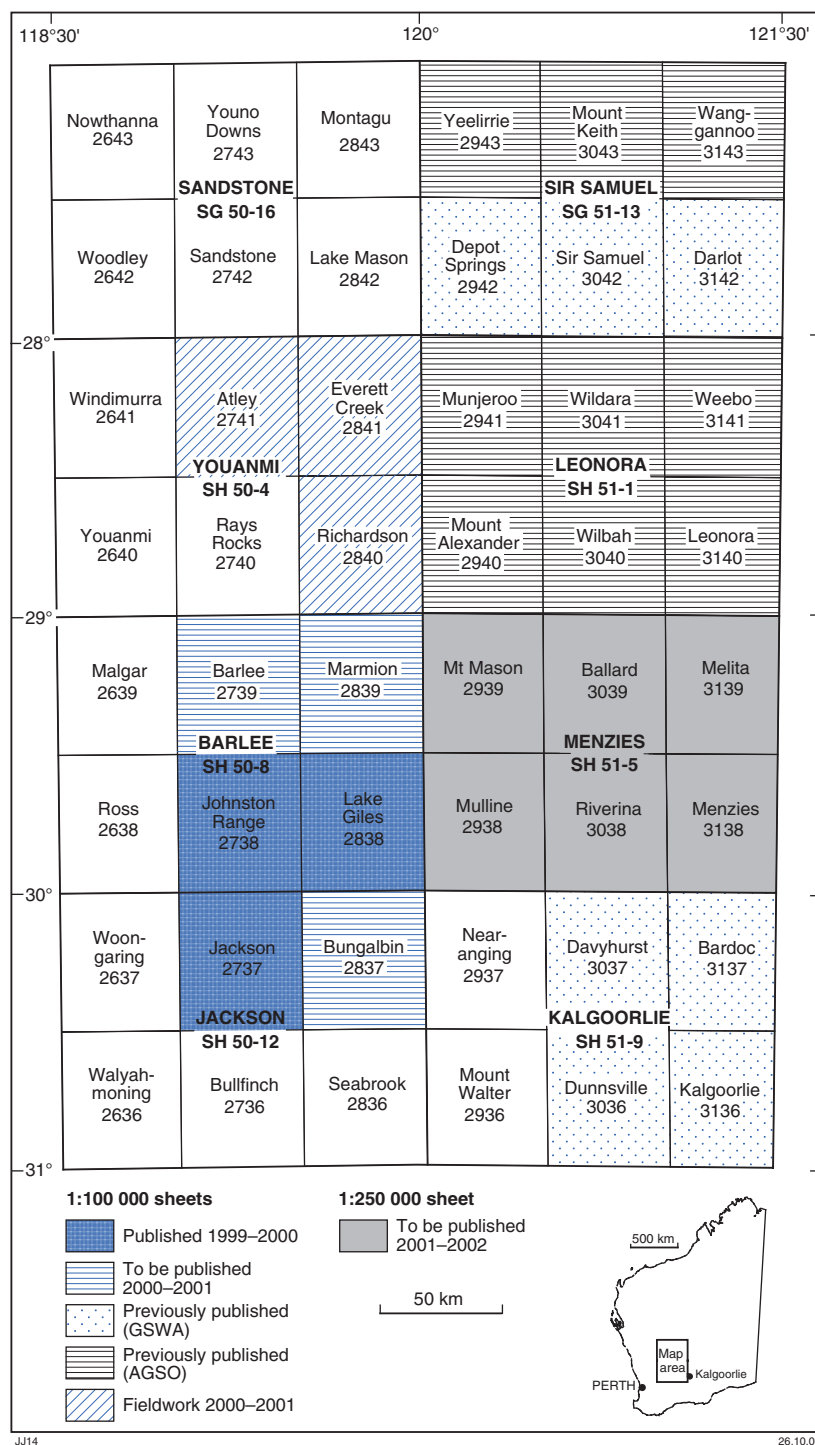


Figure 14. Progress of geological mapping for the central Yilgarn (Southern Cross) project

Future work

Fieldwork on the RICHARDSON and EVERETT CREEK 1:100 000 sheets will be completed in 2000–01, and these sheets will be compiled with a view to release in the following year. Fieldwork will be completed on the MENZIES 1:250 000 sheet and this map will be released the following year. Field mapping will begin on the

ATLEY 1:100 000 sheet. Explanatory Notes will be completed for the JOHNSTON RANGE and LAKE GILES 1:100 000 sheets, and draft Explanatory Notes will be written

for the JACKSON and BUNGALBIN 1:100 000 sheets.

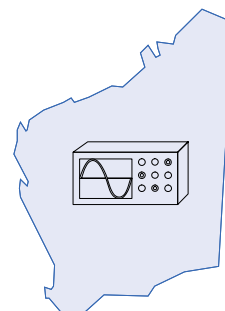
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Subprogram 3104 SCIENTIFIC, TECHNICAL, AND FIELD SUPPORT

Geoscientific specialist support

Geochronology

Objective: *To increase the knowledge of the geology of Western Australia by the collection, interpretation, and synthesis of geological, geochronological, and geophysical information for dissemination and to support the regional mapping projects.*



Geochronology is an essential component of geological interpretation, particularly for the Precambrian rocks that constitute a major part of Western Australia and contain most of its known mineral resources.

Highlights and activities 1999–2000

Almost 70 samples were dated by the sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon and monazite techniques, with typical precision of ± 6 Ma, for incorporation into GSWA geological maps and projects.

Samples included granitic and volcanic rocks from the Gascoyne, Narryer, Pilbara, Southern Cross, and Eastern Goldfields regions, and sedimentary rocks from the Bangemall and Yeneena Basins. GSWA Record 2000/2 documents all results from the geochronology work undertaken during the calendar year 1999.

During the year, efficient new laboratory procedures for the isolation of baddeleyite were developed. Improvements were also made to the data-processing software for clearer presentation in Record 2000/2 of analytical data obtained from sedimentary rock samples.

1999–2000 publications and products

Record 2000/2: 'Compilation of geochronology data, 1999'.

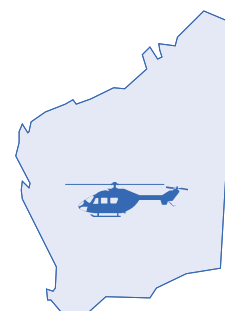
Future work

Further sampling is planned for the Pilbara, Southern Cross, and Bangemall regions before the end of 2000–01.

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Geophysics

Objectives: *To provide geophysical maps and interpretation products to support the regional mapping projects and for publication. To provide advice and liaison with industry.*



Regional airborne geophysics

During 1999–2000, the GSWA contracted Tesla Airborne Geoscience to acquire approximately 40 000 line km of new magnetic and radiometric data over the STANLEY

and YOUNAMI 1:250 000 sheet areas. The new data were merged with older private company data that were purchased jointly with AGSO in 1998–99 to provide complete coverage of the two sheet areas at survey line spacings from 200 to

400 m. The located and gridded data were made available for public access, together with magnetic and radiometric images.

