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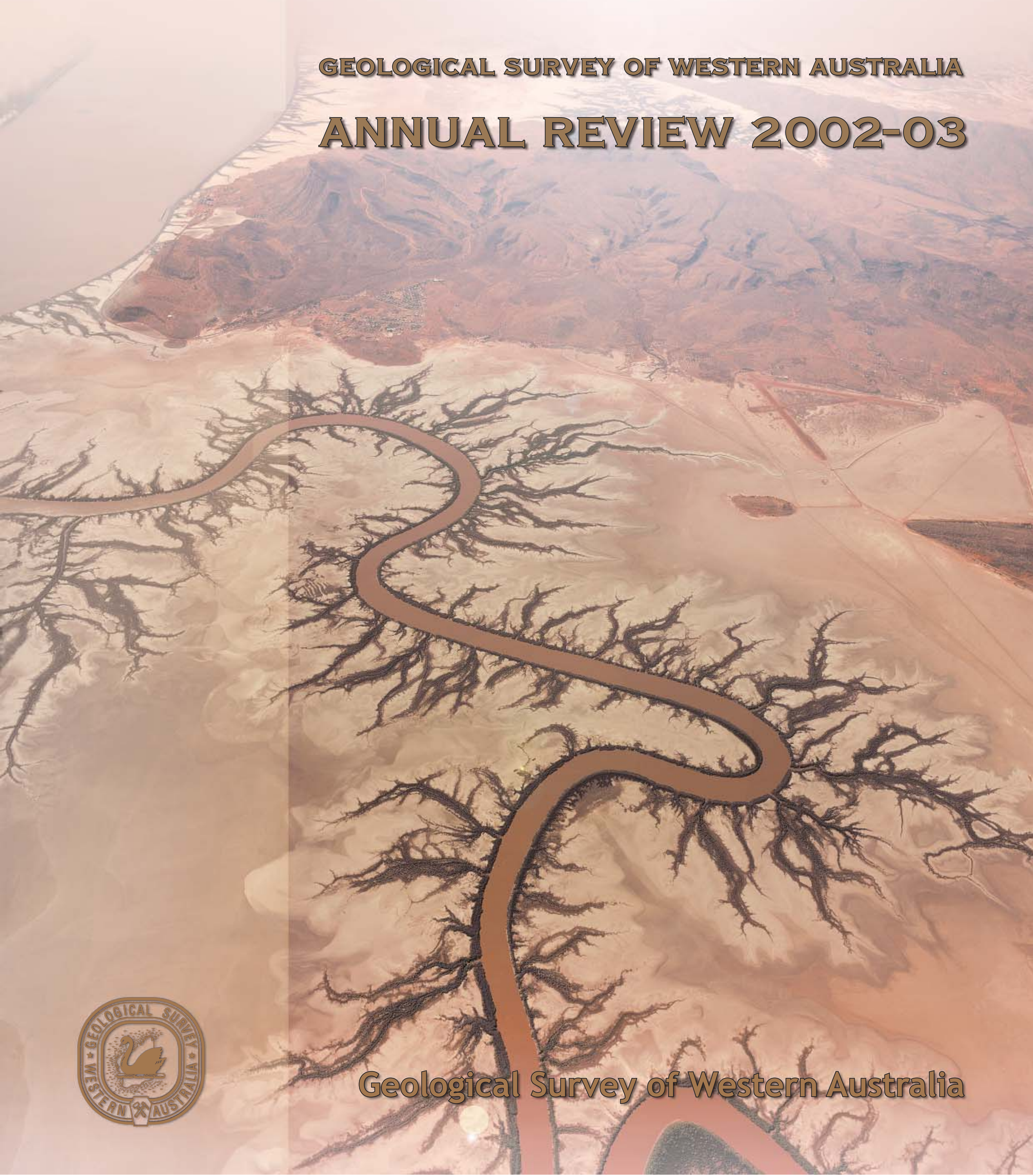

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REVIEW 2002-03

Geological Survey of Western Australia

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Perth 2003

MINISTER FOR STATE DEVELOPMENT
Hon. Clive Brown MLA

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Jim Limerick

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Tim Griffin

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Cover:
Oblique view of mangrove-fringed King River meandering across Quaternary tidal flats to flow into the west arm of Cambridge Gulf. Wyndham is visible in the foothills of the Bastion Range, which is of Palaeoproterozoic age. Photo reproduced by permission of the Department of Land Information, Perth, Western Australia, Copyright Licence 52/2003

Frontispiece:
Lake Carnegie, Earaheedy Basin. False colour image from NASA satellite, north is to left of page. Sandstone ranges of the Tooloo Subgroup of the Palaeoproterozoic Earaheedy Group are south of the lake, siltstone plains and limestone ranges of the Miningarra Subgroup (Earaheedy Group) are north and northeast of the lake respectively. Patterns in the lake reflect flooding and subsequent drying out of the lake sediments, and the islands are formed by eolian sands. Image is about 60 km across

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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-enchancing, 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 land use 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 land use 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 2002–03 year in review

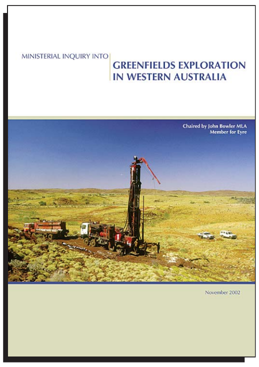
by Tim Griffin

Last year's review began with the news that the former Department of Minerals and Energy had been merged with the Department of Resources Development to form the Department of Mineral and Petroleum Resources. Change in the Western Australian public service continues, and in early 2003, the State Government announced that the Department of Mineral and Petroleum Resources would merge on 30 June 2003 with the Department of Industry and Technology to form a new Department of Industry and Resources (DoIR).

It is likely that GSWA will remain as an entity in the new Department, probably in the Investment Services Group where the Survey's role of promoting the prospectivity of WA to investors in exploration and mining has a natural fit.

Recent Australian Bureau of Statistics data appear to show that expenditure on mineral exploration has at last stabilized, following a five-year decline in spending from the peak of 1996–97. Western Australia, however, has maintained it pre-eminent position, attracting 58% of mineral exploration expenditure in Australia, which reflects the prospectivity of the State. It is the Survey's role to encourage and support resources exploration within Western Australia.

Industry Reviews and Inquiries



A major item in 2002–03 was the release of the report arising out of the Ministerial Inquiry into Greenfields Exploration in Western Australia. Chaired by John Bowler MLA, the inquiry made 33 recommendations to the Minister for State Development to improve the investment climate for exploration in Western Australia. Recommendations 2 (increase spending on pre-competitive geoscience data gathering) and 18 (introduce legislation to allow statutory mineral exploration reports to be released after 10 years of confidentiality) have particular relevance to GSWA. Similar recommendations were made in the Fardon Report tabled in Parliament by the State Government in 2001.

At the Federal level, written submissions and public hearings were conducted around Australia to gain industry input into the House of Representatives Inquiry into Resources Exploration Impediments chaired by Bob Prosser (MHR), which is due to report in September 2003. During the first half of 2003, the Mineral Exploration Action Agenda (MEAA) Strategic Leaders Group, comprising industry representatives and Commonwealth and State public servants, was developing recommendations for presentation to the Federal Minister for Industry, Tourism and Resources in July 2003. Federal Cabinet is expected to consider these recommendations in December 2003 and decide which of them would form part of an ongoing Mineral Exploration Action Agenda.

The Bowler Inquiry and the MEAA, and probably the Prosser Inquiry, have identified pre-competitive geoscience information as a major factor in stimulating modern exploration. Although the recommendations for increased spending on pre-competitive geoscience information are encouraging, the WA Government has made it clear that spending will be tightly constrained in the next few years. I hope that the Government will recognize GSWA as an **investment** rather than as a **cost** centre and that we can accelerate modern airborne geophysical survey and geological mapping programs.

These three inquiries all looked at options to redress the severe downturn in mineral exploration expenditure, particularly on greenfields exploration. More recently, we have been encouraged by a modest upturn in exploration expenditure that may herald a more robust return to higher levels of exploration (see 'Overview of mineral exploration in Western Australia for 2002–03' by D. J. Flint, this volume). Anecdotal evidence suggests that the exploration scene is improving, but the jury is still out on whether greenfields exploration is increasing. Some industry observers suggest that a fundamental shift has occurred in the exploration industry, particularly in the way that some large mining companies view greenfields exploration as a destroyer of shareholder value. What we all agree on, however, is that our geological knowledge of most greenfields areas is very incomplete because of poor surface outcrop and limited geophysical coverage. A better understanding of these areas will provide the opportunity to make the discoveries necessary to ensure the sustainability of the mining industry in this country.

Over the longer term, I am optimistic that a balance will be achieved in the proportion of expenditure that is directed to greenfields and brownfields exploration. Experience both in Western Australia and elsewhere indicates that the best way of increasing the level of greenfields exploration is by increased government expenditure on pre-competitive geoscience information gathering in such areas.

Completion of Western Australian core library facilities

Opening of the Perth core library facility in March 2003 completed a five-year construction program of facilities at Kalgoorlie and Carlisle. With a total investment of $9 million, the State Government has provided world-class core library facilities for use by mineral and petroleum industry customers, and CSIRO and University researchers. I sincerely thank the Association of Mining and Exploration Companies, the Chamber of Minerals and Energy, and the Australian Petroleum Producers and Explorers Association for the lobbying they did over the years that eventually led to the Government funding construction of these valuable facilities.

Staff maintain high productivity and quality standards

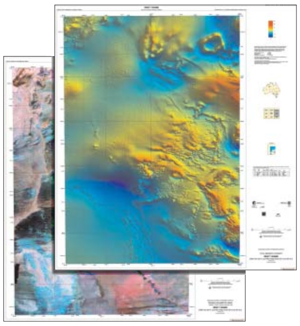
2002–03 was another highly productive year for GSWA with the completion of:

- 36 geoscience maps, including seven 1:100 000 series maps, three 1:250 000 maps, and 26 other maps
- 36 reports, records, and other publications
- 27 digital data packages

Despite a reduction in working hours to a nominal 37.5-hour week under the new industrial agreement, and a Government freeze on salaries for most staff, a modest increase in real productivity (measured on a cost basis) was still achieved. On current trends, this level of productivity will be difficult to maintain as GSWA's operational budget continues to be squeezed by rising costs in a fixed-dollar-value budget environment.

In early 2003, GSWA palaeontologist Dr Kath Grey was awarded the prestigious Gibb Maitland Medal by the Geological Society of Australia (WA Division) for her contributions to palaeontology and micropalaeontology. Kath is a tireless, gifted palaeontologist at the peak of her career. Her specialist studies on stromatolites of all ages have borne fruit and her biostratigraphic models have been integrated with stable isotope chemostratigraphy, making the dating of isolated successions, particularly from the Proterozoic, much more precise.

Work program highlights



During 2002–03, GSWA released 103 000 line km of airborne magnetics and radiometrics over the Tanami and west Musgrave areas in advance of ground-based regional geological mapping programs. Fieldwork in the Wingellina area of the west Musgrave Complex is due to commence later in 2003, and discussions are progressing well with the Ngaanyatjarra Council to undertake mapping over much of the area with the assistance of Aboriginal field officers.

In June 2003, GSWA released the Combined East Yilgarn Geoscience Database in preliminary form. This enormous GIS database incorporates information for 56 contiguous 1:100 000 sheets in the Norseman–Wiluna area of the Eastern Goldfields. The digital information includes outcrop geology, regolith, airborne geophysical data, Landsat TM images, exploration activity summaries, mines and mineral deposit data from MINEDEX, and tenement data from TENGRAPH.

An Atlas of all 1:250 000 geological maps of Western Australia was published as a CD in 2003. The atlas comprises images of the whole map sheet including the reference and cross section. The maps were scanned in cooperation with Geoscience Australia, and the availability of the entire State geology coverage at this scale (163 maps) on a single CD has proved extremely popular.

The 1:500 000-scale digital regolith map of Western Australia was released as part of GeoView.WA, accessed via DoIR's website. This new coverage complements the similar-scaled solid geology of the State released several years ago.

A report containing the first four years of data collection for the Abandoned mine sites project was released in June 2003. Locations, photos, and brief descriptions of all features associated with abandoned mine sites in high priority areas of the State are included in the digital release. The report details the technology used and outlines the statistical results of this first four-year phase.

Coincidentally, the Abandoned mine sites CD contained the first GSWA digital map product released using the GeoViewer.WA software. This software allows a user to interrogate each point or polygon on the virtual map, and the relevant summary, full description, or photograph can be displayed in seconds. The displayed maps, text, database report, or photographs can be printed directly or pasted into any Microsoft Windows-based program. The enormous flexibility of the GeoViewer.WA software provided on each CD allows users to define colours, symbols, fonts, transparency of map or image layers, and labels for data.

The future

GSWA is currently in a fixed budget environment with less flexibility in staffing than it had previously. The real financial value of the additional 'initiative' funding for regional geoscience mapping and for petroleum prospectivity enhancement that began in 1994 has declined significantly over the past nine years. Without the injection of new funding, GSWA's level of product and service delivery will inevitably decline, despite improvements in technology and continuous process improvement. This is because we have maintained staffing levels that allow us to continue to provide the full range of products and services of the past. We have done this in the expectation that the various reviews will result in additional funding to significantly extend the capture and distribution of pre-competitive information.

A significant aspect of our current work program is the requirement to establish robust databases, and to populate these with accurate data and information. This activity underlies the success of our new and expanding range of digital products.

These databases must cope with the diversity of geology and information types across the whole of Western Australia, together with the huge volume of data both from within GSWA and from the activities of the mineral and petroleum exploration industry. National standards for the geoscience databases are being developed cooperatively with Geoscience Australia and the other State and Territory Surveys.

I am hopeful that the common thread running through recommendations of the Bowler Inquiry, the Prosser Inquiry, and the Strategic Leaders Group developing the Mineral Exploration Action Agenda — the need for more, high-quality geoscience information, particularly in greenfields regions — will result in increased funding for GSWA by a Government that wants to ensure the sustainability of the mining industry in Western Australia.

Tim Griffin
Director

Overview of mineral exploration in Western Australia for 2002–03

by D. J. Flint

Overview

Western Australia continues to attract the major proportion of mineral exploration expenditure in Australia (58%), a reflection of the State's perceived prospectivity. During 2002–03, mineral exploration expenditure (excluding petroleum) figures for Western Australia rose by 8% ($30.7 million) to $423.6 million, after having fallen by 45% over the previous five years from a peak level of $806 million (2002–03 dollars) in 1996–97 (Fig. 1). Recent quarterly data show mineral exploration expenditure stabilizing at over $100 million per quarter, following the very low expenditure levels of only $87 million (seasonally adjusted terms) in mid-2002 (Fig. 2).

The Western Australian figures are consistent with worldwide trends and Australia as a whole. The 2002–03 level of mineral exploration expenditure within Australia is $732.5 million, which is 14% ($92 million) higher than during 2001–02. However, mineral exploration in Australia had declined by 45% ($508 million) during the previous five years, following the peak mineral exploration expenditure in Australia of $1149 million (2002–03 dollars) during 1996–97. The worldwide decline in exploration expenditure has been attributed to a number of factors, including continued low commodity prices, the ongoing perception of mining as a low-profit activity, lack of venture capital, slowing world economic growth, and the events of 11 September 2001. However, Australia and Western Australia continue to maintain their share of global exploration expenditure at about 18% and 10%, respectively.

Despite the downturn in exploration activities since 1997, important discoveries are still being made. These include gold discoveries in the Ashburton Basin and the northeastern part of the Kimberley Basin, the huge resource upgrade at Telfer gold mine, further base metal discoveries at and around Golden Grove and Teutonic Bore (Jaguar), and the discovery of high-grade nickel sulfides at Waterloo.

Mine development highlights include opening of the Thunderbox and Waugh gold mines, Ellendale diamond mine, West Angelas and Mining Area C iron ore mines, and Dardanup heavy mineral sands mine. The West Angelas operation represents a new phase in Western Australian iron ore mining as the first to market Marra Mamba iron ore as a standalone product. The numerous advanced projects include the direct smelting of iron ore (HIsmelt), the go-ahead for an iron ore mine at Eastern Ranges (near Paraburdoo), and the State's most advanced platinum–palladium project (Panton Sill), which is at the feasibility stage.

Mineral exploration expenditure by commodity

Exploration expenditure in Western Australia for gold and base metals (including nickel–cobalt) is near its lowest level for a decade, with exploration expenditure activity similar to the recession years of the early 1990s. Despite this, Western Australia still accounts for the major proportion of the exploration dollars expended in Australia, principally for iron ore (100%), nickel–cobalt (82%), gold (70%), diamond (60%), heavy mineral sands (28%), silver–lead–zinc (26%), and copper (7%).

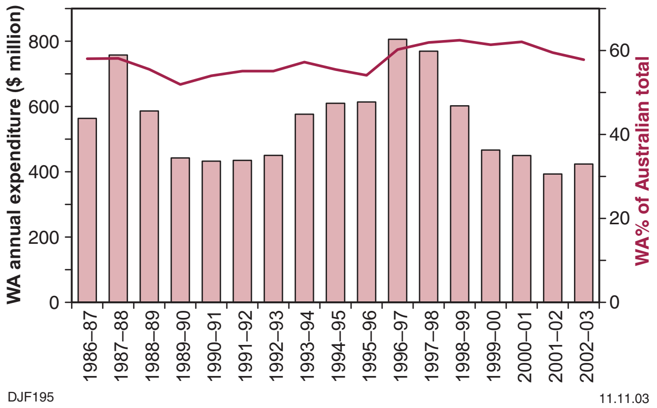


Figure 1. Mineral exploration expenditure in Western Australia, by financial year (2002–03 dollars)

Within Western Australia, gold remains the main focus of mineral exploration, accounting for about 63.6% of all exploration expenditure (Fig. 3). Other commodities, in their order of importance as exploration targets in Western Australia, are nickel–cobalt (11.7%), iron ore (8.5%), diamond (4.5%), copper–lead–zinc–silver (3.9%), heavy mineral sands (1.8%), and 'others' totalling 6.1%. 'Others' include all industrial minerals, construction materials, platinum group elements, rare earth elements, and coal–lignite.

During 2002–03, only $266 million was expended on gold exploration in Western Australia. The level is now down 57% ($354 million in 2002–03 dollar terms) from the 1996–97 peak, and represents a level that is equivalent to the bottom of the recession in the early 1990s (Fig. 4).

Exploration for base metals (including nickel and cobalt) recovered during 2002–03, following four years of substantial decline. Base metal exploration expenditure rose by 13% ($8.5 million) to $72.5 million, but is still 47% ($64 million) lower than the peak level of $136.5 million expended in 1997–98 (in 2002–03 dollar terms; Fig. 5). The recovery during 2002–03 is being led by exploration for and development of nickel sulfide deposits, particularly in the Kambalda area.

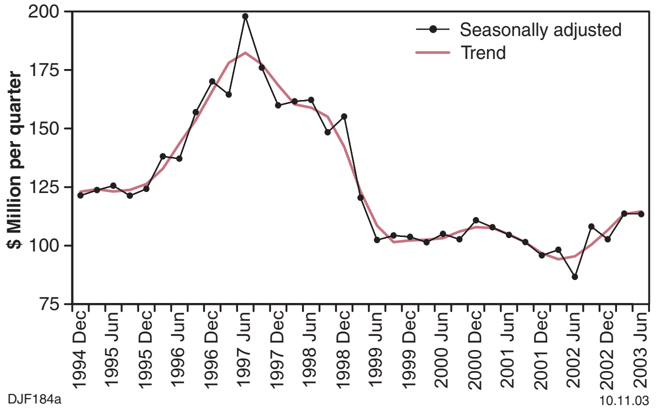


Figure 2. Mineral exploration expenditure in Western Australia, by quarter, on seasonally adjusted and trend terms (dollars of the day)

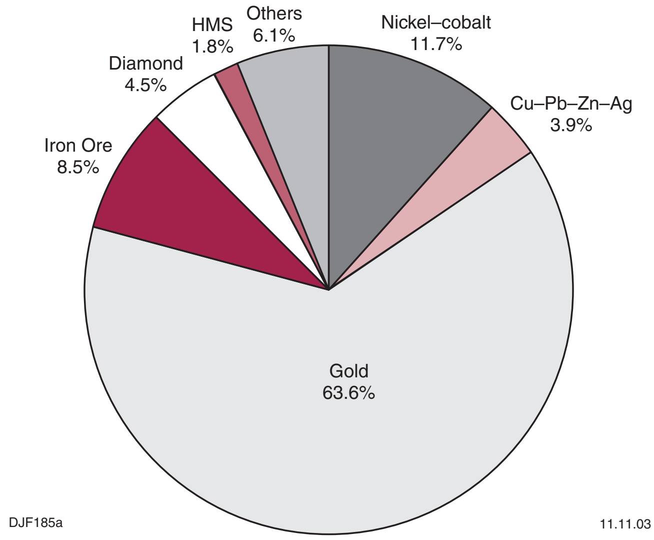


Figure 3. Mineral exploration expenditure in Western Australia, by commodity (2002–03)

Diamond exploration in Western Australia decreased by a further 43% during 2002–03, falling by $13.3 million to only $17.8 million for that period. The fall was primarily due to completion of a major phase of resource–reserve drilling at Argyle and to the Ellendale project moving to the production phase. Diamond exploration expenditure has been subdued for many years and is now far below the peak level of $131 million in 1981–82 (in 2002–03 dollar terms), reflecting the general lack of exploration success in Western Australia.

During 2002–03, iron ore exploration within the State has remained steady at around $26 million, supported by strong customer demand for iron ore, particularly from China. Significant positive developments during 2002 and 2003 included the opening of the West Angelas mine, development of Deposit C at Mining Area C, and the go-ahead for development of the Eastern Ranges deposits near Paraburdoo.