Forty-five thousand line km of private company data over the

ROBERT 1:250 000 sheet area, which were purchased by GSWA and AGSO in 1998–99, were processed by AGSO and also released into the public domain.

Fifteen thousand line km of commercial multiclient data over the ERAYINYA and MOUNT BELCHES 1:100 000 sheet areas were purchased for internal use to support GSWA's geological mapping program.

Negotiations were concluded with Fugro Airborne Surveys to bring forward plans to acquire joint ownership and copyright of a multiclient regional dataset covering 60 000 km² in the BANGEMALL–GASCOYNE region in the MOUNT PHILLIPS and parts of the EDMUND, MOUNT EGERTON, COLLIER, GLENBURGH, and ROBINSON RANGE 1:250 000 sheet areas. Digital data and imagery will be released early in 2000–01.

In March 2000, GSWA and AGSO released the Magnetic anomaly map of Western Australia, a Statewide summary of airborne magnetic survey data held in the National Airborne Geophysical Database at AGSO. The map incorporates results from the latest surveys that were undertaken by AGSO and GSWA in 1998 and 1999, and previously confidential company data, and is the most comprehensive compilation of Statewide data to date. It forms a companion product to the Geological map of Western Australia released by GSWA in 1998.

Airborne geophysical survey register and data repository

During 1999–2000, about 130 new survey datasets, containing approximately 700 000 line km of data, were received for inclusion in the Minerals and Energy Airborne Geophysical Information eXchange (MAGIX) data repository. About 3.2 million line km of data from almost 600 surveys are now held in the repository.

Most of the companies submitting data have agreed to make public the location and basic specifications of their surveys; this information is available through a graphical interface on the Department's web site (www.dme.wa.gov.au).

Regional gravity surveys

GSWA continued its helicopter-assisted regional geochemistry and gravity survey program, with one field program during 1999–2000 over the WINNING POOL – MINILYA 1:250 000 sheet area. Six hundred and twelve gravity readings were taken on an irregular 4 km grid using La Coste and Romberg gravity meters (on loan from AGSO). Height control to an accuracy of 50–80 cm was achieved with the use of differential GPS receivers in the survey helicopters. The data were merged with earlier survey data in the AGSO national database to provide complete sheet coverage.

1999–2000 publications and products

Record 2000/6: 'Operations and processing methodology used in GSWA regional gravity surveys 1998–99';

Record 2000/12: 'Gravity data – Ajana 1:250 000 sheet, Western Australia';

Record 2000/15: 'Gravity data – Fraser Range region, Western Australia';

Magnetic anomaly map of Western Australia;

AJANA gravity image;

KINGSTON gravity image;

STANLEY gravity image;

Fraser Range region gravity image;

WINNING POOL – MINILYA gravity image;

STANLEY total magnetic intensity image;

YOUANMI total magnetic intensity image;

STANLEY ternary radiometric image;

YOUANMI ternary radiometric image.

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Carlisle operations

- Objectives:**
- To manage field support services, including transport and other equipment, and field assistants, and provide a communications link for all GSWA field parties
 - To ensure quality laboratory services for the preparation of samples for geochronology and other laboratory requirements
 - To manage inventory services for all GSWA publications, including maps, Bulletins, and Reports
 - To manage drillcore library facilities to service the needs of industry and GSWA
 - To promote and monitor safety both in the field and throughout the Carlisle operational areas



The Carlisle operations team provides a wide range of support services to geoscientists, including

vehicles, equipment, field assistants, and laboratory services. A drillcore store in Perth is also maintained as a

service to industry and used as an archive for rock, fossil, and soil samples collected by the Geological

Survey. Construction of the Kalgoorlie core storage facility and operational base for the East Yilgarn Terrane custodianship was completed at the end of June 2000. Operations will commence early in July 2000 when staff are transferred to the site. The facility will be officially opened by the Premier, the Hon. Richard Court MLA, on 17 July 2000. Viewing of core by the public will begin in August.

The Geological Survey's laboratory at Carlisle continued to maintain its high standard of excellence, with its focus on the preparation of samples for geochronological analysis. During the year, a total of 89 zircon samples were processed for SHRIMP analysis. In addition, specialized techniques continued to be developed for the preparation of zircon and other minerals suitable

for SHRIMP analysis work. As a result of this work, four baddeleyite and three monazite specimens were successfully prepared for analysis. The laboratory was also responsible for the supervision and quality control of work carried out by external contract service providers who prepared 1328 thin and polished thin sections, and 243 associated petrological reports.

Demand continued to be high for public access to local core storage facilities at Dianella, Carlisle, and the Star Street storage sites. During the year, 147 visitors spent almost 720 hours viewing core and cuttings, and took about 1840 samples for further analysis. A total of 116 sets of cuttings and 98 sets of core were accessioned into the collection and 7000 ditch-cutting samples were rebagged.

During the year, a program of monthly process improvement meetings was introduced to develop improved work practices and address risk-management issues, both in the field and throughout the Carlisle operational areas. This process resulted in the implementation of compulsory training in communication procedures, and in the safe operation and maintenance of field vehicles and equipment, for all field staff. A Field Vehicle Safety Manual was also produced.

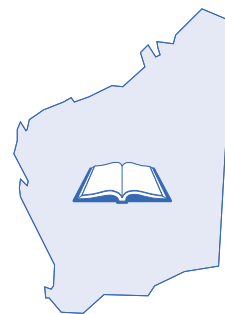
Provision of most field assistants by an employment agency continues to allow flexibility in meeting short-term needs for field staff at short notice.

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Subprogram 3105 GEOSCIENCE EDITING AND PUBLISHING

Publications and promotion

- Objectives:**
- To provide a quality and timely editing and publishing service for geoscientific manuscripts and maps produced by Geological Survey geoscientists
 - To promote GSWA products and services through displays, advertising, and other promotional events
 - To monitor product sales and develop marketing strategies to ensure products are reaching the appropriate market
 - To provide information and advice for the general public on all aspects of Western Australian geology



Editing and publishing

During 1999–2000, a total of forty-seven manuscripts were edited, illustrated, and published (Appendix, p. 122–124).

Explanatory Notes to accompany published maps continued to dominate our manuscript output. Of the forty-seven manuscripts published for the year, eighteen were Explanatory Notes. The

remainder included seven substantial Reports, fifteen Records, the GSWA Annual Review, and several miscellaneous publications. An increasing number of Geological Survey publications are now being provided with digital datasets enclosed. In 1999–2000, twelve such packages were released, most on CD-ROM in GIS format, and several with self-loading viewing software. The Publications

section provided editorial services for these products, and graphic design for their packaging.

Geoscience editorial services were also provided to support the forty-one geological maps, cross sections, well correlations, and geophysical images released during the year (see also Geoscience data management and Appendix, p. 121–122).

Promotional activities

During the year advertisements and short articles publicizing the release of GSWA published products were placed in a number of newspapers, industry magazines, and journals. Publication of FIELDNOTES (the GSWA quarterly newsletter first published in January 1996) continued during 1999–2000 and provided a medium for informing our customers about our activities, and promoting newly released maps, publications, and datasets.

Some important advances were made with GSWA content on the Department's web site:

- the release of DME.bookshop – a web-enabled electronic bookshop that allows on-line purchase of Geological Survey maps, publications, and datasets, and which is supported by a comprehensive, key-worded database containing all published output of the Geological Survey over the last 100 years or so
- implementation of user-friendly web-based front ends to allow simple and convenient access to the WAMEX and WAPIMS database systems via the Internet.

Displays of ongoing and completed geoscientific work by GSWA were presented at the following industry events:

- Exploration geochemistry for the new millennium (Perth, November 1999)
- Australasian minerals and markets – industrial minerals (Perth, November 1999)
- New Generation Gold Conference (Perth, November 1999)

- Prospectors and Developers Association of Canada – PDAC 2000 (Toronto, March 2000)
- Australian Society of Exploration Geophysicists – ASEG 2000 (Perth, March 2000)
- International Congress on Industrial Minerals (Denver, March 2000)
- Australian Gold Conference (Perth, April 2000)
- American Association of Petroleum Geologists – AAPG 2000 (New Orleans, April 2000)
- Australian Petroleum Production and Exploration Association – APPEA 2000 (Brisbane, May 2000)

In addition to the above, the DME/GSWA held three events to promote communication with our customers. These were:

- Petroleum Open Day – recent work by the Department and issues of interest to petroleum explorers (Perth, October 1999)
- Open day and display of recent work in the Eastern Goldfields (Kalgoorlie, October 1999, in association with AGSO)
- GSWA 2000 – Geological data for WA explorers in the new millennium (Perth, March 2000)

Of the above events, GSWA 2000 was a highlight, with industry feedback supporting the continuation of this event as a regular item on the promotional calendar. The promotion of Western Australia's prospectivity overseas continued in 1999–2000, with a presence at PDAC 2000 in Toronto, and geoscientific displays at AAPG 2000 in New Orleans and the International Congress on Industrial Minerals in Denver.

Public enquiries

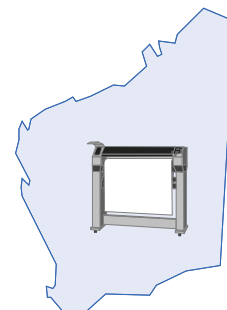
The rate of response to public enquiries in 1999–2000 was steady through the year, apart from surges coinciding with geoscience and mining units appearing in the school syllabus. Geoscientists in the Publications section received and responded to enquiries requiring information and assistance for prospectors, tourists and amateur fossickers, urban geology for land owners, mining and its environmental implications, and educational geology for students and teachers.

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Geoscientific data management

Objectives: To meet the needs for a spatial geoscientific database, ensuring access to and advancing the application of this database for users. In support of this mission we will:

- ensure the production and availability of geoscientific information in the form of high-quality maps
- ensure the production and availability of geoscientific information in the form of high-quality digital spatial geoscientific database products and services
- provide the infrastructure for the management of spatial geoscientific data
- develop and coordinate spatial geoscientific database policies and standards



1999–2000 publications and products

Multicoloured map printing

The Geoscientific data management group continued to produce high-quality lithographically printed and plotter-generated geological maps. Forty-one maps and images were produced in 1999–2000 (Appendix, p. 121–122), including 31 incorporating GSWA's new GDA format:

- One 1:50 000 urban and development areas series geological map
- Fifteen 1:100 000 series geological maps
- Two 1:250 000 series geological maps
- Four 1:250 000 regolith geochemical maps
- Nine project maps
- Five gravity images
- Three total magnetic intensity images
- Two radiometric images.

Digital data packages

The following geoscientific digital data packages were released in 1999–2000. Most of these incorporated the new 'autoloading' format:

- Four regolith geochemistry data packages
- Two mineral occurrence and exploration potential data packages
- One MINEDEX data package
- One gazette of onshore seismic surveys

- One CD containing eight plates to accompany Report 73: 'Geology and petroleum potential of the Peedamulla Shelf'
- One urban and development areas geology data package
- One annual update for the Pilbara iron ore resources package.

Other activities

RoxMAP.WA

RoxMAP.WA, an interactive map-on-demand application, has been developed and represents a new approach by GSWA to providing geoscience information to its customers. RoxMAP.WA provides customers with the capability to create their own geological maps meeting their specific requirements. This application is resident on GSWA's public-accessible computers in Kalgoorlie and Perth. The application is an extension to ArcView.

GeoBASE.WA

A pilot project titled 'Geoscientific Database of Western Australia Environment' (GeoBASE.WA), formerly GEODE, has been completed. The primary objective of the GeoBASE.WA project is to investigate approaches for integrating GSWA's geoscientific attribute and spatial data such that there is access to a single source of all 'GSWA corporate' geoscientific data. Access to this source will be provided through easy-to-use

interfaces that provide results in a responsive manner. Implementation of a production system will commence in 2000–01.

Databases

A number of key geoscientific databases have been migrated to Oracle, with users having access via web interfaces. The databases support field observations (WAROX), the mineralization program (WAMIN), regolith observations (WAREG), geochemical analysis (WACHEM), and the core library facilities (CORELIB). It is planned these databases will be integrated within the GeoBASE.WA environment.

GDA conversion

GSWA commenced implementation of its strategies for the adoption of the Geodetic Datum Australia. These include field operations, manuscripts, hard copy, and digital mapping.

Public enquiries

The Geoscientific data management group responded to 183 public enquiries for the supply of GIS data or products.

Data access initiatives

A number of new initiatives have been undertaken by GSWA to provide remote access to its geoscientific data. These include:

- Interactive web-based mapping tools provided on the DME

home page using AVIMS. Datasets include the petroleum management system (WAPIMS) and the aeromagnetic index (MAGIX). The 1:100 000 and 1:250 000 geological series maps will be added shortly

- Interactive CD-ROM packages using ArcExplorer. The interface

visualization and querying of the geoscientific data without the need to own a GIS software package

- Implementation of the Geoscientific data management group Intranet site. The site provides on-line mapping, and the provision to download

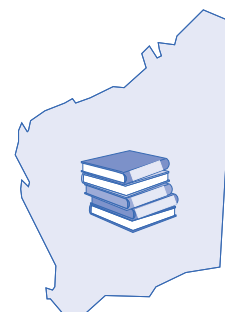
commonly used digital files and documents relating to procedures and standards.

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Subprogram 3106 GEOSCIENTIFIC AND EXPLORATION INFORMATION

Geoscience information library

Objective: To provide an effective and efficient geoscientific information service that meets the needs of the minerals and petroleum industry, educational institutions, the general public, and the Department.