After the switch during the 1990s by mineral sand explorers to the Murray Basin in Australia's eastern states, exploration in Western Australia had stabilized at around $8.0–$8.5 million per year. As a result of that refocusing, Western

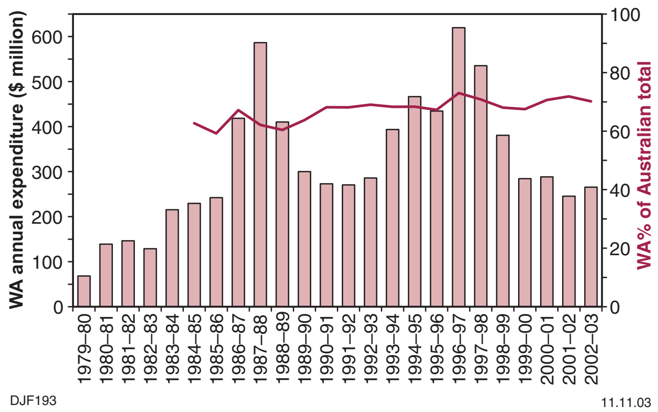


Figure 4. Gold exploration expenditure in Western Australia, by financial year (2002–03 dollars)

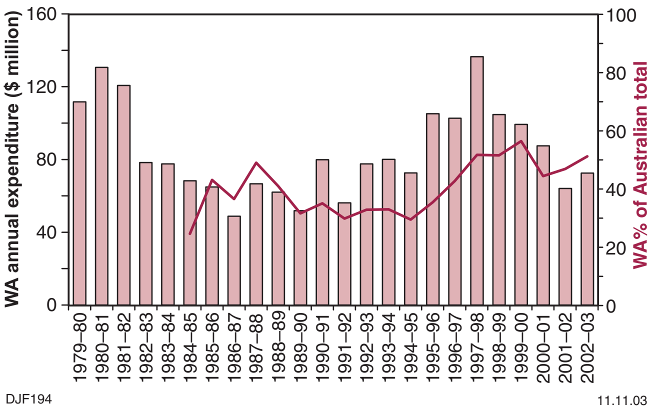


Figure 5. Base metal exploration expenditure in Western Australia, by financial year (2002–03 dollars). Base metals include copper, lead, zinc, silver, nickel, and cobalt

Australia's share of the Australian exploration expenditure for heavy minerals has fallen from around 70% of the total in the mid-1990s to only 28% in 2002–03. During 2002–03, exploration expenditure for heavy minerals in Western Australia dropped further, falling by 40% ($3.7 million) to only $5.5 million for that year.

Mining tenement activity

In general, the broad trends in mineral exploration expenditure were also reflected in the 2002–03 mineral tenement statistics[1]. For all tenement types under the Mining Acts of 1904 and 1978, the number of tenements in force decreased by 2.9% (478 tenements) to 16 009 tenements, whereas the area under tenure has increased significantly (11.6%) from 24.0 million hectares in 2001–02 to 27.9 million hectares in 2002–03 (Fig. 6).

Figure 6 illustrates that the tenement activity has declined substantially since the peaks in about 1995–96 and 1996–97. The number of tenements and area held under tenure in Western Australia show falls of 21% and 43%, respectively. However, the area under tenure is showing signs of an increase, presumably from the grant of more or larger exploration licences.

Figure 6 also illustrates the magnitude of the continuing backlog of pending tenements. The backlog situation increased in the early and mid-1990s, but has stabilized in recent years. There are now more exploration licences and mining leases pending than are granted. This backlog is widely interpreted to be largely the result of lengthy delays in progressing many tenement applications through the Native Title process.

Drilling activity

Drilling activity[2] in Western Australia has declined markedly since the peak of exploration in 1996–97, demonstrating that cut backs in exploration budgets have adversely affected all types of drilling (Fig. 7). Rotary air blast (RAB), reverse circulation (RC), and diamond drilling have now declined by about 80%, 65% and 65%, respectively, since their peaks in 1996–98. RAB drilling was the first to be affected when companies began to reduce expenditure and move away from grassroots (greenfields) exploration. This reduction in RAB drilling was followed one year later by declining RC drilling, as expenditure cuts deepened. RAB and RC drilling continued to decline during 2001–02, and were joined by a decrease in diamond drilling during 2001–02. As this data series is a trailing indicator, it is not expected that the drilling statistics will show any improvement when the data for 2002–03 become available.

[1] Tenement data supplied by DoIR's Mineral Titles Division

[2] Drilling statistics extracted from DoIR's WAMEX database, as supplied by the mining industry and best regarded as a trailing indicator. Data for 2002–03 not yet available

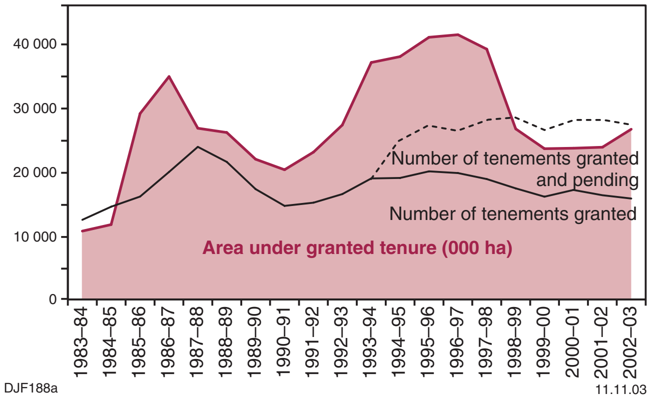


Figure 6. Tenement activity, Western Australia (1904 and 1978 Mining Acts)

Such declines in drilling activity greatly diminish the number of opportunities for significant discoveries, which are necessary to boost mineral resource inventories, sustain the current level of mining development, and provide opportunities for growth in the industry.

The falls in 'metres drilled' from earlier peak levels in 1996–97 show a more dramatic trend in reduced exploration activity than the more general fall shown in the overall trend for exploration expenditure. The decline of about 80% in RAB, 65% in RC, and 65% in diamond drilling, since the peak of the boom, should be compared with the corresponding drop of 'only' 46% in total exploration expenditure and the 57% decline in gold exploration expenditure. The generalized Australian Bureau of Statistics (ABS) data for the whole of Australia are similar, and show a decline in metres drilled of 65% for the same time.

Recent quarterly data from the ABS for Australia show that the downward trend in drilling activity since 1997 has levelled off during 2002, and drilling activity is perhaps recovering slightly in late 2002 and early 2003 (Fig. 8).

Government inquiries into reduced mineral exploration

Both the Western Australian and Federal Governments recognize that the declining level of mineral expenditure is a major issue, and two parliamentary inquiries were commissioned during 2002 — the Bowler and Prosser Inquiries, respectively.

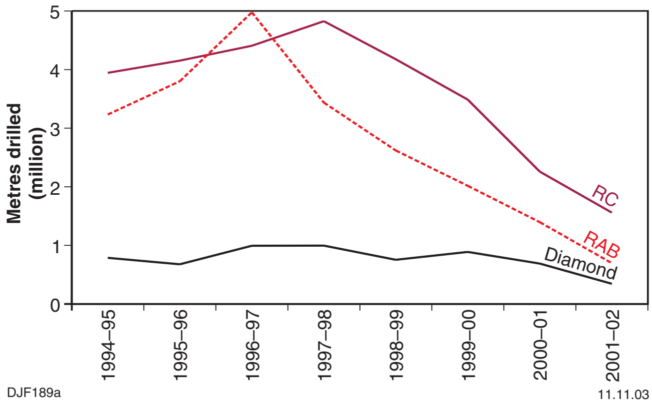


Figure 7. Mineral exploration drilling in Western Australia, by drilling type and year

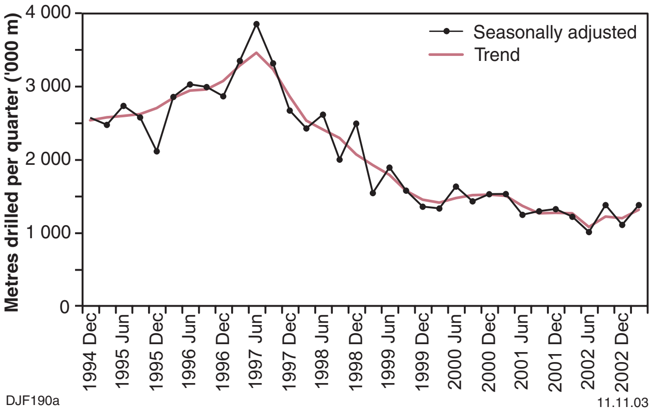


Figure 8. Australian mineral exploration drilling, by quarter

In Western Australia, the State Government instigated a Ministerial Inquiry, chaired by Mr John Bowler MLA, Member for Eyre. The Inquiry was to investigate all avenues that could lead to the increase of private investment in mineral exploration in Western Australia, particularly in greenfields or frontier areas.

The key factors identified as impacting on greenfields exploration in Western Australia included the following: reducing the backlog of mining lease applications, improving perceptions of prospectivity and the attractiveness of investing in exploration projects, managing native title issues and mineral titles, facilitating research and development, facilitating land access, Federal Government issues, including taxation, and increasing community understanding of the mineral resources sector.

The Inquiry's report, which is detailed and very comprehensive, has been presented to the Minister for State Development, Hon. Clive Brown, MLA and can be viewed in full at the website of the Department of Industry and Resources.

The Federal Government has instigated a House of Representatives Inquiry, chaired by the Hon. Geoffrey Prosser MP, Federal Member for Forrest (WA). The Prosser Inquiry aims to identify impediments to increasing investment in mineral and petroleum exploration in Australia.

Inside GSWA

Jennifer Anne Mikucki

Jenny Mikucki is the Process Leader of the Publications and Information (P&I) Unit — the publishing nerve centre of the Geological Survey. As the 30th June deadline draws near each year she has the unenviable task of ensuring that the publishing targets (colloquially termed 'wombats') for the whole Survey are met, and can be seen admonishing her troops, cajoling them, brandishing chocolate, and even offering other inducements to 'get the wombats home'. She also believes that there is no problem that cannot be solved over yum cha. In 2002–03 the Survey produced 36 books, 36 maps and images, and 27 geo-scientific digital data sets — testament to her strategic skills.

Jenny is from Melbourne — another in the long list of escapees from the insular eastern states to this occidental paradise! She grew up in Glen Waverley, and completed her undergraduate Science degree at Monash University in 1987. Jenny then set to work at Monash University in the Stable Isotope Extraction Laboratory for 18 months, where she crushed rocks and dissolved them in dangerous substances to release their gases for measurment. She and her husband moved west to follow the job trail, and Jenny worked in the E. de Courcy Clarke Museum at the University of Western Australia as well as in the Stable Isotope Laboratory at UWA. Jenny started her post-graduate studies at UWA in 1990 and completed her PhD as a part-time student in 1997. The title of her thesis was 'Contrasting fluid sources and mineralization styles in the Great Eastern Archaean lode-gold deposit, Lawlers, Western Australia'.

Jenny arrived in P&I in 1994 and immediately established herself as a force to be reckoned with.

In the time she has been in the section, she has been promoted from Level 2/4 to Level 5, and to her current position at Level 6 in recognition of her talents for organization, her supportive skills, her leadership qualities, and her thorough grounding in the various complex facets of a modern publishing house. The sophisticated digital printing process is a far cry from earlier days when hand-drawn figures were manually pasted into a master copy for copying (this was still the modus operandi about 6 or 7 years ago). However, Jenny refuses to acknowledge that she commenced work in P&I in the era of hot-metal typesetting!

Jenny is married to Ed Mikucki (an escaped American geologist) and they live in the Mundaring hills with their wildlife, including three children — Ed junior, Melissa, and Jessica. She loves playing the keyboard and the share market, and would like more time to pursue her other interests of sewing and reading.

Wayne Hitchcock

Wayne is a homegrown Western Australian who grew up in a farming environment in Gingin. After leaving Bullsbrook District High School in 1986, Wayne worked in the construction industry doing concreting and tilt-up panelling. In 1998, he completed a Mining Geoscience Course at Leederville TAFE that made him decide to pursue a career in the mining industry. He worked for Black Stump Consultancy Group, mostly with Outokumpu, as an underground sampler, until he joined GSWA.

Wayne is the Core Librarian at the Joe Lord Core Library in Kalgoorlie. The core library is in very good hands. His commencement with the organization in 2000 coincided with the completion and official opening of the core library and Wayne has been instrumental in setting up many of the operational procedures. He is actively involved with the acquisition, collection, and archiving of all drillcore to be stored there. Such drillcore includes: significant exploration and mining core that illustrates various styles of mineralization from throughout the State; historical or heritage core that is representative of past exploration and mining; and significant stratigraphic drillcore. Wayne is always happy to make core available for viewing on request — in fact he likes sharing the core.

Wayne's other significant role in the Kalgoorlie Office, apart from babysitting geologists, is to organize promotional displays, many of which are for international delegations. Wayne always goes out of his way to help customers and staff in the office and is cheerfully obliging. He is an excellent team player. The types of people and questions Wayne deals with on a day-to-day basis are extremely varied, and range from helping with tenement information to locating old graves on early mining leases.

Wayne loves the weather and the general lifestyle of Kalgoorlie. His agricultural background has manifested itself in a love of gardening — the lack of rain and the red dust are no deterrent at all. One recurring theme in Wayne's gardening is his preference for straight lines. He has been heard to comment that he doesn't like 'arty farty curvy lines' in his garden. However, it is quite obvious from Wayne's gardening efforts that he does have a green thumb. His garden at home also incorporates fish and several chickens. The eggs from the chickens are perfect for toasted egg and cheese sandwiches. Whether the ever-expanding cactus garden in his office is meant to portray to customers how much he loves gardening or to ward off potential burglars is unclear. Wayne also has some cattle and a pet stock horse on a property 40 km out of Gingin on the Moore River, which he regularly visits. Wayne's other great passion is breeding marine fish. He doesn't have a favourite fish, but does admit this might be because they all taste good. Despite all Wayne's interests he is still willing to give up his free time to lend his handyman skills to friends.

Wayne is a true bargain hunter! Anyone wanting to find the best bargains need only talk to him. His main sources are the 'Quokka' and garage sales and he is always finding very cheap, interesting 'things' to buy. Only he, however, knows and understands the value and use of many of these 'things'. One significant failure on his part in his bargain-hunting career was when he **didn't** purchase a bargain stuffed crocodile that was for sale through the 'Quokka'. Wayne's bargain-hunting skills have really been put to the test by his house renovating as all sorts of vital pieces of equipment and furniture have been bought for a song.

Wayne is a young, dynamic core librarian who is gathering together a storehouse of historical and current exploration artefacts that symbolize the story of mining in the goldfields.

Alan Thorne

Alan was born and brought up in South Wales before graduating with a BSc (Hons) from Southampton University, and a PhD from University College, Swansea. After completing his doctorate on the Carboniferous Limestone in South Wales (the field work for which was done by corporation bus), he worked as a petrographic consultant before emigrating to Australia, where he joined the Geological Survey of Western Australia in 1980. He has worked in the Regional Mapping branch (formerly the Precambrian Geology branch) ever since. At one stage he was the sole representative in the Survey's Karratha Office before it was closed in 1987. He is at present Project Manager of the newly named Capricorn Orogen Project. Alan takes his project leader responsibilities very seriously — even scheduling board meetings during lunch times.

Alan has co-authored major bulletins on the geology of the Ashburton Basin and the Fortescue Group, and has also mapped a number of sedimentary basins in the east Kimberley region. He is very well known and respected for his rigorous work on sedimentary basin analysis in Western Australia, which is underpinned by careful and methodical field observations. The sedimentological interpretion of the Ashburton Formation constructed by Alan and Dave Seymour in the 1980s is being supported by new geochronological data on detrital zircons nearly 20 years later. These days he is to be found working his way eastward along the vast extent of siltstone and carbonate that form the Edmund and Collier Basins (formerly Bangemall Basin).

Alan's expertise and enthusiasm in applying computing to geology is much sought after in the Regional Mapping branch. He is part of a small group that is pioneering the use of GIS in the Survey's regional map compilation and the production of seamless digital data packages. Alan has always readily shared his knowledge and experience with his colleagues and, in particular, the younger geologists.

The spirit of scientific enquiry and a fondness for the peace and quiet of the bush have maintained Alan's enthusiasm for fieldwork. He is notorious for being early to bed, and even earlier to rise, much to the consternation of one or two of his colleagues who prefer a more leisurely start to the day (i.e. when it gets light). However, he never allows his propensity for rising early to dull his enthusiasm to offer empty beer cans (and the occasional champagne/port bottle) to the gods at Beer O'Clock each evening. Being a light sleeper, Alan has devised various elaborate setups over the years to keep the light of the moon at bay. These problems are now a thing of the past with his 'superswag', a custom-designed combination of swag and small tent. His desire to camp well away from any road at night may owe something to having once camped next to a dirt road that turned out to be the access for a constant stream of water trucks filling up at a nearby standpipe and coating the camp in dust all night.

Alan is one of GSWA's gourmet bush cooks and believes that a little of bit of chilli never goes astray. His field vehicles usually have Tardis-like properties, containing everything to cover any eventuality. An avid West Coast Eagles supporter, he listens to their evening matches on ABC radio in the bush. However, he has been known to periodically mumble about 'poor reception' (particularly when the Eagles are being thrashed).

His sporting interests and hobbies include cricket, Aussie Rules footy, furniture making, gardening, and playing guitar. His passion for music ranges from classical to jazz and blues. Married to Christine (who acted as his field assistant for a season during the Ashburton Basin mapping) for 22 years, he has two children — Daniel (18) and Sarah (16).

Staff list
(30 June 2003)

GRIFFIN, Tim (Director)

Regional Geoscience Mapping Branch

DONALDSON, Mike (General Manager)
TYLER, Ian (Chief Geoscientist)

Terrane Custodians
MORRIS, Paul (Archaean and Regolith — Chief Geochemist)
SHEPPARD, Steve (Proterozoic Orogens)
HOCKING, Roger (Basins)

Capricorn Orogen
MARTIN, David
THORNE, Alan

Earaheedy Basin
JONES, Amanda
PIRAJNO, Franco

East Yilgarn (Kalgoorlie Office)
GROENEWALD, Bruce
GOSCOMBE, Ben
HALL, Charlotte
JONES, Sarah
RIGANTI, Angela

Central Yilgarn
CHEN, She Fa
DOYLE, Mark
WYCHE, Stephen

Pilbara Craton
BAGAS, Leon
FARRELL, Terry
HICKMAN, Arthur
SMITHIES, Hugh
VAN KRANENDONK, Martin
WILLIAMS, Ian

Lennard Shelf
PLAYFORD, Phillip

Geochronology
BRZUSEK, Marianna
CLANCY, Lisa
NELSON, David
WILLIAMS, John

Geophysics, Remote Sensing and Regolith
HOWARD, David
MARNHAM, Jodi
SHEVCHENKO, Sergey
WATT, John

Publications and CAD
COSGROVE, Lisa
DAY, Lyn
DOWSETT, Suzanne
EDDISON, Fiona
FOGARTY, Louise
HALL, Glennis
HARTLEY, Gary
HOFFMAN, Arthur
JOHNSTON, Jean
JONES, Murray
KUMAR, Manjeet
LENANE, Tom
MIKUCKI, Jennifer
MULLIGAN, Sue
NASH, Margie
NOONAN, Kath

PRAUSE, Michael
REDDY, Devika
STRONG, Caroline
SUTTON, Dellys
WILLIAMS, Geoff

Map Production and GIS
BANDY, Stephen
BRIEN, Cameron
CLAIR, Brett
COLDICUTT, Shaun
COLLOPY, Sean
D'ANTOINE, Neville
DAWSON, Brian
FRANCOIS, Annick
GREEN, Ellis[1]
GREENBERG, Kay
HAMILL, Sammy
KIRK, John
KUKULS, Liesma (Les)
LADBROOK, David
LESIAK, Irena
LOAN, Geoff
McCABE, Marian (Kalgoorlie)
PIZZI, Trevor
SIMONETTI, Joseph
TAYLOR, Peter
THEEDOM, Erica
VICENTIC, Milan
WARD, Brendon
WILLIAMS, Brian
WRIGHT, Gareth

Data Integration
GOZZARD, Bob

Mineral and Petroleum Resources Branch

ROGERSON, Rick (General Manager)
ROBERTS, Ivor (Mineral Resource Services)

Petroleum Systems Studies
CARLSEN, Greg (Industry Liaison)
DE LEUW, Lorraine
D'ERCOLE, Cecilia
GHORI, Ameed
HAINES, Peter
IASKY, Robert
IRIMIES, Felicia
LOCKWOOD, Andrew
MORY, Arthur
SIMEONOVA, Anelia
STEVENS, Mark

Mineralization and Exploration Assessment
ABEYSINGHE, Pathmasekara (Abey)
FERGUSON, Ken
HASSAN, Lee
PEIRIS, Elias
RUDDOCK, Ian

Industrial Minerals
FETHERSTON, Mike

Mining Legislation Advice
PAGEL, Jutta

Resource Assessment and Land Access
ANDERSON, Bill
COOPER, Roger
FLINT, Don
FREEMAN, Mike
KOJAN, Chris
TRENCH, Gao Mai

Resource Mapping and Assessment
LANGFORD, Richard

Inventory of Abandoned Mine Sites
HOWARD, Heather
RISBEY, Steve
ORMSBY, Warren

Palaeontology
GREY, Kath

Executive Support
CRESSWELL, Brian
SLATER, Elizabeth
STOYANOFF, Nell

Special Projects
GOSS, Andrew

Carlisle Operations
BONER, Peter
CAREW, Eugene[1]
CLARK, Dean
ELLIOTT, Ian
GREEN, Robert
HOLMES, Mario
LOCKYER, Stuart
MEDDINGS, Garrie
MOORE, Brian

Core Libraries
HITCHCOCK, Wayne (Kalgoorlie)
BROOKS, Chris
HOLLAND, Trevor
WILLIAMS, Gary

[1] on secondment to another Division

Mineral and Petroleum Exploration Information
BELL, Ann
DODD, Fiona
EASTMAN, Rachel
ELLIS, Margaret
EMMS, Rosie
FITTON, Ann
HAWORTH, Jeffrey
HUGHES, Bernard
KARNIEWICZ, George
MASON, Jan Sandra
MacCORQUODALE, Fiona
McKEATING, Joan
NAGY, Pearl
O'BRIEN, Richard
STAPLETON, Gladys[1]
THOMSON, Amanda

Staff movements (1 July 2002 to 30 June 2003)

Internal reclassifications
D'ERCOLE, Cecilia — to Level 5
GHORI, Ameed — to Level 7
HITCHCOCK, Wayne — to Level 3
JONES, Amanda — to Level 5
MARTIN, David — to Level 6
SMITHIES, Hugh — to Level 7

Commencements
CLAIR, Brett
DOYLE, Mark
EASTMAN, Rachel
FOGARTY, Louise
GOSCOMBE, Ben
HAINES, Peter
HALL, Charlotte
HOGBEN, Jane
HOLLAND, Trevor
HOWARD, Heather
PIZZI, Trevor
RISBEY, Steve
ROSS, Adrienne
SIMONETTI, Joseph

Resignations
APAK, Sukru (Neil)
DALY, Matthew
DOWNING, John
EATON, Nathan
HOGBEN, Jane
ROSS, Adrienne
WALKER, Robert
WALLACE, Darren

Secondments
CAREW, Eugene — to Office of Major Projects
GREEN, Ellis — to Corporate Services Division
STAPLETON, Gladys — to Mineral Titles Division

Transfers in (DoIR integration)
FREEMAN, Mike — from Land Access Branch

Transfers out (DoIR integration)
WONG, Henrietta — to Petroleum Division

Casual and short term contracts
COPP, Iain
FERGUSON, Andrew
FRICK, Louise
IASKY, Victoria
SUCHODOLSKI, Christine

Corporate Services — locally delivered
Human Resources
MILLER, Ian
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- *Data Integration*
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- *Basins*
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- *Proterozoic Orogens*
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Roger Hocking: 9222 3590

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Greg Carlsen: 9327 5409

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Jeff Haworth: 9222 3214

Core Libraries
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Ivor Roberts: 9222 3783
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- *Principal Industry and Commodity Analyst*
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- *Industrial Minerals*
  Mike Fetherston: 9222 3322
- *Mineralization & Exploration Assessment*
  Ian Ruddock: 9222 3334
- *Development Areas Resource Mapping*
  Inventory of Abandoned Mine Sites
  Richard Langford: 9222 3632

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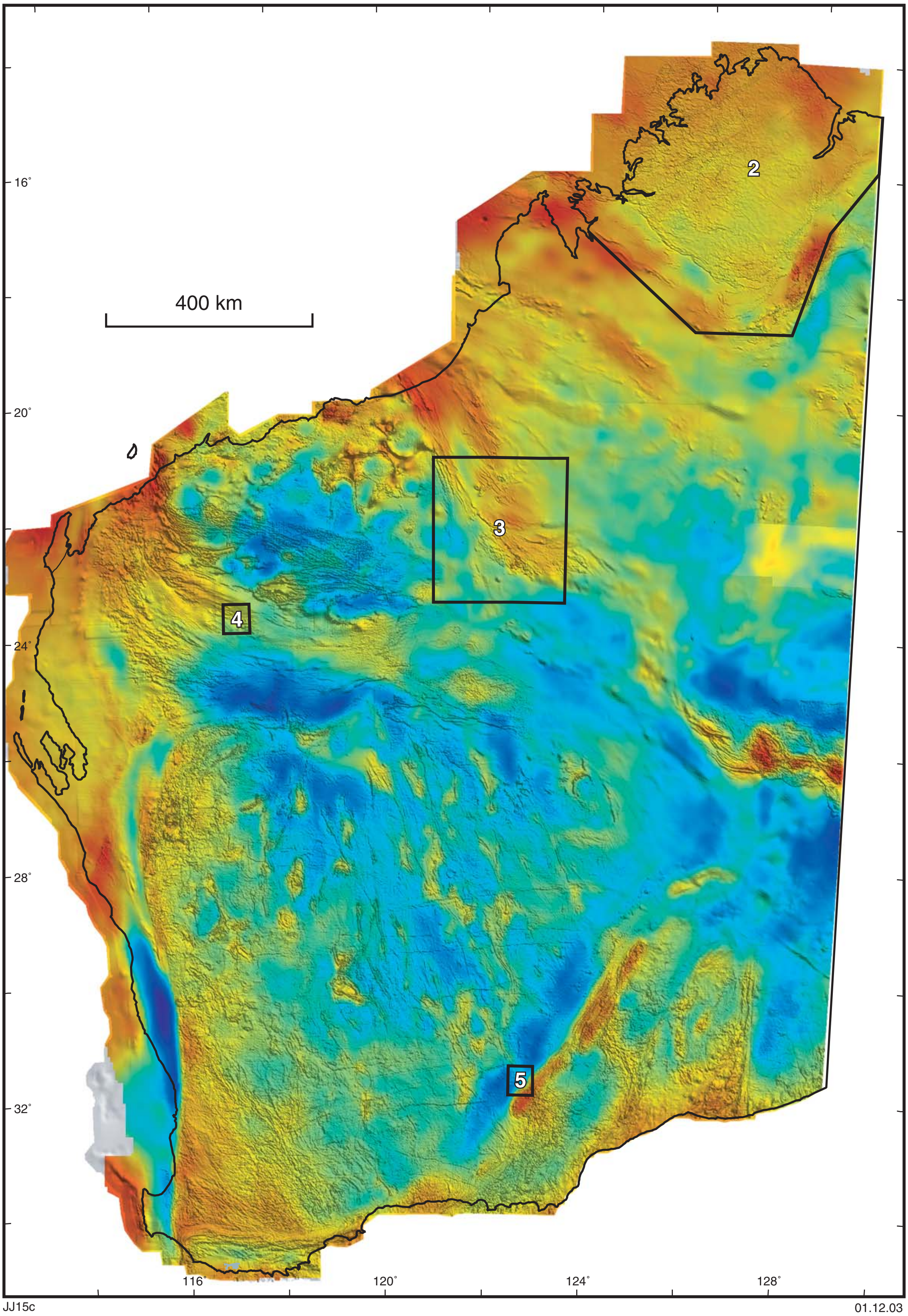

Map of Western Australia showing the locations discussed in four of the five technical papers on the following pages (Paper 1 covers the whole of Western Australia). Pseudo-colour Bouguer gravity and grey-scale Total Magnetic Intensity image. Blue = gravity low; TMI highlights structural information. Data courtesy of Geoscience Australia

Technical papers

A seamless digital regolith map of Western Australia: a potential resource for mineral exploration and environmental management

by J. Marnham and P. A. Morris

Abstract

Existing 1:250 000-scale geological maps have been synthesized and simplified to produce a seamless digital regolith map of Western Australia. Lithological units have been assigned to one of nine subdivisions, comprising areas of outcrop, residual or relict units (representing in situ regolith, or remnants of an earlier landscape), and seven transported regolith units (slope deposits, alluvium, lake deposits, calcrete, sandplain, coastal deposits, and tidal deposits). Significant areas of mining activity have also been identified. Where digital versions of geological maps were available, polygons were recoded according to the regolith classification scheme of the Geological Survey of Western Australia. For hard copy (analogue) maps, polygons were hand drawn, labelled, and scanned. All compilations were combined, edge-fitted, and the data gridded to reduce and standardize the complexity of the linework. The final product can be viewed online using GSWA's GeoVIEW.WA software.

KEYWORDS: Regolith, regolith maps, digital data, Western Australia.

Regolith and regional mapping

Regolith is the mostly unconsolidated mantle of weathered rock that covers large parts of Western Australia. Typically, regolith has been viewed as an impediment to discovering bedrock mineralization but, as it is derived from the physical and chemical weathering of bedrock, the distribution and composition of various types of regolith can be used as pathfinders to bedrock-hosted mineralization. Furthermore, regolith can host mineralization in its own right, including economic gold (Glasson et al., 1988), nickel (Burger, 1996; Hellsten et al., 1998), and bauxite (Taylor, 1990) deposits. The State's mineral production in 2002–03 was worth more than $17 billion. The regolith accounted for over 40% of this, including 5% of gold production, 25% of nickel industry production, and all mineral sands production, the latter worth almost $1 billion.

Maps showing the distribution of different regolith types (e.g. Figs 1 and 2) are important sources of data in formulating mineral exploration programs and understanding the results of regional geochemical surveys. Cornelius et al. (2001) used regolith mapping to identify ferruginous duricrust ('laterite') sampling sites for regional (9-km triangular grid) geochemical surveys, to indicate areas of mineralization in the southwest of the State. Morris et al. (2003) combined regolith mapping, geochemistry on widely spaced regolith samples (one per 16 km^2), geophysics, and bedrock mapping to delineate several areas of potential mineralization on the northeastern margin of the Archaean Yilgarn Craton. Morris et al. (2003) emphasized that regolith geochemistry can only be confidently interpreted when combined with regolith mapping, especially in areas with significant transported regolith — in the area of their study, transported material accounted for about 80% of regolith cover. Traditional approaches to regional geochemical surveys using stream sediment, soil, or lag as sample media (e.g. Fletcher, 1986) have been augmented by selective extraction techniques, and the use of other sample media, such as silcrete and calcrete (e.g. Lintern, 2001). In formulating such geochemical programs, regolith maps showing the distribution of targeted sample media are crucial.

Regolith maps also have potential for use in environmental management; for example, maps showing the distribution of lacustrine and alluvial deposits have direct application for the management of salt-affected areas. A knowledge of regolith distribution would also play an important role in infrastructure planning, flood mitigation, catchment management, and waste disposal.

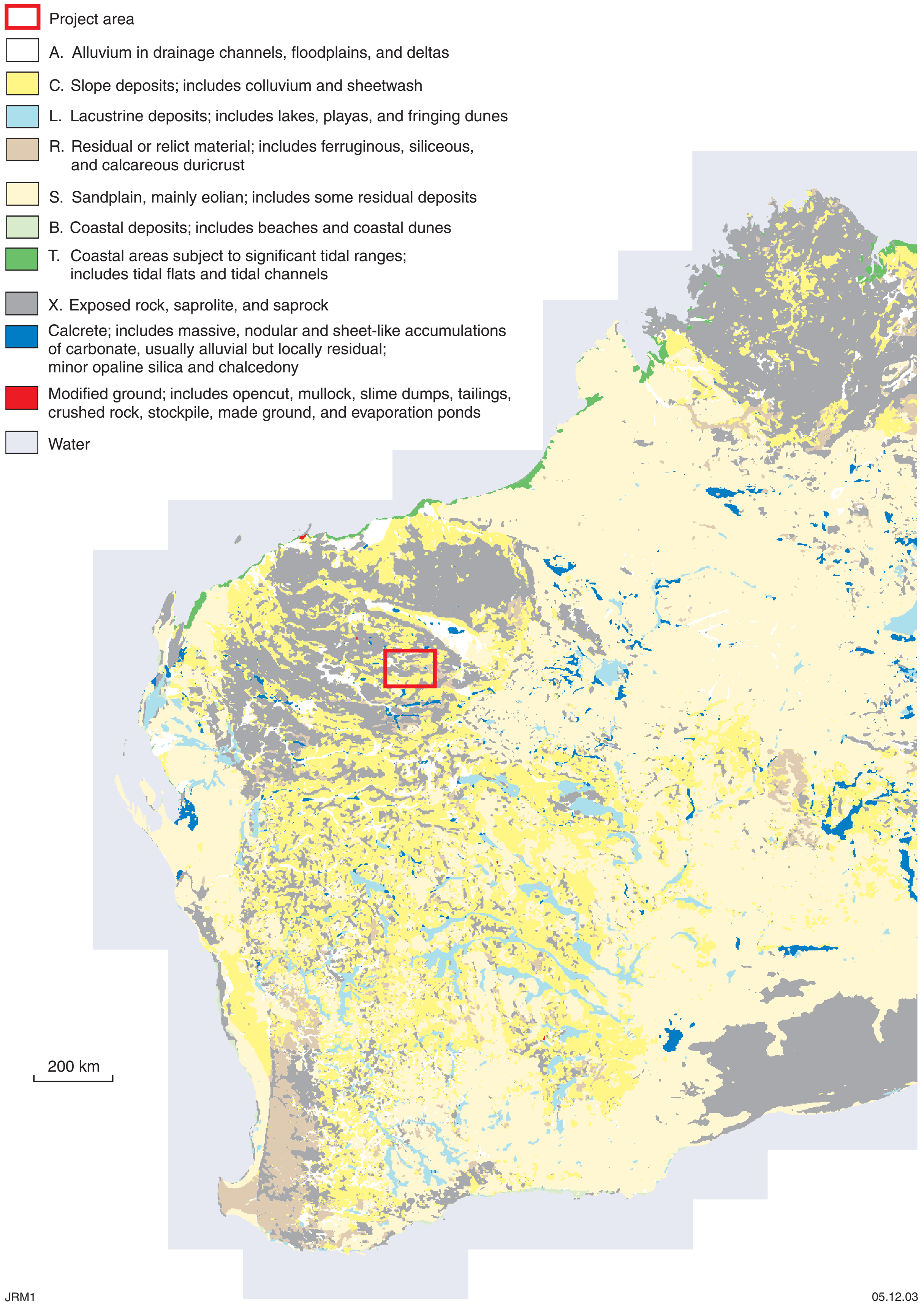

Figure 1. Regolith distribution in Western Australia, gridded at 1300-m cell size. The red rectangle shows the area covered in Figure 2

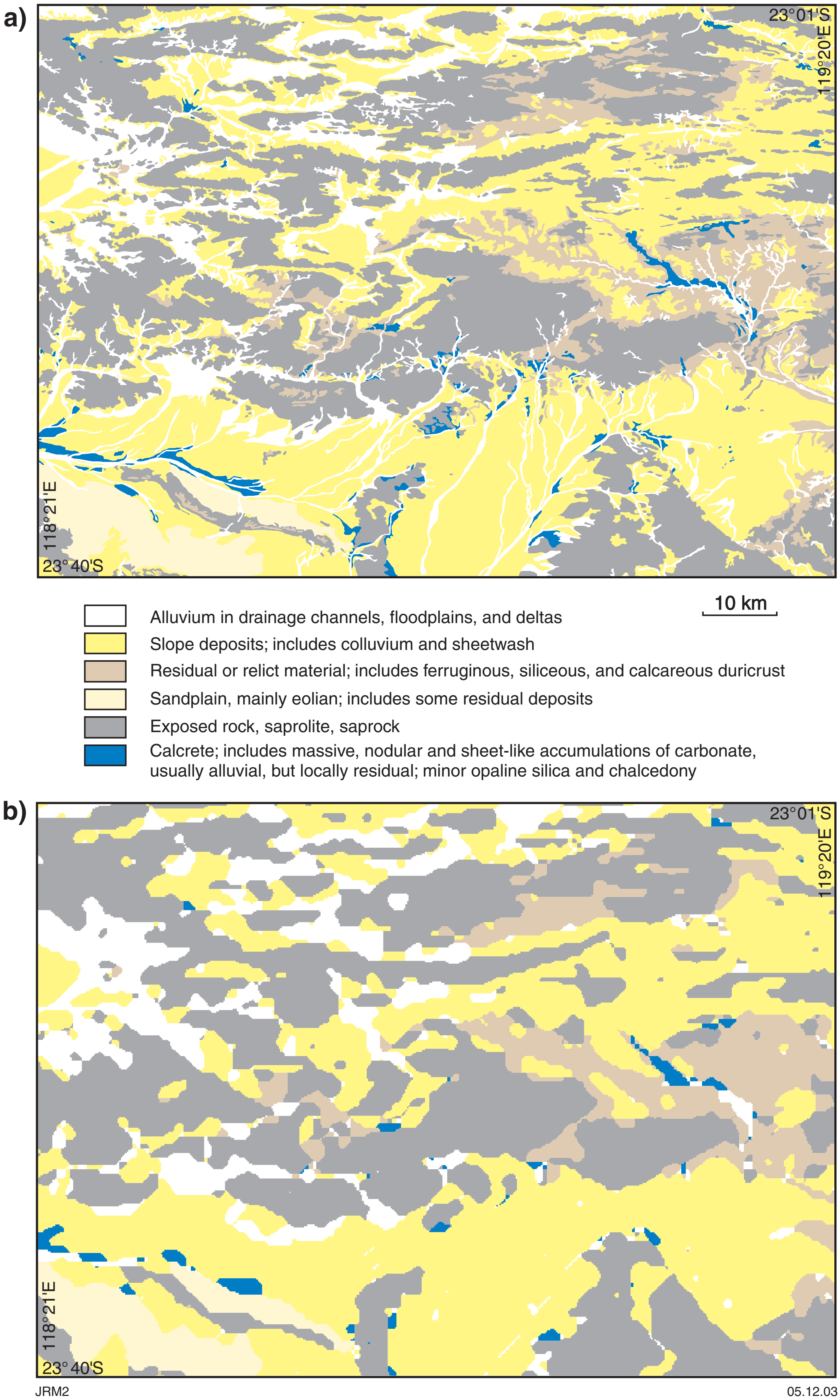

Figure 2. Regolith data between latitudes 23°01' and 23°40'S, and longitudes 118°21' and 119°20'E: a) ungridded; and b) gridded using a 500-m cell size

The digital data can also be used in formulating sampling strategies. For selected areas, the distribution of regolith types can be determined, and their area can be calculated. The spatial relationship between these units and others (e.g. outcrop and residual or relict units; lacustrine and alluvial deposits) can also be estimated. Intersection of regolith coverage with solid geology coverage means that further attributes can be added to regolith polygons, such as the composition of outcropping units.

The Geological Survey of Western Australia's (GSWA) State regolith map (Fig. 1) displayed at 1:500 000 scale will complement the existing 1:500 000-scale interpreted bedrock geology map for Western Australia (Vanderhor and Flint, 2001). As both are digital products, intersecting the two coverages will allow interrogation of both datasets to determine, for example, the composition of regolith designated as outcrop, the likely composition of proximal slope deposits, and the possible parent rock-type to residual or relict regolith units.

There are few regional-scale regolith maps available for much of Western Australia, the exceptions being the 1:1 000 000-scale map of the Kalgoorlie area (Chan, 1991) and CSIRO soil and land-use series maps (e.g. Bettenay and Hingston, 1961) — most are at a scale of 1:250 000 (e.g. Craig and Churchward, 1995), including GSWA regional regolith geochemistry series regolith maps (e.g. Kojan and Faulkner, 1994; Morris and Verren, 2001). Until the synthesis of regolith data throughout the State, discussed here, it was necessary to combine maps over the area of interest in an ad hoc fashion, and attempt to deal with discrepancies in the complexity and coding of regolith between adjacent map sheets. Completion of the State regolith map means that these issues have largely been resolved. Furthermore, as the product is digital, areas of interest are not restricted by map-sheet boundaries.

Table 1. Classification of regolith units

	Code	*Designation*	*Description*
	R	Residual	Includes ferruginous, siliceous, and calcareous duricrust
	X	Exposed	Exposed rock, saprolite, and saprock
Depositional (D)	C	Colluvium	Slope deposits, including colluvium and sheetwash
Depositional (D)	S	Sandplain	Mainly eolian, includes some residual deposits
Depositional (D)	L	Lacustrine	Includes lakes, playas, and fringing dunes
Depositional (D)	A	Alluvium	In drainage channels, floodplains, and deltas
Depositional (D)	B	Coastal	Includes beaches and coastal dunes
Depositional (D)	T	Tidal	Coastal areas subject to significant tidal ranges; includes tidal flats and tidal channels
Depositional (D)	Calc	Calcrete	Includes massive, nodular, and sheet-like accumulations of carbonate, usually alluvial–colluvial, but locally residual; minor opaline silica and chalcedony
			Anthropogenic areas
		Made ground	Areas artificially filled with earth materials
		Mining	Areas of land where metallic or non-metallic mineral deposits are being extracted
		Stockpile	An accumulation of ore-bearing rocks for milling

SOURCE: Hocking et al. (2001)

Data sources

The major source of map data is the GSWA 1:250 000-scale geological series maps, so that the capture scale for the State regolith map was maintained at 1:250 000. Of the 163 1:250 000-scale maps that cover Western Australia, 73 (45%) are available as vector data and the remaining 90 are raster images. Where 1:100 000-scale maps covering a complete 1:250 000 map sheet are available (WILUNA*, SIR SAMUEL, DUKETON, LEONORA, LAVERTON, MENZIES, EDJUDINA, KURNALPI), these were used in compiling the final map. Publication of the 1:250 000-scale geological maps span an interval of almost 40 years, from the RAWLINSON map sheet (Wells and Forman, 1964) through to DAMPIER – BARROW ISLAND (Hickman and Strong, 2001). No attempt has been made to modify the geological coverage on these maps, apart from simplification of some drainage areas, and ensuring smooth map-edge transitions.

Classification of regolith

Since 2001, regolith on all GSWA geological maps has been classified according to a hierarchical scheme discussed by Hocking et al. (2001). This scheme uses the current landform position, regolith composition, and (where known) the parent lithology to classify regolith, and is loosely based on the Relict–Erosional–Depositional (RED) scheme of Anand et al. (1993). The classification scheme adopted for the State regolith map (Table 1) is based upon the nine primary (landform-based) codes of the GSWA regolith classification scheme. The adoption of this scheme attempts to maintain some level of consistency with the GSWA approach to classification of regolith, and at the same time preserve as much information as possible from the original maps. However, in many cases it has not been possible to determine if calcrete is residual or depositional, and all such units have been grouped as 'calcrete'. As these maps were compiled by various geologists over a long time period, there are often inconsistencies between map sheets that reflect slightly different interpretations of the same, or similar, rock or regolith units, or different levels of subdivision of the regolith. The remaining category comprises anthropogenic areas, including made ground, mining areas, ore stockpiles, and areas of infrastructure.

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

Map compilation methodology

For areas covered by vector data, attribute tables describing the features of each geological unit were edited to conform to the regolith classification approach (Table 1). On joining the edited tables to the map sheet, geological boundaries between polygons of the same type were removed (i.e. dissolved). After this simplification, printouts were checked and geological boundaries on map-sheet edges were aligned to create a seamless coverage.

For raster images, a simplified regolith coverage was created on a transparent overlay according to the regolith classification, and polygons colour-coded according to regolith type (Table 1). Polygons less than about 250 m^2 were omitted. The resulting compilations were scanned and the different regolith layers separated and attributed automatically according to the colour coding. The resulting map was checked and the individual map compilations were combined and edge-checked. Finally, the digital and hardcopy coverages were combined into one dataset. The coverage was divided in two at latitude 26°S, and each half checked for level of detail. Some areas still required simplification.

Because of the resulting file size, subsets of the data were gridded separately, with sufficient overlap between data in each file to allow seamless rejoining. Gridding is a process by which the data are automatically simplified according to the level of complexity required. Choosing larger cell sizes produces a simplified coverage. Polygons were gridded using 150 m, 500 m, 800 m, and 1300 m cell sizes. Following gridding, individual segments were recombined, and the linework further simplified (smoothed) by two passes of a majority filter (3 × 3 pixel). Further improvement of the linework was achieved by resampling to a smaller cell size (one third of the original cell size) using the nearest neighbour option. Another two passes of the majority filter over the new cell-size grid was then necessary to smooth the data. The data were then converted back to polygons, and checked for null-grid codes (unlabelled polygons) and 'sliver' polygons (i.e. small polygons erroneously created during joining of lines during the compilation or editing process). The boundaries between similar polygons were then dissolved.