Highlights and activities for 1999–2000

In June 2000, the Departmental Library moved to its new location on Level 1 North of Mineral House, providing external clients with improved access and closer proximity to public services available from the Information Centre. The relocation included the establishment of a new storage facility on Level 1 South to hold backruns of journals. On-site Library visits, especially by external users, has increased since the relocation.

Public access to scanned open-file company exploration reports on CD-ROM was established for customer use in the Library. Reports can now be viewed in the Library as .pdf files, which has resulted in a greatly improved quality in report viewing and reproduction. This has been complemented by the introduction of web-based ('WAMEX via the Web') access to open-file exploration reports, thus providing users with an efficient means to identify and access reports.

The Library commenced the reorganization of the GSWA thin section collection. More than 50 000 thin sections have now been placed in sequential order and stored in appropriate cabinets. Thin sections described in GSWA reports can now be readily accessed by both Departmental and external users.

The web version of the Library's online catalogue (OLIB) was made available to DME staff via the DME Intranet, and work is currently underway to make it available to the public via the World Wide Web.

Library usage

During 1999–2000, 5427 users visited the Library, a decrease of 8% on the previous year. This figure included 835 users of the microfiche facilities to access open-file exploration data. Library staff dealt with 4762 enquiries, a decrease of 19% compared with the previous year. The decline in on-site users follows the trend of the previous year and is the result of the current downturn in the resources industry.

Library collections and services

Continuing efforts were made to provide access to additional datasets for users, with all records indexed on the Library OLIB database. These included:

- The Mid West and Gascoyne imagery project data
- Unpublished reports from the various sections of GSWA. These publications provide short reports on specific areas of investigation carried out by the different sections within GSWA. To date, all reports by the Geophysics section have been indexed and those of the former Petrology section are currently being added
- The Library CD-ROM collection, which includes Landsat TM image files, GSWA 1:100 000 sheet geological data packages, offshore acreage release data packages, and more
- Publication series (e.g. Bulletins, Reports) from Commonwealth and State agencies including GSWA, DME, CSIRO, BRS, BMR,

AGSO, and MERIWA. All titles are indexed with a minimum of a title and a holdings statement, while all GSWA and DME publications will include full indexing at issue level.

Provision of services to clients included:

- The establishment of the Geoscience Data Access Station. Users can now access high-quality geophysical datasets provided by GSWA and AGSO, including aeromagnetic, gravity, and radiometric data for all of Western Australia. Access is via a high-end PC using ER Mapper 6.0 software donated by Earth Resource Mapping. Users can produce colour A4/A3 prints or colour plots
- A second microfiche reader/printer was placed in the Kalgoorlie Regional Office to

facilitate public access to open-file company exploration reports. This additional equipment, plus access to exploration reports on CD-ROM and the WAMEX *via the Web* search facility, will significantly improve data access for regional users.

Future work

Consolidation of the GSWA thin section collection will continue. This will include the completion of filing of all 3.5" sections, large plates, and polished mounts into appropriate storage. All sample data sheets will be placed into sample order number and filed. This will be the first time that all thin sections have been consolidated into a single sequence that allows ease of access for clients.

The provision of on-line access to electronic journals for DME staff

will commence. Access will be through the Library DME Intranet site, with links to all available on-line journal titles. This service will ensure users have immediate access to geoscientific literature as it is published.

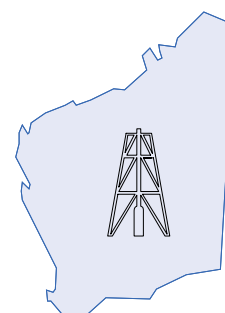
Access to the Library OLIB database will be extended to external customers via the World Wide Web. This will provide users anywhere in the world with access to the DME Library's vast holdings of information covering all aspects of the geology and mineral and petroleum resources of Western Australia.

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Statutory exploration information group

Objectives: To administer the collection and storage of statutory mineral and petroleum exploration reports relating to tenements in Western Australia, and to ensure the efficient dissemination of information in these reports to industry.



This subprogram covers all aspects of the submission, management, and release of mineral exploration data through WAMEX (the Western Australian mineral exploration database) and petroleum exploration data through WAPIMS (the Western Australian petroleum information management system).

Highlights for 1999–2000

- During 1999–2000, metadata and format standards for the reporting of exploration data in digital form were reviewed in consultation with industry groups. These standards were consolidated in 'Requirements for the submission of mineral exploration data in digital format' and form the core of standards accepted by the Chief Geologists Conference as the
- basis of national reporting requirements for the mineral exploration industry
- A web-based interface to the open-file subset of the WAMEX database was made available for public use
- The 'Schedule of petroleum exploration wells — Barrow Sub-basin' and the 'Gazette of onshore seismic surveys' were released
- Mineral exploration reports are now being submitted in digital format, as .pdf files, and tabular data as ASCII tab-delimited files. Submission of digital data is voluntary and will not preclude submission of reports in hard-copy format
- Data from several sources are being linked in the WAPIMS database to give a map-based

browser to all petroleum exploration activities conducted in the State, including seismic lines, aeromagnetics and gravity polygons, and well locations. This map-based search tool is the interface to the WAPIMS data on the World Wide Web.

Report submission

Mineral exploration

During the year, 2186 mineral exploration reports (3011 volumes) were received, representing industry activity on 10 710 tenements. The total number of volumes held is now 70 499. Gold is still the most commonly sought commodity, with over 75% of reports submitted relating to exploration programs for gold. Submission of data in digital form continues to increase, with

about 22% of all reports submitted during the year containing some digital data.

Reporting standards (mineral exploration)

This year has been the fourth full year of required compliance with the 'Guidelines for mineral exploration reports on mining tenements' and the first year in which companies could submit data in digital format conforming to the Department's requirements. Quality-control checking by Departmental staff has found that compliance with hard-copy reporting guidelines has been increasing, with a reduction to 18% in the number of reports not complying with the guidelines. The submission of digital data is voluntary and, as the 'Requirements for the submission of mineral exploration data in digital format' were still subject to revision after industry consultation, many companies had not prepared the appropriate software or templates to submit the data according to these requirements. It is anticipated that the release of the revised requirements will encourage submission of digital data in the required formats.

Petroleum exploration

During 1999–2000, activities on the 206 active petroleum tenements in Western Australia generated 33 496 sets of data, a decrease of 45% over the previous year, to make a total of 666 900 registered sets of petroleum data held or administered by the Department. The data sets include reports, seismic sections, well logs, digital data, maps, cores and cuttings, and palaeontological data.

WAMEX and WAPIMS databases development

During the year, a web-based interface to the open-file subset of the WAMEX database was made available for public use. Several enhancements were made to the original version, with the addition of more search fields.

Work on the WAPIMS database, for the management of petroleum data, has continued, with all new petroleum exploration data now being captured and managed in this database and most historical data being verified and transferred from the old WAPEX database. A regularly updated spreadsheet containing the metadata captured in WAPIMS is now accessible on the Department's web site. Towards the end of the year, a web-based map-browser front end to WAPIMS was also launched.