In order to present the data at an appropriate scale for viewing, polygons smaller than a predetermined area or perimeter were removed. Selection of a low perimeter value ensured that elongate polygons of small area (typical of drainages) were not selectively removed. Any remaining angularity in the linework was removed using a 'bendsimplify' operator, and the data were then checked for label errors.

Map viewing

Regolith cover of the State (Fig. 1) can be viewed using GSWA's GeoVIEW.WA web-based software, along with other data layers such as bedrock geology, mining tenements, roads, towns, and mineralization information from the Survey's WAMEX and WAMIN databases. The original scale of capture (1:250 000) for regolith is preserved, but the dataset is displayed at the scale most relevant to the user's needs. Three separate versions of the regolith have been grouped into one layer. Each version has been gridded at a different pixel size, with the version shown in GeoVIEW.WA dependent on the display scale of the map (Table 2). Enlarging the pixel size reduces the number of polygons (compare Figs 2a and 2b), therefore improving the speed of display.

Table 2. Designated pixel size (m) used for gridding data, and related range in scale

Pixel size (m)	*Minimum scale*	*Maximum scale*
500	n/a	1:1 499 999
800	1:1 500 000	1:2 999 999
1300	1:3 000 000	n/a

NOTE: n/a: not applicable

Discussion

The new regolith map of Western Australia has synthesized existing geological information using a standard approach to the classification of regolith. As the product is fully digital, the data can be interrogated, and the original data can be displayed at selected levels of complexity by gridding the data using a suitable pixel size. A simplified map generated from this dataset (Fig. 3) shows the distribution of regolith in terms of three components: residual or relict, erosional (essentially outcrop), and depositional (transported) regolith, the latter produced by combining the seven depositional regolith subdivisions of Table 1. Figure 3 shows that regolith is dominated by depositional material (67% of regolith coverage), especially in the Yilgarn Craton. The map also shows that few relict and residual units are visible at this scale (1:11 000 000). Of the depositional regolith material, sandplain makes up the highest proportion (64%), followed by slope deposits (25%) and alluvium (5%).

Figure 3. Regolith distribution in Western Australia simplified to areas of relict or residual regolith (R), exposed rock (X), and depositional regolith (D), derived from the original dataset

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Kimberley Basin gold

by L. Y. Hassan

Abstract

Visible gold in stream-sediment samples, and soil anomalies with up to 16 ppm gold, were reported from the Oombulgurri area in the northeast Kimberley Basin in 2002. The anomalies are associated with a large area of argillic and hematitic alteration. The alteration assemblage, together with an association with quartz veins with epithermal textures, suggests that the mineralization is epithermal. The anomalies are near the intersection of northerly, northwesterly, and/or northeasterly trending faults. Auriferous quartz veins were first reported in the southern Kimberley Basin by William Fitzgerald in 1907, and there are a few other historic accounts of gold mineralization in the Kimberley Basin. By analogy with the epithermal fluorite and base metal mineralization at Speewah in the east Kimberley, it is proposed that the gold mineralization in the Kimberley Basin could be related to carbonatites and associated alkaline igneous rocks and could be as young as Miocene. An alternative model is that the mineralization formed during high heat flow associated with rifting during the Devonian–Carboniferous.

KEYWORDS: gold, mineralization, epithermal deposits, alteration, faults, carbonatite, Kimberley Basin.

Introduction

The discovery of gold at 88 Creek in the Oombulgurri area in the northeast Kimberley Basin (Fig. 1) was announced by Striker Resources NL (Striker) in January 2002, following the delineation of a large area of argillic alteration during an airborne hyperspectral scanning survey carried out by DeBeers Australia Exploration Ltd, and the recovery of gold grains during sampling for diamond indicator minerals (Striker Resources NL, 2002a). Striker took up the gold rights on the tenements and subsequently recovered 88 grains of gold from one stream-sediment sample, giving the 88 Creek Prospect (Fig. 1) its name. In September 2002, Striker announced that it had confirmed a new gold province in the north Kimberley (Striker Resources NL, 2002b). However, the gold potential of the Kimberley Basin had been recognized by Fitzgerald (1905) almost a century earlier.

Regional geology

The Kimberley Basin is situated in the northern part of Western Australia. The basin contains predominantly sedimentary rocks (sandstone with minor siltstone, shale, and dolomite) and mafic igneous rocks (the Carson Volcanics) of the Palaeoproterozoic Kimberley Group (Fig. 1), which was deposited within a broad, semi-enclosed, shallow-marine basin. The Kimberley Group unconformably and disconformably overlies sedimentary rocks of the Palaeoproterozoic Speewah Group and both groups are intruded by the c. 1790 Ma Hart Dolerite (Thorne et al., 1999). The Kimberley and Speewah Basins are flanked by metamorphic rocks and granites of the Palaeoproterozoic Lamboo and Hooper Complexes. A more detailed description of the geology of the Kimberley Basin is given in Hassan (2000, in press) and Ruddock (2003).

Historic gold occurrences

In 1905, William Fitzgerald[1] accompanied surveyor Chas Crossland on a government expedition to the west Kimberley. Fitzgerald was employed to assess the agricultural potential of the area, but he also described the geology and botany of the areas he passed through and collected rock and botanical specimens. Fitzgerald (1905, 1907) noted the presence of probable auriferous quartz veins in the Carson Volcanics over a wide area, and submitted samples to E. S. Simpson, the Government Mineralogist and Assayer, for gold assay. A sample from a westerly trending, 1.5 m-wide quartz

[1] Although referred to in the geological literature as a botanist, Fitzgerald studied geology at the School of Mines in Tasmania and learnt botany later by corresponding with the famous Australian botanist Ferdinand von Mueller (Hall, 1978).

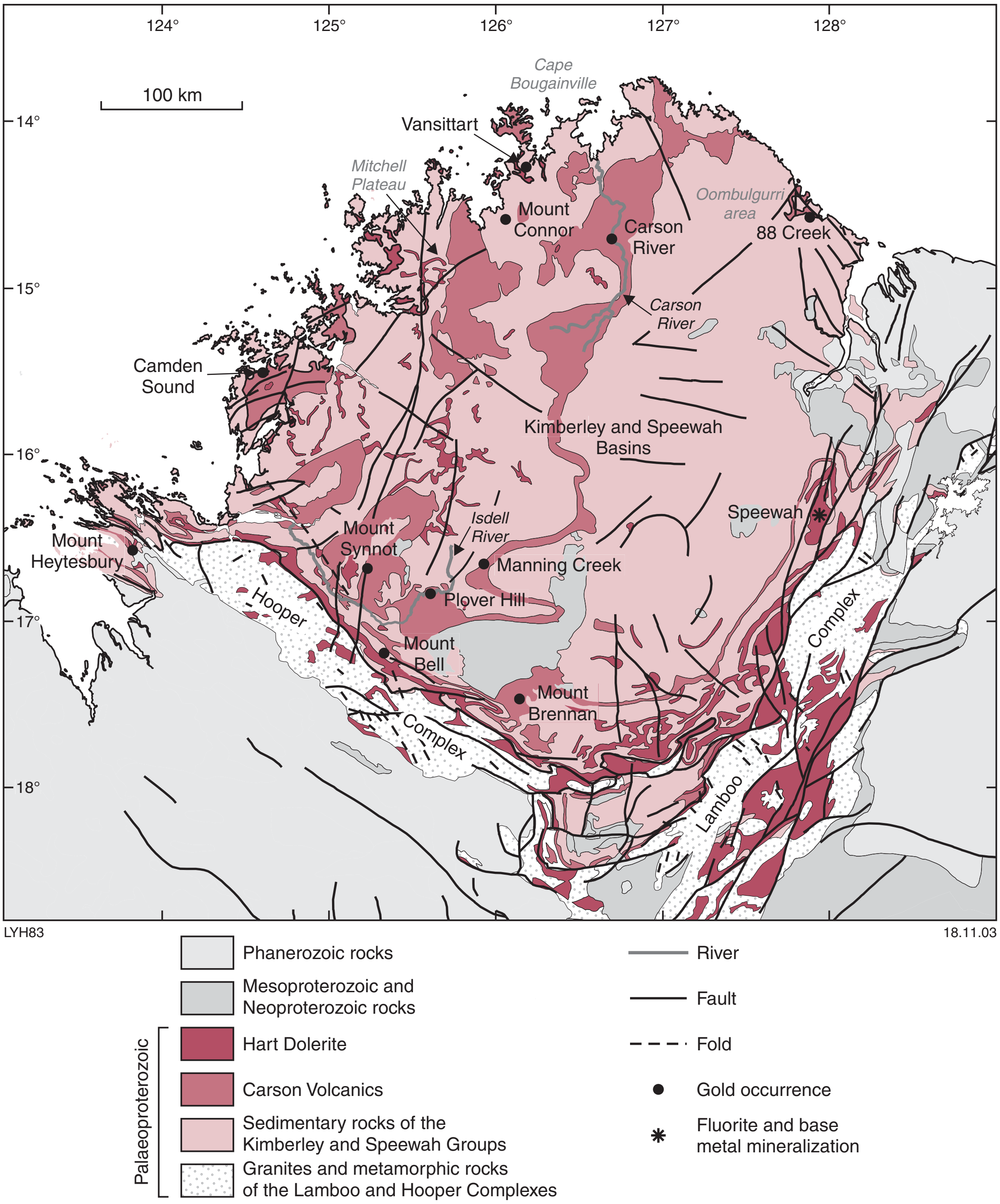

Figure 1. Simplified geological map of the Kimberley Basin showing the location of known and reputed gold occurrences and the Speewah fluorite and base metal mineralization

reef from the Isdell River near Plover Hill[1] (Fig. 1) assayed 71.0 g/t Au (2 oz 5 dwt 18 grs). Other assayed samples included quartz from a reef adjacent to a westerly trending dolerite dyke in Manning Creek (12.3 g/t Au), and pyritic quartz from a major northerly trending quartz body at Mount Synnot (2 g/t Au; Fitzgerald, 1907). Fitzgerald (1905, 1907) also reported auriferous quartz reefs, veins, and stringers associated with abundant hematite and limonite on the lower slopes of Mount Brennan. Samples from three of the larger reefs at Mount Brennan assayed between 1.3 and 2.5 g/t Au. These locations are shown on Figure 1. Fitzgerald (1907) stated that the results 'demonstrate conclusively that at least a portion of the Kimberley basalts constitute a gold-bearing area'.

Intriguingly, until recently, Fitzgerald's discovery of gold in the west Kimberley appears to have been overlooked by prospectors and geologists. Maitland (1919) makes no mention of gold in the west Kimberley in his summary of gold occurrences in Western Australia, even though he was Government Geologist at the time of Fitzgerald's discovery. Harms (1959) dismissed persistent reports of gold in the Kimberley Basin as pyrite in the Carson Volcanics and appeared unaware of the high assays obtained by Fitzgerald, even though Harms cited Fitzgerald's (1907) report in his bibliography. There is also no mention of Fitzgerald's gold discoveries in the explanatory notes for CHARNLEY (Gellatly and Halligan, 1971; Gellatly et al., 1974) or LANSDOWNE* (Gellatly and Derrick, 1967; Gellatly et al., 1975).

There are a few other early reports of gold in the Kimberley Basin. A convict named Wildman claimed he found eight gold nuggets near Camden Sound (Fig. 1) in 1856. When it was confirmed that he had sold gold nuggets in London, an expedition was sent to search for gold but none was found; however, Scholl, who established a government settlement on the Glenelg River, reported finding indications of gold whilst exploring the country between Camden Sound and the King Leopold Ranges in 1865 (Battye, 1915). A report in the Victorian Naturalist in 1886 stated that there was 'every indication of gold' in the valley of the Carson River (Fig. 1). Prospector Charlie James reported finding gold in a series of ferruginous quartz veins from rough country north of Mount Heytesbury (Fig. 1; Sunday Times, 1909a,b,c).

Recent exploration in the Kimberley Basin

Prior to 2002, with the exception of a Temporary Reserve for bauxite on the Mitchell Plateau and mining leases for bauxite at Cape Bougainville, most of the tenements over the Kimberley Basin were held for diamond exploration. Some gold was reported during routine diamond indicator sampling: Faustus Nominees Pty Ltd and Lental Pty Ltd (1996) reported panning significant gold from Vansittart and Mount Connor (Fig. 1). Century Metals and Mining NL (1987) reported a rock-chip sample assaying 0.5 ppm Au from the Isdell River area, but did not give coordinates. In addition, low-grade gold values (1.03 m at 0.69 ppm Au, between 126 and 127 m, and 0.9 m at 0.64 ppm Au, between 432.1 and 433.0 m) were reported from a vertical diamond drillhole (DD88MB2), drilled by CRA Exploration in hematitic sandstone of the King Leopold Sandstone at Mount Bell near the southern margin of the basin (Hamdorf, 1989).

Following the announcement by Striker of gold and hydrothermal alteration in the Oombulgurri area, and the awareness of the possible significance of Fitzgerald's discoveries, many applications for exploration licences have been lodged (Fig. 2). Striker's gold interests over the Kimberley Basin were to be floated on the Australian Stock Exchange (Napier Minerals Ltd, 2003), but the float has subsequently been withdrawn. Striker had not located the veins described by Fitzgerald (1905, 1907) at the time the Napier Minerals prospectus was compiled, although they had found veins with anomalous levels of copper and lead (Fig. 3) and a stream-sediment sample containing 139 ppb Au (Garlick, 2003).

Oombulgurri mineralization

The Oombulgurri area is characterized by widespread argillic alteration with zones of dickite, paragonite, and pyrophyllite identified using De Beers Airborne Multispectral Scanner (Striker Resources NL, 2002a; Garlick, 2003). Although surficial iron oxides are widespread in the Kimberley Basin, Garlick (2003) reported a specific association of iron oxide alteration (hematite) with gold mineralization in the Oombulgurri area. Epithermal textures, such as colloidal banding, are common in quartz veins (Fig. 4), but the highest gold concentration to date from these veins is 491 ppb Au (Striker Resources NL, 2002b). Three areas with anomalous gold values have been defined from soil sampling over a northwesterly trending strike length of 12 km: 88 Creek, Epithermal Creek, and Magnesite Creek. Soil samples containing up to 16 ppm Au have been reported (Striker Resources NL, 2002c; Garlick, 2003). There is generally no correlation of base metal and pathfinder elements with gold, although thallium and uranium anomalies extend over parts of the strongest gold anomalies and there are isolated arsenic and tungsten anomalies associated with the gold anomalies (Garlick, 2003). Optical

[1] Fitzgerald (1907) described the location as adjacent to the Isdell River and almost opposite Plover Hill, but, according to his diary (Fitzgerald, 1905), Fitzgerald only travelled 10 miles (16.7 km) down the Isdell River from Graces Knob on the day he found the quartz vein. Since the vein was in Carson Volcanics, the sample probably came from north of Plover Hill, possibly from a point where a weak easterly trending photolineament is visible. Fitzgerald made a map showing the agricultural potential of the area, which may have shown his sample locations. The map was supposed to have been included with his 1907 report but was omitted. An old Lands Department file in the State Archives (5843-1906) indicates that 270 copies of the map were printed in 1908, but no copies have been preserved in the State Archives.

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

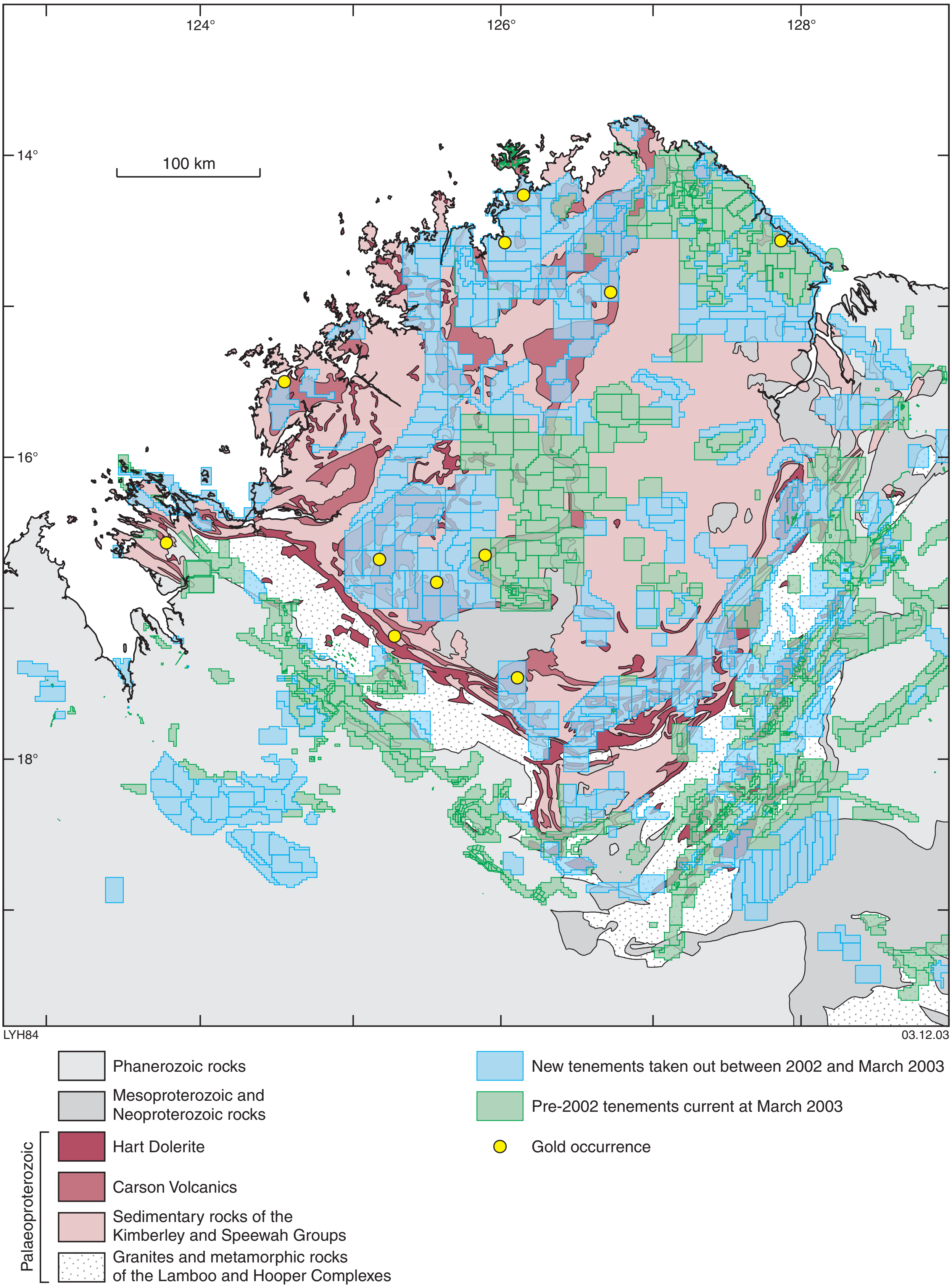

Figure 2. Pre-2002 and 2002–2003 tenements superimposed on a simplified geological map of the Kimberley Basin

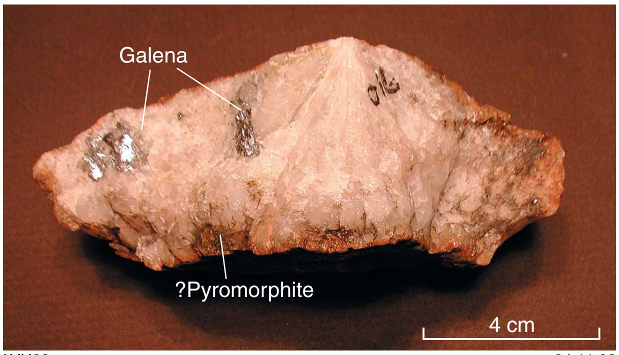

Figure 3. Quartz vein with galena and an olive-green mineral, which is probably pyromorphite; found by Striker Resources southwest of Plover Hill

and scanning-electron microscope studies of the gold grains from 88 Creek indicate that the grains have not been transported very far — they show little mechanical damage, have quartz, calcite, and aluminium oxides attached, and are irregular or xenomorphic in form suggesting they are primary. The 88 Creek soil anomaly has been tested by 48 reverse circulation drillholes. Drilling at the time of prospectus compilation resulted in a best intersection of 1 m at 1.4 ppm Au; this low-grade mineralization is hosted by Warton Sandstone containing quartz micro-veins, phyllosilicate alteration, and disseminated pyrite (Garlick, 2003).

Gold genesis

The presence of quartz veins with epithermal textures (Striker Resources, 2002b) and the widespread argillic alteration suggest an epithermal origin for the gold mineralization in the Oombulgurri area. However, there is no obvious igneous event associated with the mineralization, and the age of mineralization is uncertain. Three models for the mineralization are considered below:

1. Striker/Napier Minerals' model, in which a Phanerozoic granite body provides the heat source.
2. A carbonatite complex as the source of heat and fluids.
3. Rifting and high heat flow associated with continental breakup as a source of fluids.

Phanerozoic granite model

Garlick (2003) proposed a model for the gold mineralization in the Oombulgurri area, whereby a buried igneous intrusion generated a heat cell that focused gold-bearing fluids along near-vertical conduits where northerly, northwesterly, and possibly north-easterly trending faults intersected. Garlick (2003) questioned that the Kimberley Basin is a relatively stable area cratonized in the Palaeoproterozoic, as his proposed model requires that there has been intrusive activity after the deposition of the Palaeoproterozoic Kimberley Group.

There is a prominent magnetic high, 50 km in diameter, in the north-eastern part of the Kimberley Basin (Fig. 5). It may be interpreted to lie on the same trend as a series of offshore magnetic anomalies along a major rift zone known as NW1 (O'Brien et al., 1999), located between the Browse and Bonaparte Basins (Fig. 5). O'Brien et al. (1999) interpreted these magnetic anomalies as mafic igneous intrusions that could be Permian or Mesozoic in age and possibly related to continental breakup. They could, however, also be interpreted as volcanic rocks; Burmah Oil Company of Australia Ltd (1968) reported an intersection of Upper Jurassic volcanic rocks in petroleum well Ashmore Reef 1 (Fig. 5). Napier Minerals' preferred model for the epithermal mineralization in the Oombulgurri area is that the large magnetic anomaly represents a

Figure 4. Laminated epithermal quartz vein (photograph by Striker Resources)

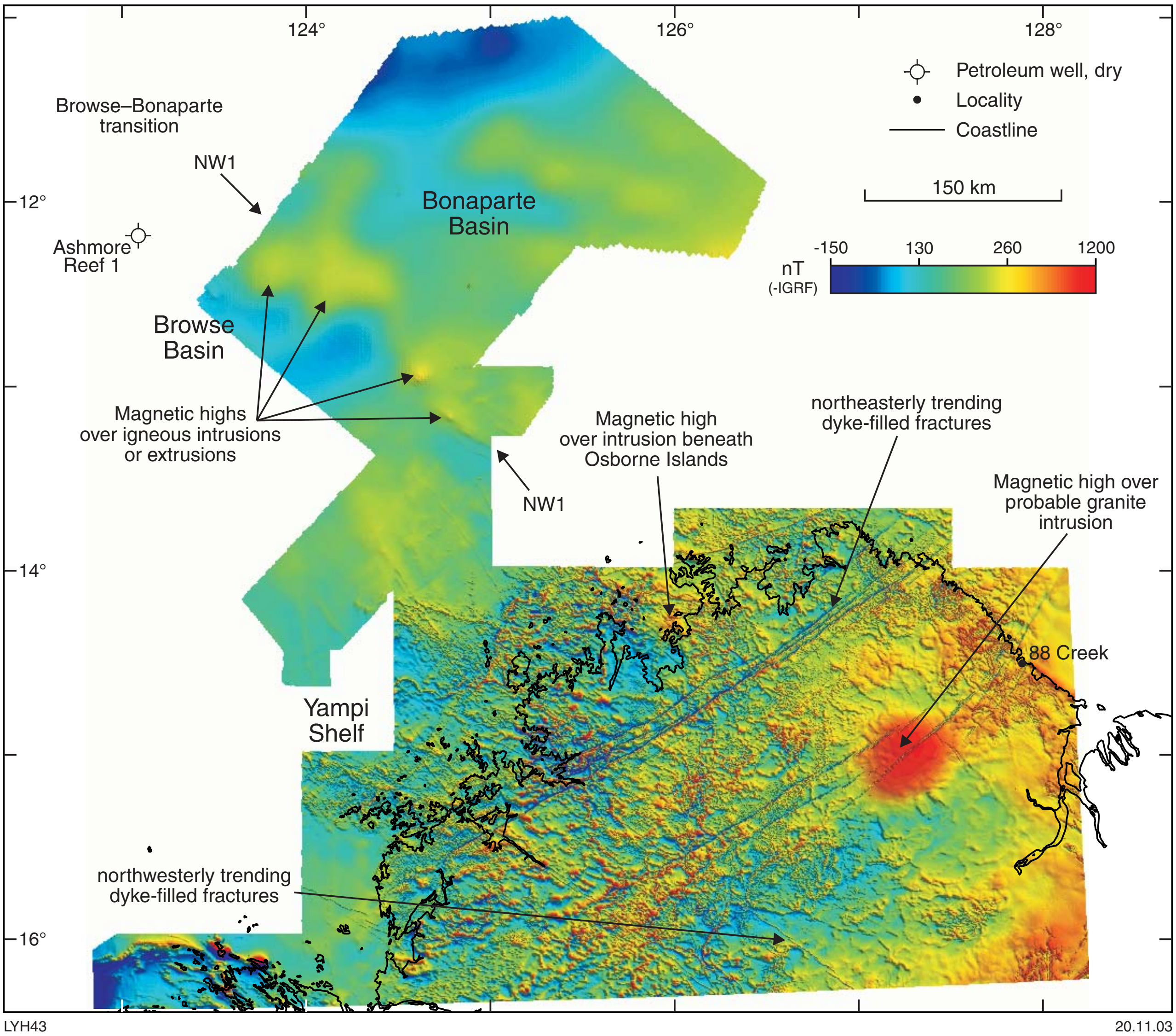

Figure 5. Total magnetic intensity image showing intrusions or extrusions along the Browse–Bonaparte rift zone (NW1) and intrusions along the same trend in the north Kimberley; note also the northwesterly and northeasterly trending dyke-filled fractures (modified from O'Brien et al., 1999 and Gunn and Meixner, 1998)

Phanerozoic granite body related to the intrusions along NW1, and that the granite has introduced mineralizing fluids into the overlying sedimentary pile (Garlick, 2003). However, Garlick (2003) noted that, alternatively, the anomaly could represent a magnetic granite in the underlying Archaean basement. The modelling of Gunn and Meixner (1998) suggests that the large magnetic anomaly is a magnetic granite in the basement, unconformably overlain by about 5 km of Kimberley and Speewah Basin rocks. If this modelling is correct, then the magnetic granite could not have played any role in the Oombulgurri mineralization. Furthermore, it seems unlikely that an intrusion 80 km southwest of the 88 Creek prospect could have resulted in the zoned alteration observed in the area.

Carbonatite model

Epithermal mineralization is known from the Speewah area in the east Kimberley (Hassan, 2000), where fluorite and base metal veins are hosted predominantly by sills of the Hart Dolerite and sedimentary rocks of the Speewah Group. A carbonatite dyke and a hydrothermal–tectonic breccia are associated with the fluorite at West Ridge to the west of the main Speewah deposits (Alvin, 1993). Quartz syenite, diorite, and quartz–feldspar porphyry rubble have been found in a soil-covered area. One of the fluorite veins cuts the Antrim Plateau Volcanics, indicating that the mineralization is younger than Cambrian. Galena from base metal and fluorite veins at Speewah has given model lead ages of between 15 and 131 Ma, and direct Sm–Nd dating of the veins gave an age of 120 Ma (Alvin, 1993). On the basis of aeromagnetic data and aerial photographs, Rogers (1998) identified circular and curvilinear structures inferred to be ring structures within the Speewah Dome. Rogers (1998) suggested that fractures related to caldera collapse, resurgence, and subsequent rifting could have acted as pathways for hydrothermal fluids and that the carbonatite and associated alkaline rocks might have been the source of the fluids. Only minor gold mineralization has been found in association with base metal and fluorite veins at Speewah, but Rogers (1998) suggested that there could be rich epithermal gold mineralization at depth. Gold enrichment (up to 3.8 g/t) has been reported from weathered carbonatite pyroclastics of the Kruidfontein Volcanic Complex in South Africa (Pirajno et al., 1995). Groves and Vielreicher (2000) interpreted the Palabora carbonatite in South Africa, from which gold is produced as a by-product, as an end member of the iron oxide – copper–gold deposit group. No carbonatites are known from the Oombulgurri area, but since carbonatites may be small and poorly exposed, it is possible that they are present in the Oombulgurri area and other parts of the Kimberley Basin but have not yet been recognized.

Century Metals and Mining NL (1987) searched for diamonds in the vicinity of Plover Hill during 1986–87 on the basis of a prospector's report of a roughly circular occurrence of carbonated agglomerate; it would be worthwhile locating this to determine if it is a carbonatite. This company also named Pegmatite Creek, a tributary of the Isdell River near Plover Hill, so it is possible there are unmapped intrusions in the area that could be a source of ore fluids. A previously unmapped rhyolite porphyry was located in 2003 from PRINCE REGENT (Donaldson, M. O., 2003, written comm.); however, it is not known whether this is related to the Palaeoproterozoic Wotjulum Porphyry, which outcrops 230 km to the west, or is a younger intrusive.

Rifting model

Another possible source of epithermal activity and mineralization is rifting and high heat flow associated with continental breakup, without any associated igneous activity. Such a model was postulated for the Late Permian – Early Cretaceous epithermal gold deposits at Donnybrook in the southwest of Western Australia (Hassan, 1998).

The Oombulgurri gold occurrences are found near the intersection of northerly, northwesterly, and/or northeasterly trending faults (Garlick, 2003), suggesting faults have played a significant role in focusing mineralization. However, there are few age constraints on the faults. The northeasterly and northwesterly trending faults in the Kimberley Basin were interpreted by Gunn and Meixner (1998) to be extensional faults related to a phase of Devonian–Carboniferous rifting. However, some of the faults could be deep-seated crustal structures that were initiated in the Palaeoproterozoic and reactivated many times, similar to the northeasterly trending faults in the Lamboo Complex of the east Kimberley (Tyler et al., 1995). Positively magnetized dykes have intruded some of the northwesterly trending faults; one of these, the Milliwindi Dyke near the southern margin of the Kimberley Basin, has a SHRIMP zircon age of 513 ± 12 Ma (Hanley and Wingate, 2000). The Miocene lamproites in the west Kimberley are localized along inferred northwesterly trending faults (Smith, 1984). The c. 800 Ma kimberlites in the north Kimberley generally have a northeasterly trend (Jacques et al., 1986), including the kimberlites at Seppelt, which lie along northeasterly trending fractures (Striker Resources NL, 2002c). Negatively magnetized dykes intrude northeasterly trending faults, but no dates are available for them. The age of the northerly trending faults is unknown.

West Kimberley deposits

The genesis of the gold mineralization in the west Kimberley is even less certain. Fitzgerald (1907) described the quartz reefs near Plover Hill as 'true fissure reefs', but from his description it is impossible to determine whether the veins are epithermal or mesothermal. At both Plover Hill and Manning Creek, the quartz veins are between or along the wall of easterly trending mafic dykes (Fitzgerald, 1907), suggesting that the veins are syn- or post-dyke in age. According to Fitzgerald (1907), most of the quartz reefs at Mount Brennan also have an easterly trend. In contrast, the pyritic quartz found by Fitzgerald at Mount Synnot is associated with a major northerly trending fault that is visible on Landsat images. Fitzgerald (1905, 1907) noted that there are abundant iron oxides in the Mount Brennan area, both in sandstone and quartzite on the ridges, and in mafic volcanic rocks farther down the slope, where there are masses of hematite and limonite together with quartz veins containing specular hematite.

Conclusions

Epithermal gold mineralization in the Oombulgurri area is associated with an extensive zone of argillic and hematitic alteration, and exists near the intersection of major faults. It is not certain whether the mineralization found by Fitzgerald (1905, 1907) and other early explorers in the west Kimberley is epithermal or mesothermal, or how it relates to the Oombulgurri mineralization. However, as in the Oombulgurri area, at least some of the mineralization described by Fitzgerald is associated with major faults. Hematite alteration is also present at Mount Brennan. If the mineralization found by Fitzgerald is related to that at Oombulgurri, then the Kimberley Basin gold province was discovered nearly 100 years ago. By analogy with the epithermal fluorite and base metal mineralization at Speewah, it is possible that carbonatites and associated alkaline rocks could be a source of heat and fluids, and the gold mineralization in the Kimberley Basin could be as young as Miocene. Another possibility is that the mineralization is related to high heat flow during rifting in the Devonian–Carboniferous. Additional fieldwork may assist in evaluating these models. If auriferous quartz veins are intersected during diamond drilling, fluid-inclusion studies would provide information on the temperature of deposition and the composition of the ore-forming fluids. A more detailed study of the alteration assemblages would also assist in determining the conditions of ore formation.

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Zircon provenance in the basal part of the northwestern Officer Basin, Western Australia

by L. Bagas[1]

Abstract

The Neoproterozoic (c. 900 Ma) Tarcunyah Group forms the base of the Centralian Superbasin in the northwestern Officer Basin, immediately west of the Vines–Southwest–McKay fault system in the central part of Western Australia. The group consists of metasedimentary units that unconformably overlie the southeastern part of the Archaean Pilbara Craton and the eastern part of the Bangemall Supergroup. Sandstone at the base of the group has age populations derived from detrital zircons that are comparable with principal sources from the northern part of the Palaeoproterozoic Gascoyne Complex, Mesoproterozoic Bangemall Supergroup, and Mesoproterozoic to Neoproterozoic Pinjarra Orogen. These units are located about 800 km to the west of the Tarcunyah Group, which is consistent with a predominance of east- to northeast-directed palaeocurrent data from trough cross-bedding in the basal part of the group. This study shows that cumulative-probability plots for zircons can be powerful tools in identifying the source regions for sedimentary rocks.

KEYWORDS: Neoproterozoic, Officer Basin, Tarcunyah Group, zircon dating, statistical analysis.

Introduction

Modern studies of sedimentary provenance rely heavily on U–Pb ages of detrital zircon grains (e.g. Halilovic et al., in press). Zircons are durable in environments of weathering, erosion, and sedimentation, are largely unaffected by low- to moderate-temperature (greenschist to amphibolite facies) metamorphism, and can survive many cycles of erosion and sedimentation during transport over distances of many hundreds of kilometres. Therefore, the age and relative abundance of different populations of detrital zircons in sedimentary rocks should provide maximum age constraints for their deposition and reflect the age and the degree of exposure of the source region.

The Tarcunyah Group lies in the northwestern part of the Paterson Orogen, east of the Pilbara Craton (Figs 1 and 2). Its precise age has been controversial. Blockley and de la Hunty (1975) assigned units in the group to the former Mesoproterozoic 'Bangemall Group', which has been elevated by Martin et al. (1999) to supergroup status. Williams et al. (1976) included the Tarcunyah Group in the former 'Yeneena Group', and suggested that it was Mesoproterozoic in age and unconformably overlain by rocks assigned to the 'Bangemall Group'. These unconformably overlying rocks were subsequently found to include Neoproterozoic tillite units and were included in the former 'Savory Group' (Williams, 1992) and, subsequently, in the Officer Basin (Bagas et al., 1995, 1999). Chin and de Laeter (1981) reported a Rb–Sr isochron age of 1132 ± 21 Ma for pegmatite veins cutting foliation in the Rudall Complex. They proposed that the pegmatite was emplaced after the waning stages of an early deformation. Consequent recrystallization during deformation of the 'Yeneena Group', which then included the Tarcunyah Group, may have been responsible for resetting the Rb–Sr isotopic system, giving the younger age. They alternatively proposed that the pegmatite could have been generated during the early part of this later deformation event at about 1132 ± 21 Ma. Williams (1992, p. 89) suggested an age of between c. 1200 and 1000 Ma for the Tarcunyah Group (then included in the 'Yeneena Group'), based on assumptions at that time that earlier deformation in the Rudall Complex was at c. 1300 Ma (Clark, 1991) and that the former 'Savory Group' was c. 900 Ma, and younger than the Tarcunyah Group.

[1] This contribution forms part of a Masters of Economic Geology thesis project at the Centre for Ore Deposit Research (CODES, Special Research Centre), University of Tasmania, Hobart, Tasmania 7001, Australia.

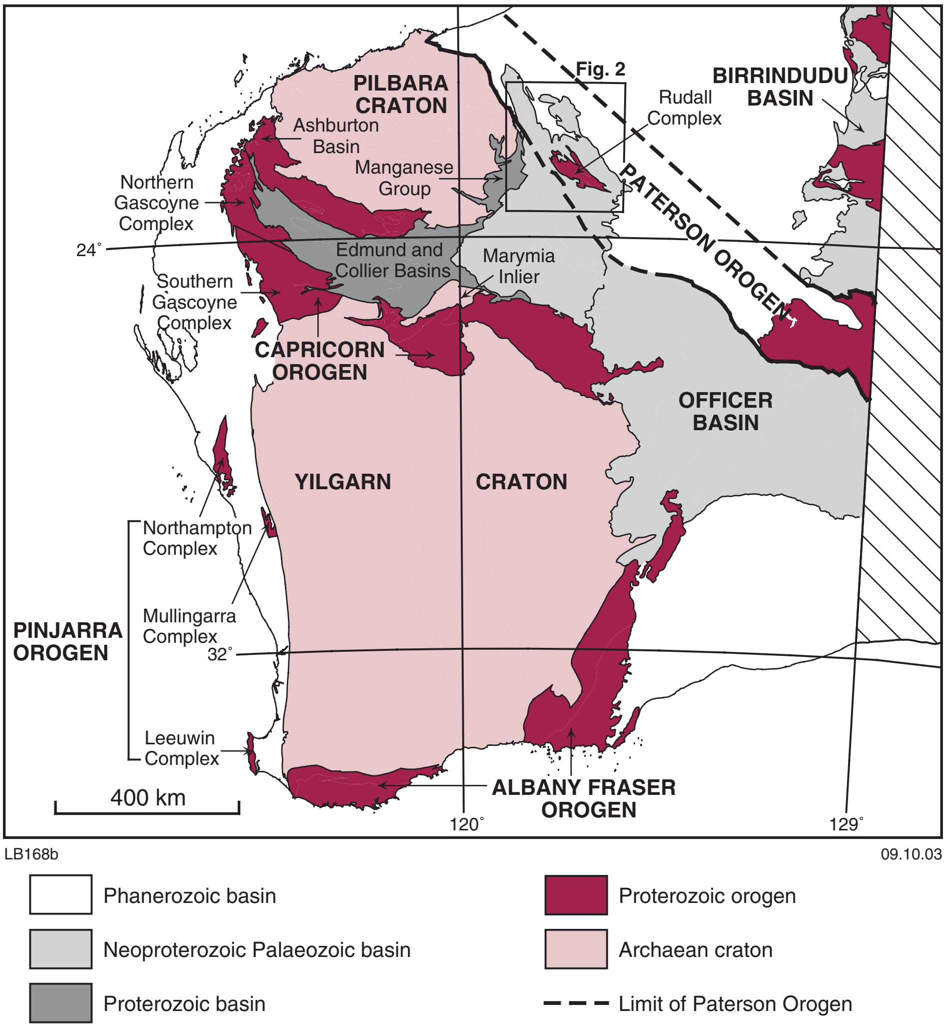

Figure 1. Main tectonic units

Bagas and Smithies (1998) suggested that the earlier deformation affecting the Rudall Complex had a minimum age of c. 1760 Ma based on the ages of cross-cutting granitic rocks, and Bagas et al. (1995, 1999) showed that the basal part of the former 'Savory Group' was a correlative of the Tarcunyah Group.

The wide range of suggested dates and proposed correlations not only reflected uncertainties caused by the lack of adequate dating, but also pointed to more fundamental problems in the understanding of the stratigraphic relationships between units in the Paterson Orogen. The results of recently completed mapping in the region, together with biostratigraphic evidence, have led to a better understanding of the orogen. Bagas et al. (1995) concluded that the Tarcunyah Group is equivalent to Supersequence 1 of the Centralian Superbasin (Walter et al., 1995) and part of the northwestern Officer Basin. They also proposed an age of c. 820 Ma for the group based on correlations with the Adelaide Geosyncline, although the base of the Centralian Superbasin is poorly constrained between 1050 and 800 Ma (Scrimgeour et al., 1999). This correlation was strengthened by detailed seismic interpretation (Perincek, 1996), palynology (Grey and Stevens, 1997), and the presence of the c. 800 Ma *Acaciella australica* and *Baicalia burra* stromatolite assemblages (Stevens and Grey, 1997) in carbonate units in both the Tarcunyah and Sunbeam Groups (Fig. 3).

This study examines new constraints on the age and provenance of the 500 m-thick Neoproterozoic Gunanya Sandstone in the basal part of the Tarcunyah Group using palaeocurrent data and sensitive high-resolution ion microprobe (SHRIMP) U–Pb detrital-zircon ages. In the fluvial to deltaic Gunanya Sandstone (Hickman and Bagas, 1998), palaeocurrent data from trough cross-bedding (Fig. 2) indicate a source region to the west and southwest (Fig. 2), and the SHRIMP U–Pb detrital-zircon age distribution data presented here reveal that the provenance contains Palaeoproterozoic to late Mesoproterozoic rocks. The areas containing rocks of

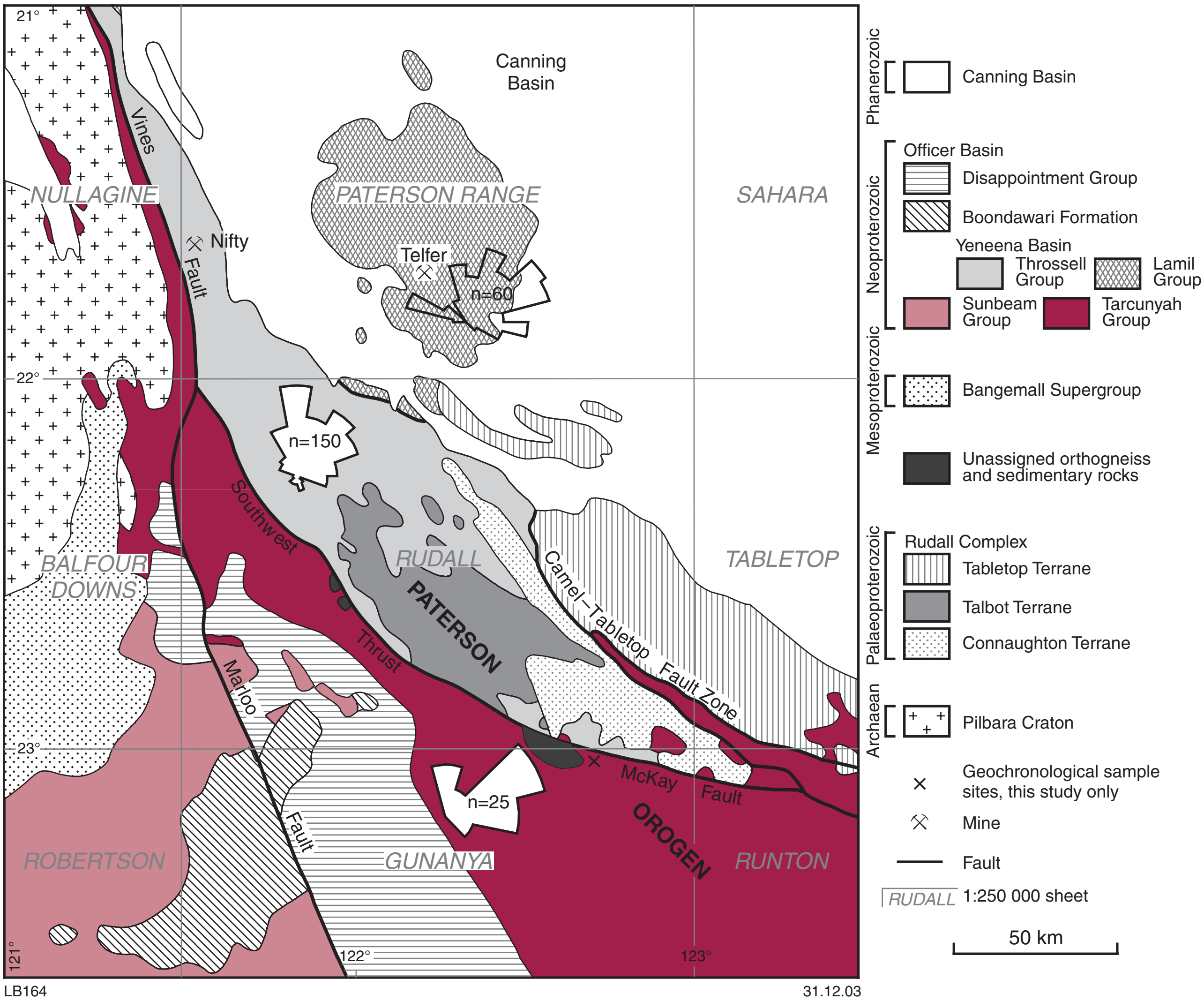

Figure 2. Regional geological setting of the northwestern Paterson Orogen. Rose diagrams show palaeocurrent directions from the Tarcunyah, Throssell, and Lamil Groups

this age are those of the orogens around the Archaean Pilbara and Yilgarn Cratons. These orogens are briefly described below and their relative cumulative zircon age profiles are compared with the detrital zircon age profile for the Gunanya Sandstone (Fig. 4).