Data release

Mineral data

During the year, 1299 reports were released to open file, bringing the total number of open-file mineral reports to 22 575 reports. The reports, which had previously been released as microfiche, are now being released in digital form. Hard copies are being scanned to .pdf and, where appropriate, zipped with digital data supplied by the companies.

Petroleum data

During 1999–2000, 635 reports (made up of 184 basic, and 451 basic and interpretive reports), 12 sets of well logs, and 18 sets of seismic

sections were released. The group responded to 130 requests for access to tapes from 380 seismic surveys (6625 seismic tapes) and 123 petroleum wells. In addition, 46 requests for sample drillcore or cuttings from 205 wells and 18 requests for palaeontological data were satisfied.

Future work

- Implementation of the revised 'Requirements for the submission of mineral exploration data in digital format'
- Development of a web-enabled, map-based search front-end to the WAMEX database
- Progressive capture of metadata for digital files submitted prior to the release of the 'Requirements for the submission of mineral exploration data in digital format'
- Progressive acquisition in digital format of legacy tabular data previously submitted in hard-copy reports
- Implementation of the strategy developed for the progressive release to open file of the 10 year 'Sunset Clause' mineral exploration reports
- Management of the pilot project and subsequent implementation of the Petroleum Data Management Strategy, including the transfer of the WAPIMS database from a PC-based platform to a more robust, secure system that can support World Wide Web links to non-confidential information.

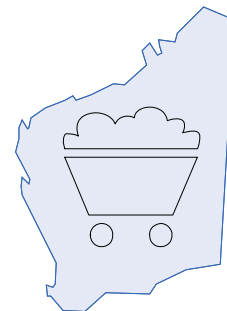
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Subprogram 3107

INVENTORY OF ABANDONED MINE SITES

Inventory of abandoned mine sites

Objectives: *To locate abandoned mine sites in the State and determine the safety and environmental hazards they pose. This will provide a sound basis for future planning of the necessary remedial action and rehabilitation of high-risk abandoned mine sites.*



Highlights and activities 1999–2000

During 1999–2000, the first year of the program, a database and field data collection system were successfully designed and implemented. The innovative GSWA method of recording the field data was recognized widely and requested by the Department of Primary Industries and Resources of South Australia and the Northern Territory Department of Mines and Energy.

Fieldwork was conducted at high-priority sites in the Lake Austin, Cue, Lake Annean, Meekatharra, Darling Fault (near Perth), Ravensthorpe, Northampton, Yalgoo, Paynes Find, and Mount Magnet areas. In addition, an

inventory of the 73 State battery sites was prepared for Gold Corporation. The end-of-year target of 5000 points in the database was exceeded, with 8920 points at 30 June 2000.

Substantial quantities of historic production data were captured into MINEDEX, and capture of locations of historic production sites through tenement information was almost completed. About 12 162 sites of historic mineral production are known; most of these (9874) represent gold production. Of the 9874 known gold production sites, 3810 are within 10 km of towns, an additional 476 are less than 1 km from major roads, and 4590 are less than 1 km from minor roads. Priority is being given to those sites in close proximity to towns and major roads.

All mines that closed prior to 1990 may fall within the abandoned category. Mines that have closed since 1990 are already well located and have environmental matters addressed within either Notices of Intent to commence mining operations (introduced in 1986) or by DME's environmental management system (introduced in 1990).

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Appendices

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Geological Survey Liaison Committee	128



List of acronyms and abbreviations

AAPG	American Association of Petroleum Geologists
ABS	Australian Bureau of Statistics
AESIS	Australia's National Geoscience, Mineral and Petroleum Reference database
AGIA	Australian Geoscience Information Association
AGSEAN	Australian Geologist Skills and Employment Advancement Network
AGSO	Australian Geological Survey Organisation
AMF	Australian Mineral Foundation
AMIRA	Australian Mineral Industries Research Association Limited
ANZMEC	Australian and New Zealand Minerals and Energy Council
ANU	Australian National University
APLA	Australian Prospectors and Leaseholders Association
APPEA	Australian Petroleum Production and Exploration Association Limited
ASEG	Australian Association of Exploration Geophysicists
ASX	Australian Stock Exchange
AusIMM	Australasian Institute of Mining and Metallurgy
AVIMS	ArcView Internet Map Server
BMR	Bureau of Mineral Resources
BRS	Bureau of Resource Sciences
CSIRO	Commonwealth Scientific Industrial Research Organisation
DME	Department of Minerals and Energy
DOLA	Department of Land Administration
EXACT	Western Australian Mineral Exploration Activities database
GIS	Geographic Information System
GSLC	Geological Survey Liaison Committee
GSWA	Geological Survey of Western Australia
JORC	Joint Ore Reserves Committee of the Australasian Institute of Mining and Metallurgy, Australian Institute of Geoscientists, and Minerals Council of Australia
Landsat TM	Landsat Thematic Mapper
LME	London Metals Exchange
MAGIX	Mineral Airborne Geophysics Information eXchange
MERIWA	Minerals and Energy Research Institute of Western Australia
MINEDEX	DME's mines and mineral deposits information database
MINESTAT	Mineral production module of MINEDEX
NGMA	National Geoscience Mapping Accord
OLIB	Oracle Libraries database
PALAEODATABASE	GSWA's palaeontological database
PDAC	Prospectors and Developers Association of Canada
PESA	Petroleum Exploration Society of Australia
REGOCHEM	GSWA's regolith and geochemistry database
RFA	Regional Forest Agreement
SHRIMP	Sensitive high-resolution ion microprobe
SPOT	Satellite Pour L'Observation de la Terre
TENGRAPH	DME's electronic tenement-graphics system
WACHEM	Western Australian inorganic geochemistry database
WACHRON	Western Australian geochronology database
WAMEX*	Western Australian mineral exploration database
WAMIN	Western Australian mineral occurrence database
WAMPRI	Western Australian Minerals and Petroleum Research Institute
WAPEX*	Western Australian petroleum exploration database
WAPIMS	Western Australian petroleum information management system database
WAREG	Western Australian regolith observation database
WAROX	Western Australian field observation database

NOTE: * WAMEX and WAPEX are registered Trade Marks



Planned achievements and publications released

Major planned achievements for 1999–2000

The GSWA had an ambitious project-based program of work designed to promote Western Australia's exploration potential. The programmed planned achievements for 1999–2000 were:

- release of 32 geological maps at various scales;
- publication of 52 geoscientific Bulletins, Reports, Explanatory Notes, Records, and other papers;
- publication of four GIS-based regolith geochemistry data packages;
- publication of two GIS-based mineral occurrence and exploration potential packages;
- publication of two urban and development areas resources digital datasets;
- publication of 20 seamless 1:100 000 geological maps in the Eastern Goldfields (Menzies–Norseman);
- continued and enhanced provision of geoscientific data and exploration information to industry and the public through our library services and the mineral (WAMEX) and petroleum (WAPIMS) exploration databases.