Relative cumulative-probability plots are commonly used to visually represent detrital zircon age data. This statistical technique is complementary to concordia plots and is normally used to visually assess the similarities or differences between samples and potential source regions. The vertical peaks in the graphs represent mean values, and the horizontal spread for each peak relates to the standard deviation and reflects the accuracy of the data. The height of each peak is relative and has no fixed scale. The probability of the sample containing zircons of any particular age is determined by calculating the area under each peak and dividing by the area under the whole curve (which is equal to 1).

This study highlights the potential value in comparing detrital-zircon age populations in order to fingerprint otherwise indistinct sedimentary rocks within structurally complex regions. When accompanied with palaeocurrent data for a formation, zircon-age distribution plots can be powerful tools in identifying possible provenances for the formation.

Northwestern Paterson Orogen and Officer Basin

The northwestern-most part of the Paterson Orogen consists of the Palaeoproterozoic Rudall Complex basement, unconformably overlain by or faulted against the Neoproterozoic Tarcunyah, Throssell, and Lamil Groups (Fig. 2; Bagas et al., 1995; Bagas, in press). These units were deformed during the c. 550 Ma Paterson Orogeny, and for this reason are included in the Paterson Orogen. The other Neoproterozoic units

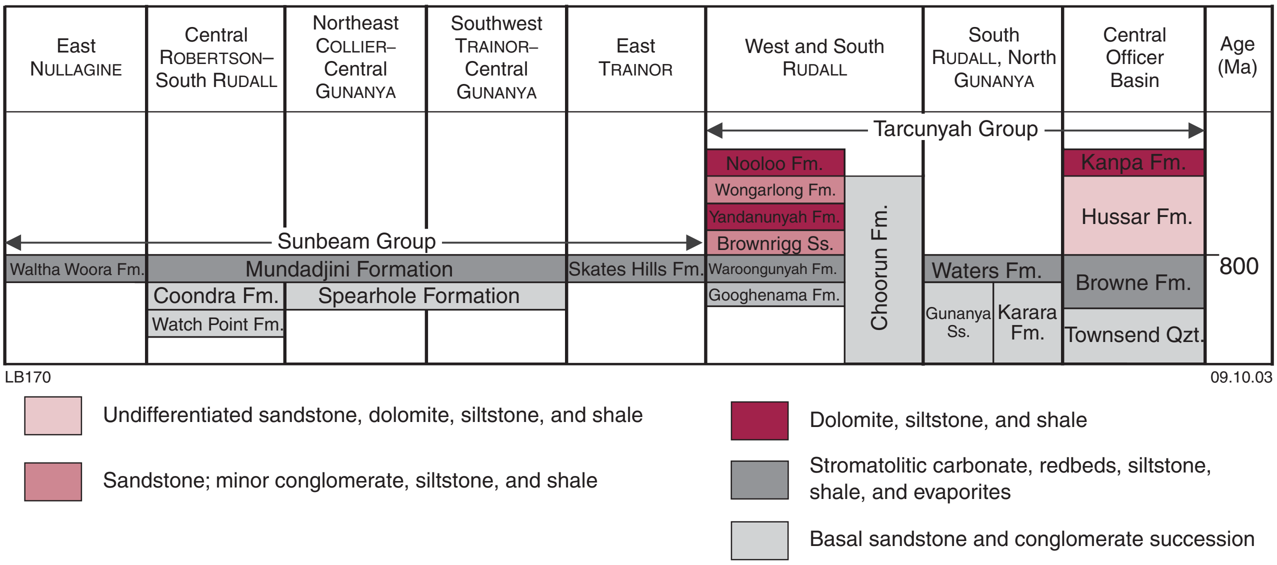

Figure 3. Generalized stratigraphic correlations between units of Supersequence 1 in the northwestern Officer Basin. Capitalized names refer to standard 1:250 000 map sheets (modified from Bagas et al., 1999; see also Hocking and Jones, 2002)

shown in Figure 3, which were not significantly affected by the orogeny, are not included in the orogen. The Tarcunyah Group, which is also included in the northwestern Officer Basin (Bagas et al., 1995, 1999), unconformably overlies the Archaean Pilbara Craton and Mesoproterozoic Bangemall Supergroup (Williams and Trendall, 1998), and is in faulted contact with the Throssell Group along the Vines–Southwest–McKay fault system (Fig. 2).

The Officer Basin (Fig. 1) is one of a number of intracratonic basins interpreted by Walter et al. (1995) as remnants of the once continuous Centralian Superbasin in central Australia. These basins developed after amalgamation of several segments of Precambrian crust to form the Mesoproterozoic supercontinent, named Rodinia by McMenamin and McMenamin (1990), between 1300 and 1100 Ma (Myers et al., 1996).

Basal part of the Tarcunyah Group

To better constrain the maximum age for the basal part of the Tarcunyah Group (Fig. 3) and define possible source regions, 107 detrital zircon grains from three samples of the fluvial to deltaic Gunanya Sandstone (Fig. 3) were analysed using SHRIMP to provide U–Pb ages (Nelson, in prep.). The sandstone is 500 m thick and consists of medium- to coarse-grained arkosic sandstone with interbeds of coarse-grained, pebbly feldspathic sandstone that are common in the uppermost 100 m of the unit. The sandstone exhibits abundant trough cross-bedding, which provide palaeocurrent data (Fig. 2), and indicate that the source region was to the west or southwest (Hickman and Bagas, 1998).

The relative cumulative-probability distribution diagram for zircons from the lower part of the Tarcunyah Group (Fig. 4a) shows that the maximum age of the group is less than 1000 Ma, and assists in fingerprinting the possible source regions for the group. There are two major zircon populations from the group at c. 1780 and 1680 Ma, with a significant proportion between 1310 and 1000 Ma, and a less significant proportion between 1670 and 1310 Ma. The remaining 4% of detrital zircons range from lowermost Palaeoproterozoic to Archaean in age. The presence of both Proterozoic- and Archaean-aged zircons in these samples indicates multiple provenances, a single complex provenance, or multi-cyclic zircons. The primary provenances for these samples are regions containing c. 1800 to 1000 Ma zircons (Fig. 4a).

Geochronological data have been compiled from the literature for the Palaeoproterozoic to Mesoproterozoic terranes around the Pilbara and Yilgarn Cratons that may have contributed detritus to the Tarcunyah Group. This was done because, from the discussion above, the source region of the lower part of the Tarcunyah Group contains Proterozoic rocks and the group contains palaeocurrents that indicate a provenance to the west or southwest. The data are presented as relative cumulative-probability distribution diagrams to provide visual fingerprints (Fig. 4)

Possible source regions for the basal part of the Tarcunyah Group

Regions containing Palaeoproterozoic and Mesoproterozoic rocks that are possible sources for the Neoproterozoic sedimentation in the basal part of the Tarcunyah Group are the orogens around the West Australian Craton to the west and south of the Paterson Orogen (Fig. 1). These orogens are considered sufficiently distinct to be identified as discrete source regions.

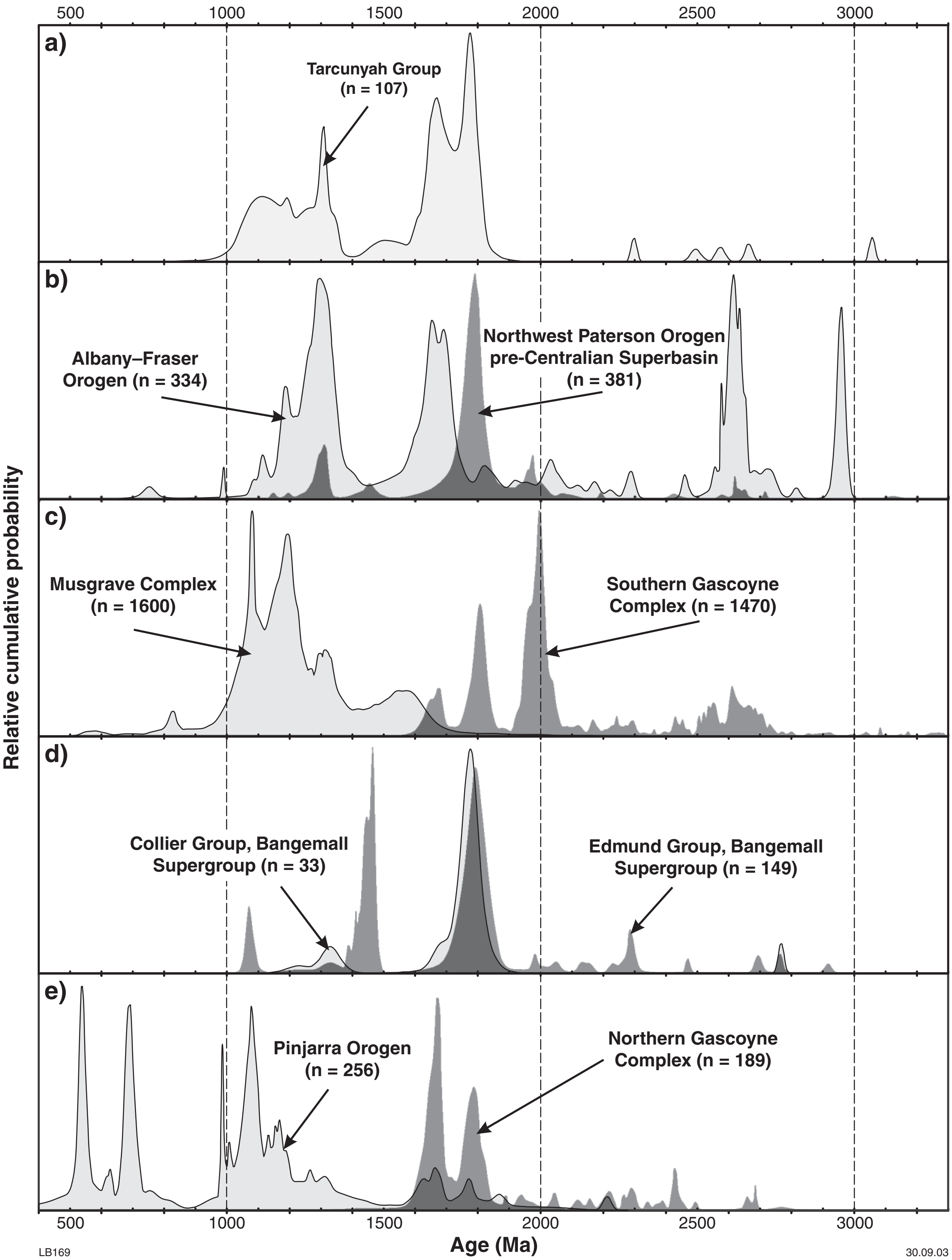

Figure 4. Relative cumulative-probability diagrams of U–Pb SHRIMP ages of zircons from a) the Gunanya Sandstone in the lower part of the Tarcunyah Group (Nelson, in prep.); and potential source areas for these zircons:
b) Albany–Fraser Orogen (Nelson, 1995a, 1996) and northwestern Paterson Orogen (Nelson, 1995a, 1996);
c) Musgrave Complex (Camacho et al., 2002) and southern Gascoyne Complex (Nelson, 1998, 1999, 2000, 2001, 2002);
d) Collier and Edmund Groups of the Bangemall Supergroup (Nelson, 2002; Wingate, 2002); and
e) Pinjarra Orogen (Bruguier et al., 1999; Nelson, 1995b, 1996, 1999) and northern Gascoyne Complex (Nelson, 2002)

The West Australian Craton comprises the Archaean Pilbara and Yilgarn Cratons sutured along the intervening Palaeoproterozoic Capricorn Orogen (Myers, 1990a). It is bound to the north by the Phanerozoic Northern Carnarvon Basin, to the northeast by the Paterson Orogen, to the south and southeast by the Albany–Fraser Orogen, and to the west by the Pinjarra Orogen (Fig. 1).

The Palaeoproterozoic rocks of the Capricorn Orogen comprise plutonic and medium- to high-grade metamorphic rocks of the Gascoyne Complex and Ashburton, Blair, Yerrida, Bryah, Padbury, and Earaheedy Basins, together with deformed Archaean to Palaeoproterozoic rocks at the margins of the Pilbara and Yilgarn Cratons (Cawood and Tyler, in press). Deformation, metamorphism, and associated magmatism took place in the orogen during the c. 2200 Ma Ophthalmian Orogeny (at the northern margin), the 2000–1960 Ma Glenburgh Orogeny (at the southern margin), the 1830–1780 Ma Capricorn Orogeny, and a more localized unnamed event between c. 1670–1620 Ma (Cawood and Tyler, in press). In this part of Western Australia, 1670–1620 Ma felsic magmatism (Pearson et al., 1996; Nelson, 1998, 2002; Cawood and Tyler, in press) is only known from the northern part of the Gascoyne Complex; the nearest known granitic rocks of this age elsewhere are found in the Arunta Orogen of central Australia (e.g. Bagas, in press).

The Mesoproterozoic Edmund and Collier Groups (Bangemall Supergroup) unconformably overlie Archaean and Palaeoproterozoic rocks in the central part of the orogen (Fig. 1), and were deformed during the poorly defined Neoproterozoic Edmundian Orogeny (Martin and Thorne, 2001). The Edmund and Collier Groups are intruded by extensive dolerite sills emplaced during at least two distinct magmatic events, with SHRIMP U–Pb zircon and baddeleyite ages of c. 1465 and c. 1070 Ma (Wingate, 2002).

The Paterson Orogen is a 2000 km-long arcuate belt of folded and metamorphosed sedimentary and igneous rocks that range in age from Palaeoproterozoic to Neoproterozoic and have a linked tectonic history (Williams and Myers, 1990; Tyler et al., 1998). The orogen is exposed in the northwest of Western Australia along the eastern margin of the Palaeoproterozoic West Australian Craton (Myers et al., 1996), and 400 km to the southeast in the Mesoproterozoic Musgrave Complex (Williams and Myers, 1990; Camacho and Fanning, 1995; Camacho et al., 2002) of central Australia (Fig. 1).

The Proterozoic Albany–Fraser Orogen (Myers, 1990b) is faulted against the southern and southeastern margins of the West Australian Craton, and is truncated by the Pinjarra and Paterson Orogens (Fig. 1). The Albany–Fraser Orogen is characterized by polyphase deformation, and consists of reworked Archaean to Palaeoproterozoic high-grade gneiss with c. 1300 Ma layered-gabbroic intrusions, and intensely deformed high-grade orthogneiss and paragneiss intruded by sheets of c. 1300 Ma granite (Myers, 1990b; Nelson, 1995a; Fitzsimons, 2003). Rocks representing four major magmatic events at c. 2630, 1700–1600, c. 1300, and 1160 Ma have been identified in the orogen (Clarke et al., 2000). The orogen also records two tectonic events at c. 1350–1260 (Stage I of Clarke et al., 2000) and c. 1210–1140 Ma (Stage II of Clarke et al., 2000).

The late Neoproterozoic Pinjarra Orogen (Myers, 1990b) truncates the Archaean Pilbara and Yilgarn Cratons, the Palaeoproterozoic Capricorn Orogen, and the Palaeoproterozoic to Mesoproterozoic Albany–Fraser Orogen. Its northern extent is concealed by Phanerozoic sedimentary rocks of the Carnarvon Basin (Fig. 1). It is part of an orogenic belt that can be traced to East Antarctica (Fitzsimons, 2000), and probably relates to a Neoproterozoic suture zone between India and Australia (Fitzsimons, 2000, 2001). The orogen includes isolated and relatively small gneissic basement inliers of the Northampton, Mullingarra, and Leeuwin Complexes, which are unconformably overlain by Phanerozoic sedimentary rocks of the Carnarvon and Perth Basins (Fig. 1). The Northampton and Mullingarra Complexes consist of granulite-facies paragneiss and minor mafic gneiss, pegmatite, granite, and migmatite or their equivalents (Myers, 1990b). The Leeuwin Complex consists of intensely deformed orthogneiss, anorthosite, and minor metabasite, metamorphosed to granulite facies.

Paragneiss from the Northampton Complex has detrital zircons ranging from 1059 ± 32 to 2043 ± 136 Ma, with significant populations at c. 1000–1300 Ma and c. 1600–1700 Ma (Bruguier et al., 1999), and paragneiss from the Mullingarra Complex has detrital zircons with peaks at c. 1200, 1300–1450, and 1600–1800 Ma (Cobb et al., 2001). Metamorphic zircons in gneisses from the Northampton and Mullingarra complexes have SHRIMP U–Pb ages of 1079 ± 3 and 1058 ± 83 Ma, respectively (Bruguier et al., 1999; Cobb et al., 2001). Porphyritic granites from the Northampton Complex have SHRIMP U–Pb zircon crystallization ages of 1068 ± 13 Ma, whereas younger pegmatites have SHRIMP U–Pb zircon crystallization ages of 989 ± 2 Ma (Bruguier et al., 1999).

Zircons in felsic gneiss from the Leeuwin Complex have SHRIMP U–Pb dates of between 779 and 524 Ma (Nelson, 1995b). Orthogneiss in the complex has zircon crystallization ages of 1091 ± 8 and 1091 ± 17 Ma (Nelson, 1999), similar to those in the Northampton Complex.

Possible assignments of zircon populations from the basal part of the Tarcunyah Group

The minor zircon population from the Tarcunyah Group in the range c. 2700–2600 Ma (Fig. 4a) is similar to possible sources from the Yilgarn Craton (not shown in Fig. 4), but detrital zircons with a c. 2500 Ma age are rare in Western Australia and known only in the Yelma Formation of the Earaheedy Basin (Halilovic et al., in press; not shown in Fig. 4), northern Gascoyne Complex (Nelson, 2002; Fig. 4e), and Albany–Fraser Orogen (Nelson, 1995a, 1996; Fig. 4b). The Yelma Formation is not considered a possible single source for the lower Tarcunyah Group because the youngest zircons in the formation are c. 1800 Ma (Halilovic et al., in press).

The possible provenance of detrital zircons with a c. 2300 Ma age in the Tarcunyah Group are limited in Western Australia to metasedimentary rocks in the southern part of the Gascoyne Complex (Kinny et al., in press; Fig. 4c) and in the Earaheedy Basin (Halilovic et al., in press) of the Capricorn Orogen. As mentioned above, the youngest detrital zircon dated from the Earaheedy Basin is c. 1800 Ma (Halilovic et al., in press), making it an unlikely single provenance for the Tarcunyah Group.

The major age populations for zircons from the Tarcunyah Group at 1780 and 1670 Ma best match those from the northern Gascoyne Complex (cf. Figs 4a and 4e). The c. 1780 Ma detrital zircons may have been sourced from granitic rocks of the southern Gascoyne Complex. However, zircons from the southern Gascoyne Complex show a unique and prominent peak at c. 2000 Ma (Nelson, 1998, 1999, 2000, 2001, 2002; Occhipinti et al., 2001) that is not present in the detrital zircon populations from the Tarcunyah Group (cf. Figs 4a and 4c). Alternatively, the c. 1780 Ma detrital zircons may have come from the Rudall Complex (Fig. 4b) in the northwest Paterson Orogen (Bagas, in press). Similar aged detrital zircons are known in the Collier and Edmund Groups (Fig. 4d) of the Bangemall Supergroup (Nelson, 2002), but no detrital zircons with a c. 1670 Ma age have been found in these two groups. Significant zircon populations with an age c. 1670 Ma are found only in the Albany–Fraser Orogen (Nelson, 1995a, 1996; Fig. 4b) and northern Gascoyne Complex (Fig. 4e), and a minor population is found in the southern Gascoyne Complex (Fig. 4c), but the Albany–Fraser Orogen lacks the c. 1780 Ma zircon population.

Dolerite sills that intrude the Edmund Group have magmatic zircons with SHRIMP U–Pb zircon ages of c. 1465 and c. 1070 Ma (Wingate, 2002; Fig. 4d). The Collier Group also has dolerite sills that are yet to be dated and probably contain similar populations of magmatic zircons. Even though detrital zircons with c. 1465 Ma age are relatively rare in the Gunanya Sandstone, both the c. 1465 and c. 1070 Ma ages are represented in the formation, suggesting that the Edmund Group (and probably the Collier Group) could be a source for at least some of the detrital zircons in the basal part of the Tarcunyah Group. The younger age range of detrital zircons in the lower Tarcunyah Group, between 1300 and 1050 Ma, coincides with zircons from the poorly exposed Pinjarra Orogen (cf. Figs 4a and 4e), which extends north beneath the Phanerozoic Perth and Carnarvon Basins. This age range also partly correlates with zircon ages from the Bangemall Supergroup (cf. Figs 4a and 4d). Therefore, the most likely source of these younger zircons is either buried under Phanerozoic sedimentary units immediately west of the northern Gascoyne Complex, or lies to the east in the Bangemall Supergroup. The Musgrave Complex and Albany–Fraser Orogen have similar age distribution profiles to the Pinjarra Orogen (cf. Figs 4b, 4c, and 4e), but the Musgrave Complex has a significant peak at c. 1200 Ma that is not developed in either the Pinjarra Orogen or the basal part of the Tarcunyah Group. Furthermore, both the Musgrave Complex and Albany–Fraser Orogen, which are now exposed to the southeast and south of the Tarcunyah Group respectively, seem to be unlikely provenances for these younger zircons because the palaeocurrent data indicate a westerly provenance.

Discussion and conclusion

From these observations, it is most likely that the northern Gascoyne Complex is the source for the Palaeoproterozoic detrital zircons in the lower Tarcunyah Group. The paucity of detrital zircons with Archaean ages implies that the Tarcunyah Group was not derived by erosion of the Pilbara and Yilgarn Cratons. This suggests that Proterozoic sediments covered the Archaean cratons at the time, and the few Archaean zircons in the lower Tarcunyah Group samples were probably recycled through Palaeoproterozoic sedimentary rocks.

If a combination of the northern Gascoyne Complex, Bangemall Supergroup, and Pinjarra Orogen were the source of sedimentary rocks in the basal part of the Tarcunyah Group, these units must have been exposed at c. 1000 Ma. Furthermore, Figure 4 shows that the Pinjarra Orogen and lower Tarcunyah Group share similar zircon profiles until c. 900 Ma, suggesting that if the provenance included the Pinjarra Orogen (which has younger zircon populations not found in the lower Tarcunyah Group), then the minimum age of this part of the group is c. 900 Ma.

The ‘Gascoyne biotite domain’ of Libby et al. (1999), which coincides with the northern edge of the Yilgarn Craton and southern edge of the southern Gascoyne Complex, is an area that records biotite Rb–Sr ages of c. 800 Ma. One interpretation of this age is that it records cooling after extensive and rapid uplift of rocks previously buried at depths greater than 10 km (assuming a modern geothermal gradient of about 30°C/km; Allen and Allen, 1990). At this depth the ambient temperature would have exceeded the Rb–Sr blocking temperature of biotite, which Cliff (1985) places at 300 ± 50°C. However, Figure 4 shows that the southern Gascoyne Complex did not contribute to the filling of the basal part of the northwestern Officer Basin, 800 km east of the complex. This suggests that the region covering the northern Gascoyne Complex and Pinjarra Orogen must have been exposed or uplifted earlier than the southern Gascoyne Complex (i.e. between 800 and 1000 Ma) if it was the provenance for the sedimentary rocks in the basal part of the Tarcunyah Group.

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Peperite in the Backdoor Formation and its significance to the age and tectonic evolution of the Bangemall Supergroup

by D. McB. Martin

Abstract

Present constraints on the age of the Bangemall Supergroup are based primarily on c. 1465 Ma and c. 1070 Ma dolerite intrusions, which have been interpreted to approximate the ages of the Edmund and Collier Group respectively. New data from a dolerite sill on KENNETH RANGE support intrusion of the c. 1070 Ma suite into wet or inhomogeneously lithified sediments, resulting in the formation of localized peperite and associated fluidized sediment. The fluidized horizon is interpreted to affect the upper Edmund Group and basal Collier Group, suggesting that the significance of the intervening regional unconformity requires further investigation. Estimates of the depth of intrusion, combined with the dominantly below-wave-base depositional environment of the host rocks and distribution of other c. 1070 Ma sills, suggest that sedimentation and subsidence rates were high. Integration of palaeocurrent data further suggests that dolerite intrusion may have played an active role in the evolution of the Collier Basin, initially through the generation of local and regional uplifts, and later as a driver for subsidence through increased loading. The large volume of sills, combined with anomalous subsidence and sedimentation rates, may be related to mantle plume activity.

KEYWORDS: Peperite, fluidization, metamorphism, Bangemall Supergroup.

Introduction

Despite almost half a century of geological investigation, no reliable depositional ages have been determined for the Bangemall Supergroup. This situation is due mainly to the scarcity of contemporaneous volcanic units suitable for isotopic dating. Until recently, the Bangemall Supergroup was considered to be younger than 1638 ± 14 Ma (Nelson, 1995), but stratigraphic relationships with precisely dated granites in the underlying Gascoyne Complex show that it must be younger than c. 1620 Ma (Martin and Thorne, 2002). Currently the best constraints on the age of the Bangemall Supergroup come from SHRIMP U–Pb dating of zircon and baddeleyite in dolerite sills (Nelson, 2001; Wingate, 2002), integrated with palaeomagnetic studies (Wingate, 2002). These studies have identified sills belonging to two discrete mafic intrusive events at c. 1465 Ma and c. 1070 Ma that constrain the minimum ages of the Edmund Group and unconformably overlying Collier Group respectively. However, Wingate (2002) suggested that the sills mark the culmination of extensional basin cycles and constrain the approximate depositional ages of the groups.

Dolerite sills in sedimentary basins generally intrude at depths less than 10 km, prior to regional deformation (Francis, 1982). They may also feed extrusive magmatism. Sharp, planar contacts with well-defined chilled margins reflect intrusion into a lithified host, whereas vesicular upper contacts and mixing with host sediment are more characteristic of shallow-level intrusions and extrusive flows. Peperite records a specific kind of shallow-level magma–sediment mixing that typically develops at the margins of intrusions due to the interaction between hot magma and wet, unconsolidated sediment. This interaction involves fluidization of the host sediment and fragmentation of the cooling magma by a variety of processes (Kokelaar, 1982), and may also be accompanied by dynamic magma–sediment mixing (Busby-Spera and White, 1987). Fluidization also provides a mechanism whereby large volumes of host sediment can be passively displaced by the intruding magma (Kokelaar, 1982). The presence of peperite is therefore a reliable indicator of the broad contemporaneity of magmatism and sedimentation. This paper describes peperite and associated features related to a dolerite sill on KENNETH RANGE*, and considers the geochronological

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

and tectonic implications, based on field relationships, petrography, and geochemistry.

Geological setting

The Bangemall Supergroup is the youngest tectonic element within the Capricorn Orogen, and unconformably overlies the Pilbara and Yilgarn Cratons, the Ashburton, Hamersley, and Earaheedy Basins, and the Gascoyne Complex. It comprises mainly lower greenschist facies, fine-grained siliciclastic and carbonate rocks that are divided into the Edmund, Collier, and Manganese Groups (Martin and Thorne, 2002). The Collier Group is separated from the underlying Edmund Group by a regional low-angle unconformity, across which there may be a 400 m.y. hiatus (Wingate, 2002). The erosional level is deepest in the east where the Collier Group and correlative Manganese Group are thickest. Uplift and erosion on this unconformity appears to be related to westward tilting of the Edmund Group.

Dolerite sills within the Bangemall Supergroup do not appear to be linked to feeder dykes, and in some cases are regionally discordant. The oldest, and volumetrically smallest, sills intruded the middle to upper Edmund Group at c. 1465 Ma (Wingate, 2002). However, the bulk of the sills in the Bangemall Supergroup intruded both the Edmund and Collier Groups at c. 1070 Ma (Wingate, 2002), occupy an area of about 143 000 km^2 (Muhling and Brakel, 1985), and may be part of a large igneous province (LIP; Pirajno et al., 2002). Most Bangemall sills are characterized by planar upper and lower contacts, well-defined chilled margins, and rare xenoliths, suggesting intrusion into a lithified host. The localized presence of fine-grained amygdaloidal to vesicular tops (Daniels, 1969) and plastically deformed sedimentary xenoliths (Muhling and Brakel, 1985) have been used as evidence that some sills may have been emplaced at relatively shallow depths. Individual sills may be more than 100 m thick, but thermal aureoles are generally thin (<30 cm) and characterized by silicification or development of hornfels. Many sills contain a coarse, locally granophyric phase in their central to upper parts. Both sets of sills were folded and metamorphosed under lower greenschist facies during the Edmundian Orogeny, which pre-dates the northeast-trending 755 Ma Mundine Well dyke swarm (Wingate and Giddings, 2000).

On central KENNETH RANGE, a regionally discordant dolerite sill, up to 125 m thick, intrudes the Edmund Group and transgresses the overlying unconformity into the Collier Group. At its northwestern end, the sill is concordant within the upper Edmund Group, but links into a dyke where it transects the unconformity, only to become weakly discordant within the lowermost Backdoor Formation (Fig. 1). Discordance within the Backdoor Formation can be traced by reference to the basal unconformity (Fig. 1a; Martin and Thorne, 2002). The base of this marker is displaced about 10 km in an apparent sinistral strike-slip sense, suggesting coincidence of the sill with a fault (Fig. 1a). The relative timing between fault displacement and sill intrusion is difficult to determine because the two structures are roughly coplanar. However, folds and cleavage preserved at a number of localities along the northern margin of the sill provide structural evidence for a component of steep reverse faulting that post-dates intrusion.

Contact relationships and petrography

This sill is of particular interest because features commonly interpreted to be the result of the interaction between magma and wet sediment are locally preserved along the upper contact. The sill is mostly intruded into siltstone, dolostone, and minor medium-grained quartz sandstone, in which there is little evidence of disruption or contact metamorphism, except along a strike length of 4 km between localities 1 and 4 (Fig. 1b). Here the contact is locally marked by either sediment-matrix dolerite breccia, or a thin unit of mixed and remobilized sedimentary rock that resembles lithic quartz-wacke in hand specimen and separates the dolerite sill from the overlying intact host rocks.

The sediment-matrix dolerite-breccia facies comprises large (decimetre- to metre-scale) angular blocks of medium-grained dolerite and smaller fine-grained sedimentary clasts in a matrix of fine- to medium-grained sandstone. The facies is exposed in a 65 × 30 m plug-like outcrop at the upper contact of the sill at locality 1 (Fig. 1b). Dolerite clasts have planar to curviplanar margins and locally display jigsaw-fit texture, indicating minimal dispersal (Fig. 2). The sandstone matrix also contains drusy vesicles, and sedimentary clasts with alteration rims. Large (decimetre-scale) sedimentary clasts are abundant close to the contact with the host sediments. The sediment-matrix dolerite-breccia facies is overlain by non-disrupted siltstone with planar lamination that conforms to local bedding. Lithofacies characteristics are consistent with interpretation as blocky peperite (Busby-Spera and White, 1987).

Southeast of locality 1, the contact is essentially planar but locally marked by a poorly exposed unit of mixed lithic quartz-wacke facies. At locality 2, outcrop and hand-specimen relationships indicate that the mixed lithic quartz-wacke facies intruded the overlying units, producing small rafts and clasts of sandstone, and locally displacing siltstone and dolostone by a process of stoping and assimilation (Fig. 3). There is no mixed lithic quartz-wacke facies at locality 3, where the sill is overlain by at least 5 m of amalgamated, thick-bedded quartz sandstone. In contrast, southeast of locality 3, the sill intrudes parallel-planar laminated siltstone that is typical of the bulk of the Backdoor Formation (Fig. 1b). In this area, the sandstone and overlying siltstone–dolostone have been eliminated by either faulting or fluidization along the upper contact of the sill, or a combination of these. The mixed lithic quartz-wacke facies is particularly well exposed at locality 4 where it intrudes laminated siltstone (Fig. 4), and contains numerous

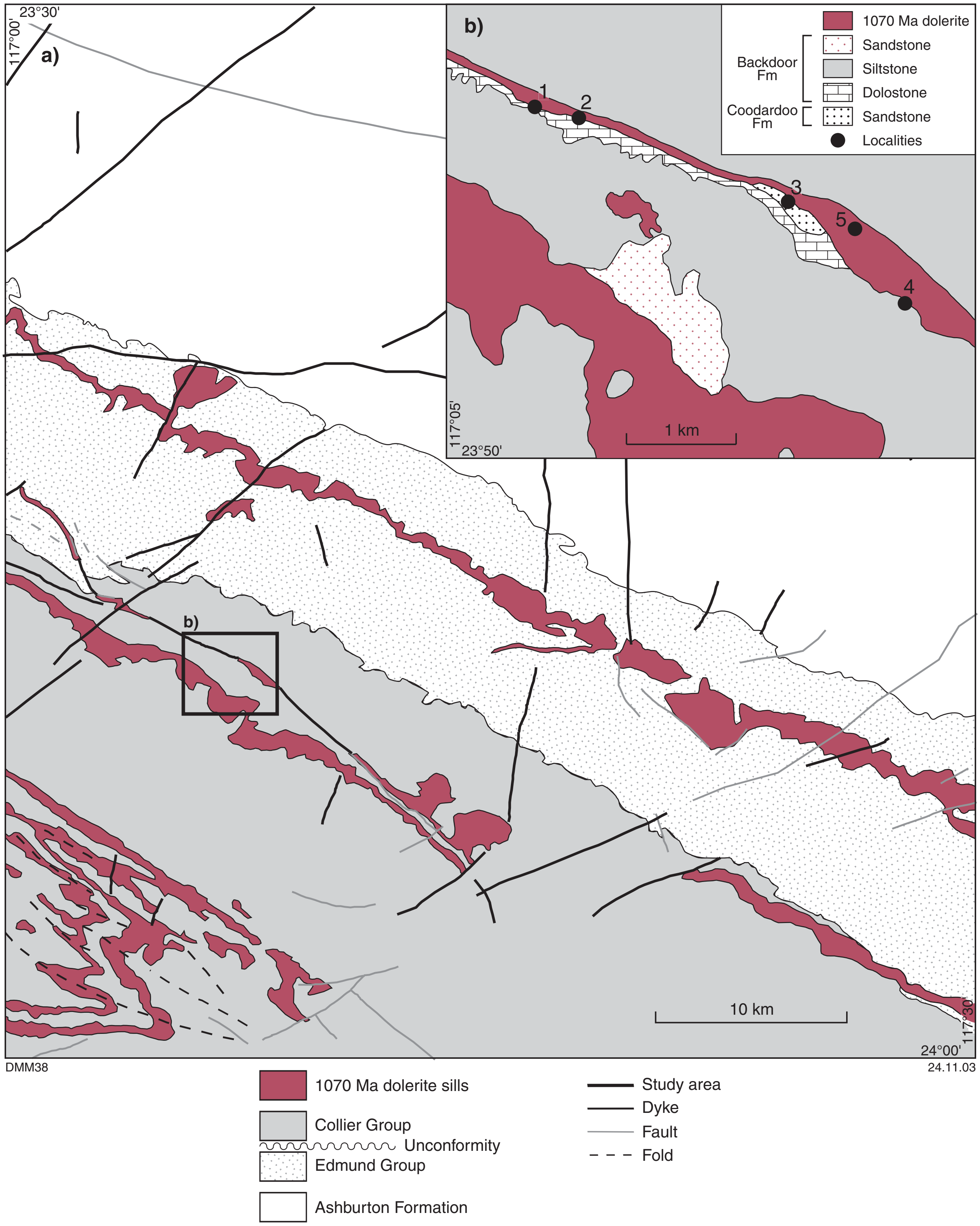

Figure 1. a) Simplified geological map of KENNETH RANGE showing the distribution of c. 1070 Ma dolerite sills, and the location of the study area. b) Detailed geological map of the exposed limits of magma – wet sediment interaction showing the position of localities 1–5.

Figure 2. Blocky peperite at locality 1, showing jigsaw-fit between dolerite clasts (arrow)

plastically deformed siltstone clasts and amygdales (Fig. 5) that are lined with drusy K-feldspar and filled with calcite (Fig. 6). The contact between the mixed lithic quartz-wacke facies and dolerite is not exposed, but the upper contact is sharp and conformable at outcrop scale.

The regional metamorphic grade in the Bangemall Supergroup is very low, except in contact aureoles around dolerite sills, and is characterized by quartz–sericite–chlorite assemblages in siliciclastic rocks and recrystallization in carbonates. Contact metamorphism adjacent to the sill in question has significantly modified syndepositional fabrics within the peperite, mixed lithic quartz-wacke facies, and adjacent reactive host rocks. The thermal aureole is seldom greater than about 20 cm in the laminated siltstone, where it is characterized by patchy silicification or development of spotted slate, but is up to 20 m thick in the more reactive siltstone–dolostone unit. Metamorphism of the siltstone–dolostone is characterized by patchy alteration or complete recrystallization to form the assemblage dolomite–quartz–calcite–diopside–tremolite. Veinlets and patches of this mineral assemblage extend into adjacent interbedded siltstones. Clearly identifiable detrital quartz grains in the sandstone immediately adjacent to the sill have undergone mild recrystallization to form a granoblastic-polygonal texture in a matrix of chlorite. At locality 1, the matrix of the peperite consists of a mixture of fine- to medium-grained quartz sand, and angular clasts of siltstone and dolerite in a matrix of chlorite, biotite, and rare calcite (Fig. 7). Dolerite clasts show strong chlorite–sericite alteration. The lithic quartz-wacke at locality 4 consists of granoblastic-polygonal and rare embayed quartz, poikiloblastic cloudy K-feldspar and biotite, and fine-grained (0.02 – 0.3 mm), spongy porphyroblastic grossularite in a matrix of radiating acicular aggregates of muscovite, chlorite, and biotite (Fig. 8). These assemblages contrast with the lower greenschist facies chlorite–sericite assemblages in the enclosing host-sedimentary facies.

Dolerite petrology and geochemistry

No distinction can be made in hand specimen or thin section between the c. 1465 Ma or the c. 1070 Ma sills. Both suites are characterized by medium-grained quartz dolerite with fine-grained chilled margins, and localized veins and enclaves of coarse-grained granophyre or pegmatoid leucogabbro (Wingate, 2002). In thin section, they contain subophitic plagioclase, augite, orthopyroxene, magnetite, minor granophyric intergrowths of quartz and K-feldspar, pyrite, and rare olivine (Muhling and Brakel, 1985). Secondary minerals, attributed to deuteric alteration, include biotite, sericite, hornblende, clinozoisite, leucoxene, chlorite, and bastite (Muhling and Brakel, 1985). This uniformity in petrology throughout the Bangemall Supergroup

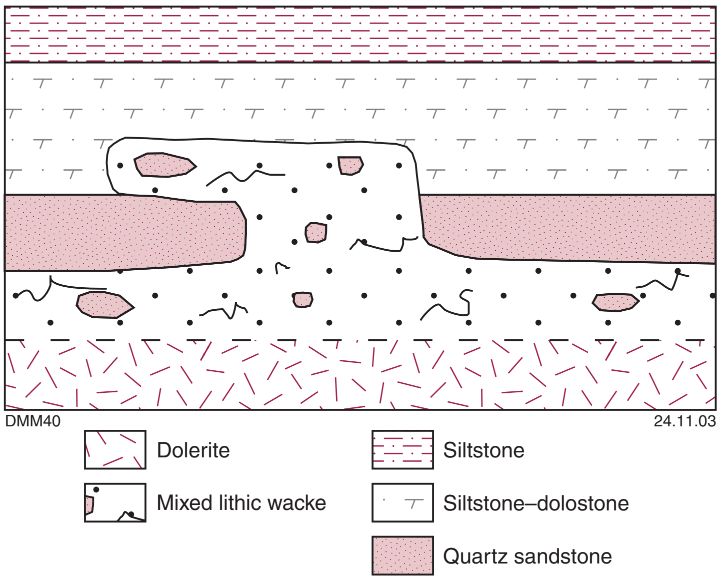

Figure 3. Schematic representation of the intrusive relationships seen in both outcrop (metre-scale) and hand-specimen (decimetre-scale) between the dolerite, mixed lithic quartz-wacke, and siltstone–dolostone facies at locality 2. Note the stoping of siltstone–dolostone and the inclusion of rafts of sandstone in the lithic quartz-wacke facies. Not to scale

was interpreted by Muhling and Brakel (1985) to indicate rapid emplacement of a single suite from a homogeneous source, without assimilation of country rock.

More recently, discrimination between the c. 1465 and c. 1070 Ma sills has been based on geochronology and palaeomagnetic remanence (Wingate, 2002), but can also be made on geochemical grounds (Morris, P. A., 2003, written comm.). Regardless of the extent of fractionation, c. 1465 Ma sills have lower incompatible-element ratios (e.g. Th/Nb) than c.1070 Ma sills, are less enriched in light rare earth elements (LREE), and have flatter heavy rare earth element (HREE) patterns. Dolerite from locality 5 (GSWA 156562; Fig. 1b) has a c. 1070 Ma geochemical signature, supporting the age implied from intrusive relationships.

Discussion

The contact relationships between dolerite and host sediments described above are atypical of sills within the Bangemall Supergroup. Similar features are commonly associated with shallow-level intrusions into wet, unconsolidated sediment (e.g. Kokelaar, 1982; Busby-Spera and White, 1987). Blocky peperite provides good evidence for the injection of fluidized sand into fractures generated by the thermal contraction of the dolerite, and possibly the explosive conversion of water to superheated steam (Kokelaar, 1982). The restricted distribution of blocky peperite may be attributed either to inhomogeneities in the distribution of pore water, or to the isolation of pockets of wet sand along the contact during intrusion, thereby restricting the lateral escape of steam.