During 1999–2000, changing priorities resulted in the completion of a different mix of published output for the year than was originally planned. The balance shifted, with fewer books (47) and maps (31) published, and more geophysical images (10) and digital datasets (12). In overall terms, GSWA publication milestones for 1999–2000 were exceeded. The total number of published products was one hundred, and exceeded our target by seven. Four GIS-based regolith geochemistry datasets were published as planned, and the 'seamless' dataset of twenty 1:100 000 geological maps from the Eastern Goldfields was released in November 1999 for evaluation and feedback from users (the final version being released in early July 2000). Only one of the two planned urban and development areas resources GIS packages was released, whereas both the planned mineral occurrence and exploration potential GIS packages were released. Nonetheless, by the end of the year, a total of twelve digital datasets had been released, which exceeded our target of nine.

Enhancements to statutory information services to industry via the WAMEX and WAPIMS database systems continued. A user-friendly, searchable version of the WAMEX system was made available via the DME web site, and access to WAPIMS data was added to the web site with a GIS-based map interface. Both of these web services are being provided to customers free of charge.

Products released in 1999–2000 allowed the Geological Survey to again (for the fifth successive year) exceed its target productivity improvement of 5%. A real productivity gain of 5.23% was achieved in 1999–2000.

Maps, books, and datasets released in 1999–2000

Geological maps

1:50 000 Regolith–landform resources map	GERALDTON (1840-III) by R. L. Langford
1:100 000 Geological Series	LAKE GILES (2838) by J. Greenfield ERRABIDY (2347) by S. A. Occhipinti and S. Sheppard MEREWETHER (2844) by D. D. Ferdinando and N. S. Tetlaw PATERSON (3354) by L. Bagas EARAHEEDY (3246) by N. G. Adamides, F. Pirajno, R. M. Hocking, and J. A. Jones GRANITE PEAK (3146) by J. A. Jones JACKSON (2737) by A. Riganti and S. F. Chen JOHNSTON RANGE (2738) by S. Wyche, S. F. Chen, J. E. Greenfield, and A. Riganti PINDERI HILLS (2255) by C. J. Kojan and A. H. Hickman ROEBOURNE (2356) by A. H. Hickman METHWIN (3047) by R. M. Hocking and J. A. Jones LANDOR (2247) by S. Sheppard and S. A. Occhipinti RHODES (3147) by F. Pirajno and R. M. Hocking WARRAWAGINE (3056) by I. R. Williams
1:100 000 Geological Series preliminary release	ULLAWARRA (2151) by I. A. Copp, D. McB. Martin, A. M. Thorne, and L. Bagas
1:250 000 Geological Series	ROEBOURNE (SF 50-3) by A. H. Hickman and R. H. Smithies WILUNA (SG 51-9) by T. R. Farrell
1:250 000 Regolith Geochemistry maps and GIS packages	STANLEY (SG 51-6) by S. A. McGuinness and A. J. Sanders AJANA (SG 50-13) by A. J. Sanders KINGSTON (SG 51-10) by S. A. McGuinness and K. J. Pye Fraser Range region (3433, 3434, 3533, 3534, 3535, 3635) by A. J. Sanders
<i>Geological maps at other scales</i>	Mineral deposits and interpreted pre-Cainozoic geology of the Gascoyne region, by F. Vanderhor (Record 2000/7, Plate 1, 1:1 000 000) Composite seismic montage, Yowalga area, Officer Basin by S. N. Apak and H. T. Moors (Report 76, Plate 1) Location map, Peedamullah Shelf and Onslow Terrace, by A. Crostella (Report 73, Plate 1, 1:500 000) Geological map of the Halls Creek Orogen, East Kimberley region, by I. M. Tyler (Bulletin 143, Plate 3, 1:500 000) Simplified geology of the Halls Creek Orogen, East Kimberley region, by I. M. Tyler (Bulletin 143, Plate 4, 1:500 000) Mineralization and geology of the west Pilbara, by L. Y. Hassan, I. Ruddock, R. W. Cooper, E. P. Peiris, A. H. Hickman, C. A. Strong, and R. H. Smithies (Report 70, Plate 1, 1:500 000) Mineralization and geology of the east Kimberley, by L. Y. Hassan (Report 74, Plate 1, 1:500 000) Iron ore deposits of the Pilbara region, by GSWA (1:500 000) Industrial minerals in Western Australia, January 2000, by J. M. Fetherston and P. B. Abeysinghe (Record 2000/3, Plate 1, 1:5 000 000)

Geophysical images

Magnetic anomaly map of Western Australia (1:2 500 000)
 YOUANMI (SH 50-4) total magnetic intensity image (1:250 000)
 STANLEY (SG 51-6) total magnetic intensity image (1:250 000)
 YOUANMI (SH 50-4) ternary radiometric image (1:250 000)
 STANLEY (SG 51-6) ternary radiometric image (1:250 000)
 STANLEY (SG 51-6) Bouguer gravity image (1:250 000)
 KINGSTON (SG 51-10) Bouguer gravity image (1:250 000)
 WINNING POOL – MINILYA (SG 49-16, SF 50-13) Bouguer gravity image (1:250 000)
 AJANA (SG 50-13) Bouguer gravity image (1:250 000)
 Fraser Range region (3433, 3434, 3533, 3534, 3535, 3635) Bouguer gravity image (1:250 000)

Digital datasets with self-loading viewing software

Mineral occurrences and exploration potential of the west Pilbara (to accompany Report 70)
 Mineral occurrences and exploration potential of the east Kimberley (to accompany Report 74)
 Regolith–landform resources of the Geraldton 1:50 000 sheet (to accompany Record 2000/17)
 Gazette of onshore seismic surveys
 GSWA palaeontology reports, 1962–96

Other digital datasets

Geochemical mapping of the Ajana 1:250 000 sheet (GIS dataset)
 Geochemical mapping of the Fraser Range region (GIS dataset)
 Geochemical mapping of the Kingston 1:250 000 sheet (GIS dataset)
 Geochemical mapping of the Stanley 1:250 000 sheet (GIS dataset)
 Digital extract from MINEDEX database (to accompany Record 2000/13)
 Plates 2–8 of Geology and petroleum potential of the Peedamullah Shelf and Onslow Terrace, Northern Carnarvon Basin (to accompany Report 73, in prep.)
 Iron ore deposits of the Pilbara region (GIS dataset)

Reports

- 57 **Geology and petroleum exploration potential of the central and southern Perth Basin**, by A. Crostella and J. Backhouse
- 58 **Subsurface facies analysis of Devonian reef complexes, Lennard Shelf, Canning Basin, Western Australia**, by I. A. Copp
- 59 **Geology and mineralization of the Palaeoproterozoic Bryah and Padbury Basins, Western Australia**, by F. Pirajno, S. A. Occhipinti, and C. P. Swager
- 60 **Geology and mineralization of the Palaeoproterozoic Yerrida Basin, Western Australia**, by F. Pirajno and N. G. Adamides
- 70 **Mineral occurrences and exploration potential of the west Pilbara**, by I. Ruddock
- 74 **Mineral occurrences and exploration potential of the east Kimberley**, by L. Y. Hassan
- 76 **Basin development and petroleum exploration potential of the Yowalga area, Officer Basin, Western Australia**, by S. N. Apak and H. T. Moors

Records

- 1999/1 **Program 2 – Industry support, Geological Survey plan for 1999–2000 and subsequent three years**, by GSWA
- 1999/10 **A modified palynological preparation technique for the extraction of large Neoproterozoic acanthomorph acritarchs and other acid-insoluble microfossils**, by K. Grey
- 2000/2 **Compilation of geochronology data, 1999**, by D. R. Nelson

- 2000/3 **Industrial minerals in Western Australia: the situation in 2000**, by J. M. Fetherston and P. B. Abeysinghe
- 2000/4 **Archaean geology of the Muccan region, East Pilbara Granite–Greenstone Terrane, Western Australia – a field guide**, by I. R. Williams and A. H. Hickman
- 2000/5 **Archaean geology of the North Shaw region, East Pilbara Granite–Greenstone Terrane, Western Australia – a field guide**, by M. J. Van Kranendonk and A. H. Hickman
- 2000/6 **Operations and processing methodology used in GSWA regional gravity surveys 1998–1999**, by S. H. D. Howard and S. I. Shevchenko
- 2000/7 **Geology and mineral resources of the Gascoyne Region**, by D. J. Flint and P. B. Abeysinghe
- 2000/8 **GSWA 2000 extended abstracts: Geological data for WA explorers in the new millennium**, by GSWA
- 2000/9 **Archaean geology of the West Pilbara Granite–Greenstone Terrane and Mallina Basin, Western Australia – a field guide**, by A. H. Hickman, R. H. Smithies, and D. L. Huston
- 2000/11 **Composition of Geological Survey of Western Australia geochemical reference materials**, by P. A. Morris
- 2000/12 **Gravity data – Ajana 1:250 000 sheet, Western Australia**, by S. I. Shevchenko
- 2000/13 **Mines and mineral deposits of Western Australia: digital extract from MINEDEX – an explanatory note**, by D. B. Townsend, Gao Mai, and W. R. Morgan
- 2000/15 **Gravity data – Fraser Range region, Western Australia**, by S. I. Shevchenko
- 2000/17 **Regolith–landform resources of the Geraldton 1:50 000 sheet**, by R. L. Langford

Explanatory Notes
1:100 000 Geological Series

- Geology of the Blanche–Cronin 1:100 000 sheet**, by L. Bagas
- Geology of the Cooragoora 1:100 000 sheet**, by I. R. Williams
- Geology of the Errabiddy and Landor 1:100 000 sheets**, by S. Sheppard and S. A. Occhipinti
- Geology of the Merrie 1:100 000 sheet**, by N. G. Adamides
- Geology of the Milgun 1:100 000 sheet**, by C. P. Swager and J. S. Myers
- Geology of the Millrose 1:100 000 sheet**, by T. R. Farrell and S. Wyche
- Geology of the Mulline and Riverina 1:100 000 sheets**, by S. Wyche
- Geology of the North Shaw 1:100 000 sheet**, by M. J. Van Kranendonk
- Geology of the Poisonbush 1:100 000 sheet**, by I. R. Williams and L. Bagas
- Geology of the Throssell 1:100 000 sheet**, by I. R. Williams and L. Bagas
- Geology of the Wiluna 1:100 000 sheet**, by R. L. Langford, S. Wyche, and S. F. Liu

1:250 000 Geological Series

- Lissadell 1:250 000 sheet, Western Australia (second edition)**, by A. M. Thorne, S. Sheppard, and I. M. Tyler
- Rudall 1:250 000 sheet, Western Australia (second edition)**, by L. Bagas, I. R. Williams, and A. H. Hickman

1:250 000 Regolith Geochemistry Series

Geochemical mapping of the Ajana 1:250 000 sheet, by A. J. Sanders and S. A. McGuinness

Geochemical mapping of the Fraser Range region, by P. A. Morris, A. J. Sanders, S. A. McGuinness, J. Coker, and J. D. King

Geochemical mapping of the Kingston 1:250 000 sheet, by K. J. Pye, P. A. Morris, and S. A. McGuinness

Geochemical mapping of the Stanley 1:250 000 sheet, by P. A. Morris, S. A. McGuinness, A. J. Sanders, and J. Coker

Miscellaneous publications

GSWA Annual Review 1998–99

Gazette of onshore seismic surveys, by J. H. Haworth

GSWA palaeontology reports, 1962–96

Summary of petroleum prospectivity, onshore Western Australia: Canning, Officer, Perth, Southern Carnarvon, and Bonaparte Basins, by GSWA and Petroleum Division

Schedule of petroleum exploration wells – Barrow Sub-basin, by J. H. Haworth and L. M. Arden

GSWA Fieldnotes v. 14

GSWA Fieldnotes v. 15

GSWA Fieldnotes v. 16

Major planned achievements for 2000–01

The GSWA will continue to pursue a project-based program of work and maintain a vigorous level of output to match funding received. Planned Achievements for 2000–01 include:

- release of 26 geological maps at various scales;
- publication of 42 geoscientific Bulletins, Reports, Explanatory Notes, Records, and other papers;
- publication of two GIS-based regolith geochemistry data packages;
- publication of three GIS-based mineral occurrence packages;
- publication of three urban and development areas resources datasets;
- publication of 20 seamless 1:100 000 geological maps in the Menzies–Norseman area and 18 seamless 1:100 000 geological maps in the Laverton–Leonora area;
- publication of a 1:500 000-scale digital solid geology map of Western Australia;
- publication of several updates of previously released digital data packages;
- collection and publication of total magnetic intensity data for part of the Bangemall Basin and the SANDSTONE 1:250 000 map sheet;
- continued and enhanced provision of geoscientific data and exploration information to industry and the public through our library services and the mineral (WAMEX) and petroleum (WAPIMS) exploration databases.

The balance of product types within the planned achievements listed above may change during the course of the year as internal priorities change and the allocation of resources to reflect those priorities takes effect.



External papers published by GSWA staff in 1999–2000

In 1999–2000, the success rate for publication by GSWA staff in external referenced geoscience journals was established as a new performance indicator for the *quality* of our geoscientific output. Our goal was set at greater than 70% acceptance of papers submitted. In 1999–2000, we achieved a 93% success rate. The following papers were published externally in 1999–2000.

- ABEYSINGHE, P. B., 1999, Limestone and limesand resources in Western Australia: Industrial Minerals' Australasian Minerals and Markets 2000 Conference, Perth, W.A., 1999, Proceedings, 8p.
- ABEYSINGHE, P. B., 2000, WA limestone/sand — developments and future potential: Industrial Minerals, no. 393, p. 60–69.
- ABEYSINGHE, P. B., BLIGHT, D. F., FLINT, D. J., and THOMSON, C., 1999, Industrial minerals in Western Australia; existing projects and future potential: Industrial Minerals' Australasian Minerals and Markets 2000 Conference, Perth, W.A., 1999, Proceedings, 16p.
- APAK, S. N., and MOORS, H. T., 2000, A sequence stratigraphic depositional model of Neoproterozoic strata, Yowalga area, Officer Basin, Western Australia, *in* Proceedings 2000 APPEA Conference, Brisbane, Qld, 2000: APPEA Journal, v. 40, (1), p. 15–25.
- AROURI, K., CONAGHAN, P. J., WALTER, P. J., BISCHOFF, G. C., and GREY, K., 2000, Reconnaissance sedimentology and hydrocarbon biomarkers of Ediacarian microbial mats and acritarchs, lower Ungoolya Group, Officer Basin: Precambrian Research, v. 100, p. 235–280.
- BAKER, J. C., HAVORD, P. J., MARTIN, K. R., and GHORI, K. A. R., 2000, Diagenesis and petrophysics of the Early Permian Moogooloo Sandstone, Southern Carnarvon Basin, Western Australia: American Association of Petroleum Geologists, Bulletin, v. 84, no. 2, p. 250–265.
- CARLSEN, G. M., 2000, Hydrocarbons of the Western Australian Officer Basin, *in* Second Sprigg Symposium: Frontier Basins, Frontier Ideas compiled by G. R. WOOD: Geological Society of Australia, South Australian Division, Second Sprigg Symposium, Adelaide, S.A., 2000, Abstracts and Programme, p. 76–79.
- DAVY, R., PIRAJNO, F., SANDERS, A. J., and MORRIS, P. A., 1999, Regolith geochemical mapping as an adjunct to geological mapping and exploration: examples from three contiguous Proterozoic basins in Western Australia: Journal of Geochemical Exploration, v. 66, p. 37–53.
- DAWES, P. R., FRISCH, T., GARDE, A. A., IANNELLI, T. R., INESON, J. R., JENSEN, S. M., PIRAJNO, F., SONDERHOLM, M., STEMMERIK, L., THOMASSEN, B., and VAN GOOL, J. A. M., 1999, Kane Basin 1999: mapping, stratigraphic studies and economic assessment of Precambrian and Lower Palaeozoic provinces in north-western Greenland: Geology of Greenland Survey Bulletin, 186, p. 11–28.
- EL TABAKH, M., GREY, K., PIRAJNO, F., and SCRIBER, P., 1999, Pseudomorphs after evaporitic minerals interbedded with 2.2 Ga stromatolites of the Yerrida Basin, Western Australia: origin and significance: Geology, v. 27, p. 871–874.

- FLINT, D. J., and BRUCE, R. H., 2000, Summary of mineral and petroleum exploration and development in Western Australia in 1998–99: Australasian Institute of Mining and Metallurgy, Bulletin, no. 2, p. 15–19.
- GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 2000, DME's mine of information — a competitive advantage for Western Australia: Prospect Magazine, May, 2000.
- GOZZARD, J. R., 2000, Re-engineering the delivery of spatial information through an integrated geoscientific data management system, *in* Improving the chances of exploration success — the surface of the earth and the challenge of better exploring it: Australian Mineral Foundation, Symposium, Perth, W.A., 2000, Extended Abstracts, 9p.
- GRIFFIN, T. J., PAGE, R. W., SHEPPARD, S., and TYLER, I. M., 2000, Tectonic implications of Palaeoproterozoic post-collisional, high-K felsic igneous rocks from the Kimberley region of northwestern Australia: Precambrian Research, v. 101, p. 1–23.
- GUO, W., and HOWARD, S. H. D., 2000, Interpretation of the crustal structure between the Hamersley and Ashburton Basins from gravity and magnetic data in the Wyloo area, Western Australia, *in* Exploration Beyond 2000 edited by M. DENTITH and M. MIDDLETON, Australian Society of Exploration Geophysicists, 14th International Conference and Exhibition, Perth, W.A., 2000, Conference Edition: Exploration Geophysics, v. 31, p. 33–38.
- HILL, A. C., COTTER, K. L., and GREY, K., 2000, Mid-Neoproterozoic biostratigraphy and isotope stratigraphy in Australia: Precambrian Research, v. 100, p. 281–298.
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- HOWARD, S. H. D., 2000, Regional geophysics in GSWA: ASEG Preview, v. 86, p. 16–18.
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- MARTIN, D. McB., POWELL, C. McA., and GEORGE, A. D., 2000, Stratigraphic architecture and evolution of the Early Palaeoproterozoic McGrath Trough, Western Australia: Precambrian Research, v. 99, p. 33–64.
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- NELSON, D. R., TRENDALL, A. F., and ALTERMANN, W., 1999, Chronological correlations between the Pilbara and Kaapvaal cratons: Precambrian Research, v. 97, p. 165–189.
- OCCHIPINTI, S. A., SHEPPARD, S., TYLER, I. M., and NELSON, D. R., 1999, Deformation and metamorphism during the c. 2000 Ma Glenburgh

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- PAINTER, M. G. M., GOLDING, S. D., HANNAN, K. W., and NEUDERT, M. K., 1999, Sedimentologic, petrographic, and sulfur isotope constraints on fine-grained pyrite formation at Mount Isa mine and environs, northwest Queensland, Australia: *Economic Geology*, v. 94, p. 883–912.
- PIRAJNO, F., 1999, Past achievements and future challenges in the use of mineral deposit models, regional tectonics and metallogeny in mineral exploration: *South African Journal of Geology*, v. 102, p. 123–138.
- PIRAJNO, F., HOCKING, R. M., and JONES, A., 1999, Geology, mineralisation and geodynamic evolution of the Palaeoproterozoic Yerrida and Earraheedy Basins, W.A., *in* Two Billion Years of Tectonics and Mineralisation: Tectonics Special Research Centre, Conference Proceedings, Perth, W.A., 1999, p. 30–33.
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Note: GSWA authors are in italics



Geological Survey Liaison Committee

The Geological Survey Liaison Committee (GSLC) meets twice a year to review progress and advise on future work programs for the Geological Survey. The three Technical Subcommittees provide comment and advice in each of the special areas for consideration by the GSLC. The Regional Geochemical and Regolith Mapping Advisory Subcommittee has now been merged with the Regional Geoscience Mapping and Mineral Resources Technical Subcommittee. Members of GSLC include representatives from the Association of Mining and Exploration Companies (Inc.), Chamber of Minerals and Energy Western Australia (Inc.), Australian Petroleum Production and Exploration Association (Ltd), Petroleum Exploration Society of Australia, Australian Geological Survey Organisation, University of Western Australia, and Curtin University of Technology.

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