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Figure 4. Intrusive relationship between mixed lithic quartz-wacke facies (M) and planar-laminated siltstone (S) at locality 4

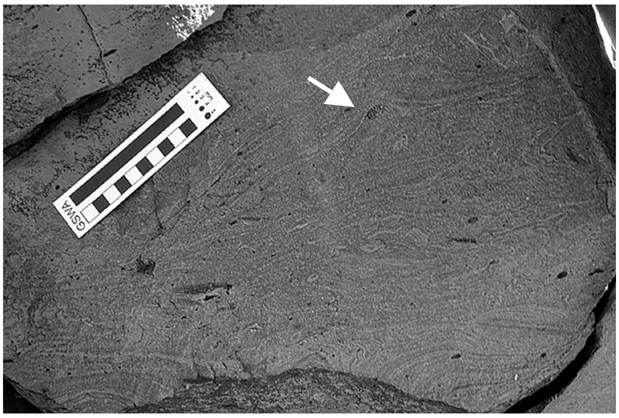

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Figure 5. Deformed platy siltstone clasts (light coloured) and amygdales (arrow) characteristic of the mixed lithic quartz-wacke facies at locality 4

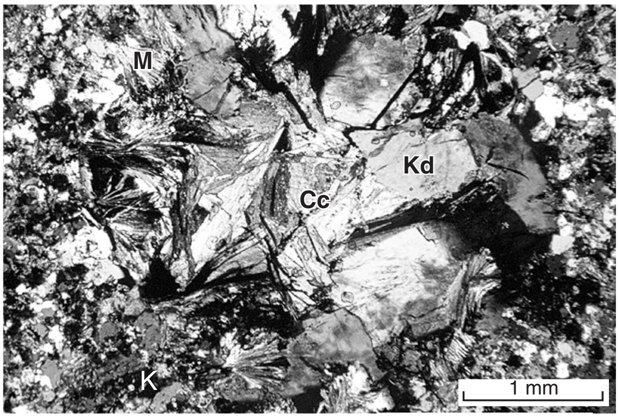

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Figure 6. Thin-section photomicrograph of an amygdale in lithic quartz-wacke at locality 4, showing drusy K-feldspar rim (Kd) and late calcite fill (Cc). Also note the radiating acicular muscovite (M) and poikiloblastic K-feldspar (K) in the matrix

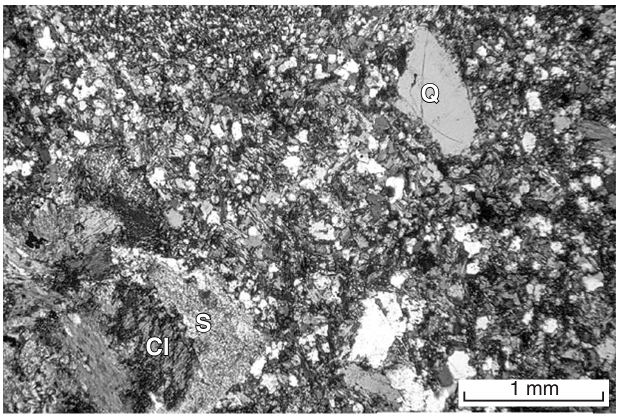

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Figure 7. Thin-section photomicrograph of blocky peperite at locality 1. Note chlorite (Cl) and sericite (S) alteration of a dolerite clast, and the matrix of quartz (Q) grains and fine chlorite–biotite

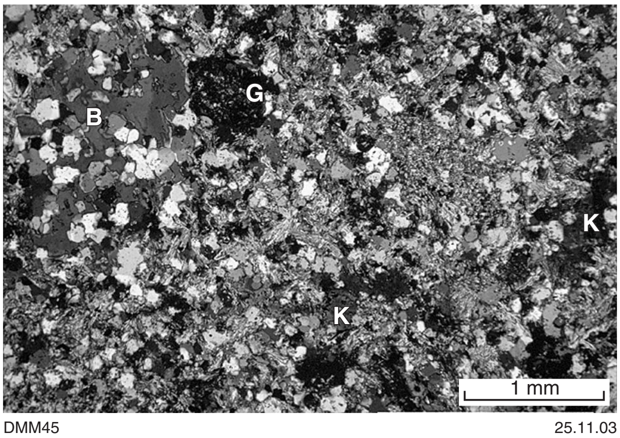

Figure 8. Thin-section photomicrograph of the mixed zone at locality 4 showing poikiloblastic K-feldspar (K) and biotite (B), and euhedral spongy grossularite (G), in a matrix of granoblastic quartz and fine-grained muscovite–chlorite–biotite

However, the textural features and contact relationships of the mixed lithic quartz-wacke facies, and the lateral discontinuity of the quartz sandstone, suggest that magma interaction was dominated by streaming of a steam-sediment slurry along the contact. This slurry was mainly produced by fluidization of the more permeable quartz sand by heated pore water that also interacted with the magma to produce K-rich fluids. Fluidization appears to have been passive, with flow mainly in the plane of the contact, but a small vertical component resulted in stoping and rafting of overlying sediments. The poikiloblastic textures that characterize the mixed lithic quartz-wacke facies are interpreted to reflect rapid crystallization of the K-rich slurry. Assimilation of host dolostone and rapid crystallization is further supported by the presence of fine, spongy grossularite.

The seemingly contradictory evidence for cohesive behaviour (stoping and fragmentation) and fluidization along the same contact, and the localized distribution of blocky peperite, suggest dolerite intrusion at relatively high confining pressure into inhomogeneously lithified sediments. Theoretical critical-pressure estimates suggest that fluidization due to heating cannot occur above 312 bars, equivalent to 3.1 km of seawater or 1.6 km of wet sediment (Kokelaar, 1982). Since the Backdoor Formation has a compacted thickness of 1.7 km in this area, and was deposited mainly below storm wave-base (>50 m), we can assume that the sill was intruded prior to deposition of the overlying Calyie Formation. The stratigraphic relationships, sedimentological characteristics, and regional distribution of the quartz sandstone that underlies the siltstone–dolostone unit suggest that it belongs to the Coodardoo Formation (Fig. 1). However, the evidence for fluidization of this unit along the dolerite contact is at odds with previous interpretations of a significant hiatus between the Edmund and Collier Groups (Martin and Thorne, 2002; Wingate, 2002). The observed relationships therefore imply that both the Coodardoo and Backdoor Formations may not be significantly older than c. 1070 Ma, and that at least part of the former could belong to the Collier Group.

The presence of sills at stratigraphic levels above the lower Backdoor Formation (Wingate, 2002) suggests that sedimentation rates were extremely high at c. 1070 Ma. Furthermore, the predominance in the Collier Group of facies deposited below storm wave-base is indicative of high subsidence rates. This coincidence of high rates of sedimentation and subsidence is most likely tectonically driven, and may be related to intrusion of the sills. The expected effects of dolerite intrusion are a combination of dynamic uplift and subsidence due to increased loading. A change in palaeocurrent direction from southwesterly to southeasterly in the upper third of the Backdoor Formation may reflect local uplift due to sill emplacement. Since there is no evidence for feeder dykes within the Collier Basin, the sills may have been emplaced from outside the exposed limits of the Bangemall Supergroup. Elsewhere, large intrusions such as this have been interpreted as the product of gravitational flow away from the culmination of a mantle plume (e.g. Aspler et al., 2002). A northwesterly palaeocurrent reversal in the Calyie Formation is a response to rapid shallowing and delta progradation from the southeast, most likely due to uplift. A mantle-plume origin for this uplift would be consistent with the LIP hypothesis of Pirajno et al. (2002), and could explain the apparent absence of intra-basinal feeders and anomalous subsidence history of the Collier Basin.

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Effects of the Mesoproterozoic Albany–Fraser Orogeny on the southeastern margin of the Yilgarn Craton

by S. A. Jones

Abstract

The YARDILLA 1:100 000 map sheet, in the southeastern Eastern Goldfields, includes parts of the Archaean Yilgarn Craton and the Proterozoic Albany–Fraser Orogen. Five deformation events were recognized in the Archaean rocks: D_1 recumbent folding; tight upright folding due to east-northeast–west-southwest compression during the D_2 event; regional scale D_3–D_4 faulting; and D_5 Albany–Fraser Orogeny-related deformation. The last event is subdivided into D_{5a} open, northeast-plunging folds and warps; D_{5b} clockwise rotation of D_1 to D_{5a} structures; development of a steep cleavage parallel to the boundary between the Yilgarn Craton and Albany–Fraser Orogen during D_{5c} with an increase in metamorphic grade towards the boundary; and late crosscutting D_{5d} brittle structures. Three deformation events (D_{F1}–D_{F3}) identified in the Proterozoic gneisses of the Fraser Range comprise: D_{F1} gneissic banding associated with a shallowly plunging lineation and dextral shear sense indicators; steep, northeast-striking D_{F2} shear bands with steep lineations; and late, subvertical, northwest-striking D_{F3} faults.

Clockwise rotation of Archaean rocks adjacent to the Yilgarn Craton – Albany–Fraser Orogen boundary and dextral shear sense indicators in gneisses of the Fraser Range are consistent with dextral transpression during a Mesoproterozoic collision event. The craton–orogen boundary represents a Mesoproterozoic suture zone. Intracrustal reactivation during renewed northwest–southeast compression is suggested by the steep D_{F2} shear bands and crosscutting, northwest-striking D_{F3} faults in the Fraser Range, and by late D_{5d} faults in the adjacent Archaean rocks.

KEYWORDS: deformation, transpression, Albany–Fraser Orogeny, Yilgarn Craton.

Introduction

The YARDILLA * 1:100 000 sheet (Jones and Ross, in prep.) is located at the southeastern margin of the Yilgarn Craton and covers parts of the Archaean Eastern Goldfields Granite–Greenstone Terrane and the Proterozoic Albany–Fraser Orogen (Fig. 1). YARDILLA is dominated by Archaean metasedimentary, metavolcanic, and intrusive rocks. Proterozoic amphibolite- to granulite-facies gneisses form the Fraser Range in the southeastern corner of the map sheet, with quartz conglomerates and quartz sandstones of the Proterozoic Woodline Formation overlying Archaean rocks in the northwest (Jones, in prep. a).

Structural trends differ markedly from the regional Archaean structural grain of the Eastern Goldfields, and reveal a complex tectonic history related to overprinting during the Mesoproterozoic Albany–Fraser Orogeny (Fig. 2). The Albany–Fraser Orogen is an arcuate belt extending along the southern and southeastern margin of the Yilgarn Craton, and is characterized by high-grade mafic to felsic gneisses and granites (Myers, 1990, 1995). Myers et al. (1996) identified the boundary between the Yilgarn Craton and Albany–Fraser Orogen as a suture zone based on the intense deformation and marked differences in age and metamorphic grades of the Proterozoic and Archaean rocks. This suture represents the part of the Mesoproterozoic assembly of Rodinia that involved the collision of the Yilgarn Craton with the South Australian Craton (Myers et al., 1996).

This paper describes structures recognized in Archaean rocks and Proterozoic rocks of the Fraser Range and Woodline Formation, and discusses their relationships and the implications for the nature of the boundary between the Yilgarn Craton and the Albany–Fraser Orogen.

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

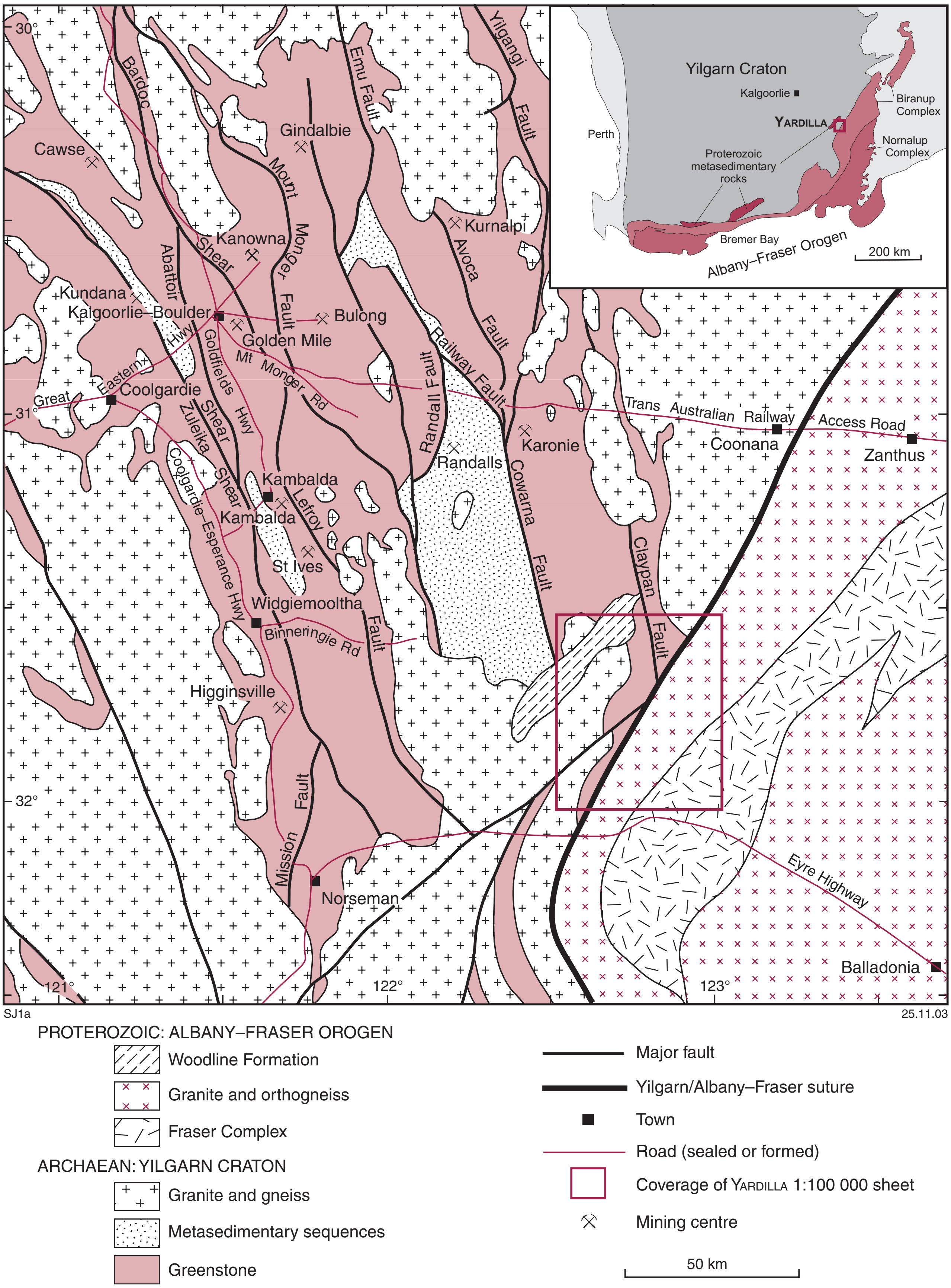

Figure 1. Location map of YARDILLA *and regional geology of the southeastern Eastern Goldfields Granite–Greenstone Terrane*

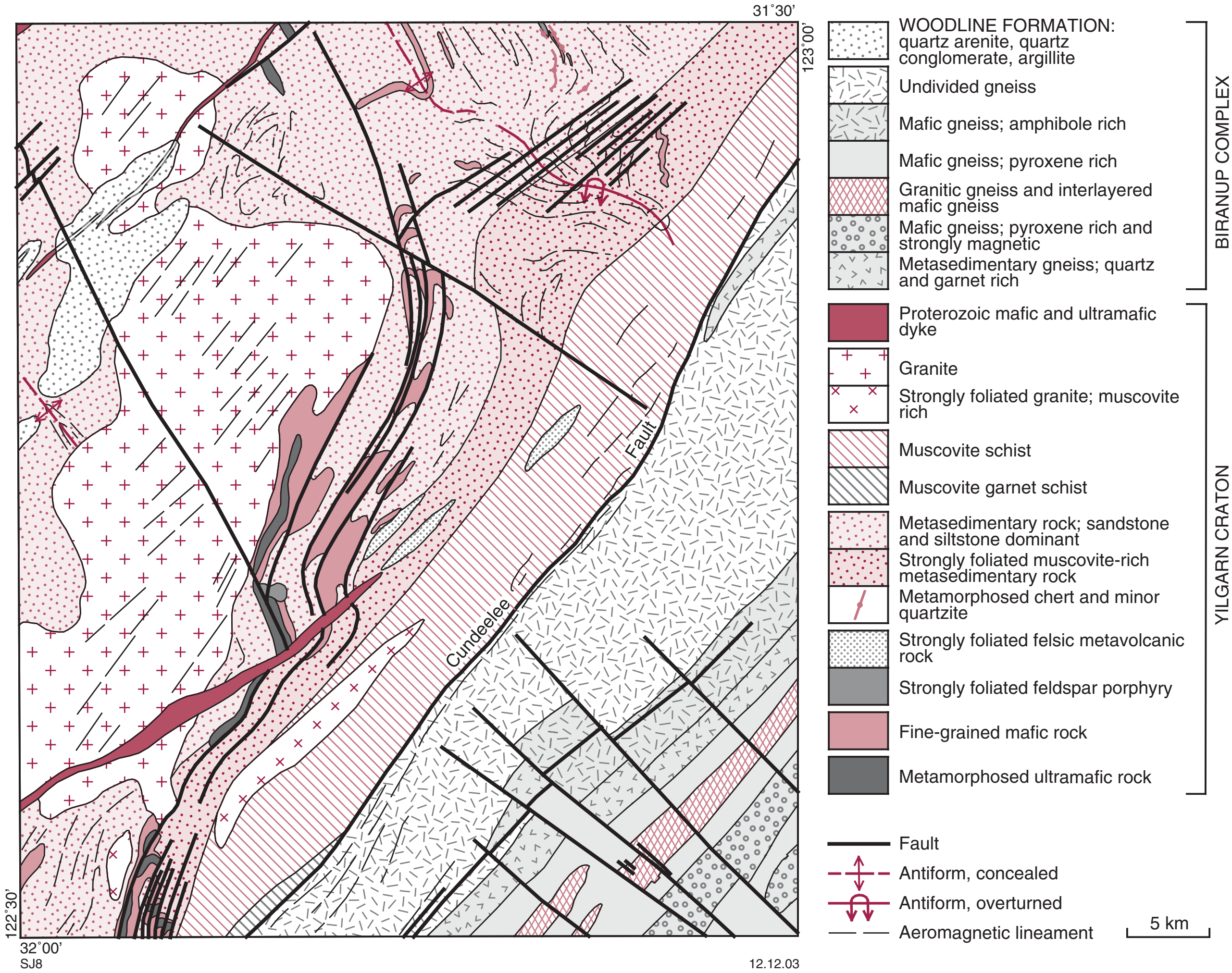

Figure 2. Interpreted geology of YARDILLA

Deformation in Archaean rocks

In northeastern YARDILLA, outcrops along the western edge of a small lake system reveal five deformation events (D_1 to D_5) in the Archaean rocks (Fig. 3): recumbent folding (D_1); upright open to tight folding (D_2); regional scale faults (D_3–D_4, observed only on aeromagnetic images); and Albany–Fraser Orogeny-related deformation (D_5).

The D_1 event is identified on YARDILLA by the development of a fine penetrative foliation (S_1), commonly parallel to bedding, and rare tight to isoclinal recumbent F_1 folds (Fig. 4a). A subhorizontal stretching lineation is commonly developed on the S_1 surface parallel to F_1 fold hinges, and is defined by recrystallized quartz and rodded quartz veins.

Deformation during the D_2 event resulted in open to tight upright folds and variable development of a penetrative foliation (S_2) during east–west compression (Fig. 4b). The S_2 fabric forms a well-developed crenulation cleavage, defined by aligned mica in hinge zones, and is best developed in fine-grained pelitic units (Fig. 4c,d). The F_2 structures refold earlier D_1 structures (Fig. 4e), and Ramsay (1967) type-1 and type-2 fold interference patterns are locally observed.

Regional scale north-northwesterly striking brittle structures (D_3 and D_4) were not observed in the field, but are visible on aeromagnetic images (Jones, in prep. a). A large north-northwesterly trending structure in the western part of YARDILLA may represent a D_3 fault, as it is truncated by the Albany–Fraser deformation front, and is most likely the southern extension of the Cowarna Fault (Fig. 1).

The D_5 event, attributed to the Albany–Fraser Orogeny, is subdivided into D_{5a}, D_{5b}, D_{5c}, and D_{5d}. D_{5a} is characterized by shallow to moderately northeasterly plunging open folds formed by southeast–northwest compression.

The D_{5b} event produced clockwise rotation of D_1 to D_{5a} structures in the Archaean rocks adjacent to the boundary between the Yilgarn Craton

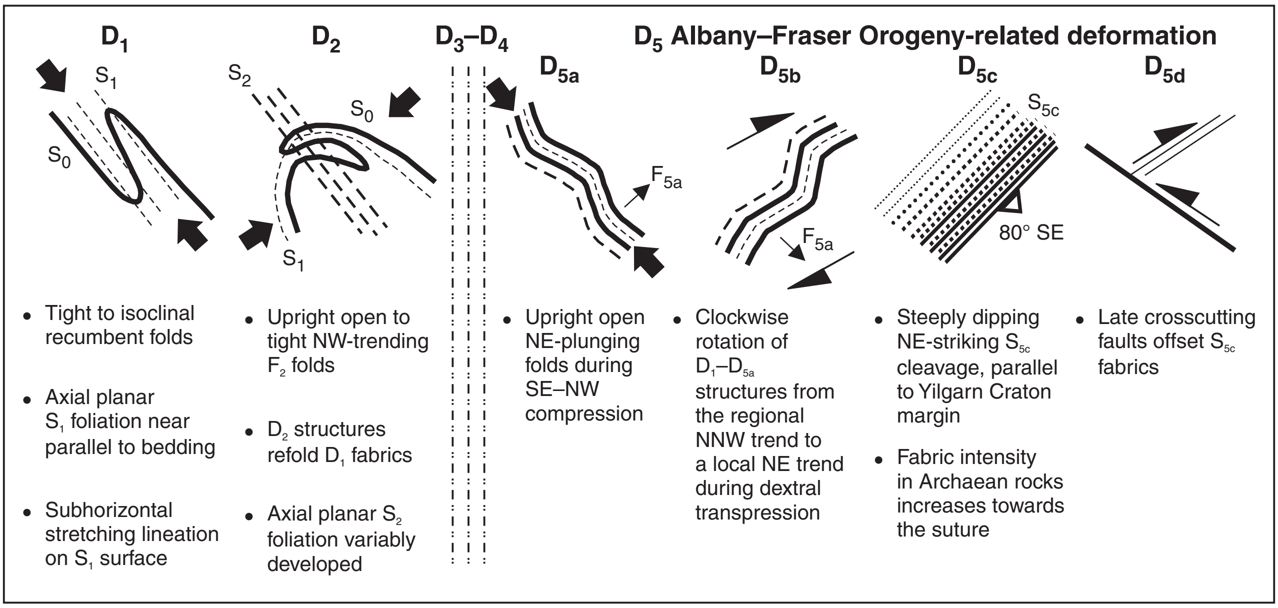

Figure 3. Deformation sequence in the Archaean rocks on YARDILLA

and Albany–Fraser Orogen. The stereoplots (Fig. 5) illustrate the change from the regional north-northwesterly structural grain in northern YARDILLA and ERAYINIA in the north, to the dominantly northeasterly, boundary-parallel trend. The foliation data also show a much greater spread in the area close to the boundary, reflecting increased F_{5a} folding in this zone.

Continued northwest–southeast directed compression during D_{5c} resulted in the development of a strong northeasterly striking, steeply dipping foliation (S_{5c}) in the highly strained Archaean rocks adjacent to the boundary. The foliation is first seen as a spaced cleavage that grades into highly schistose rocks towards the boundary, where the rocks typically become strongly recrystallized and the cleavage is defined predominantly by aligned mica and quartz ribbons. Earlier D_1 and D_2 fabrics are typically destroyed or obscured by the late S_{5c} foliation. The increasing fabric intensity is also accompanied by an increase in metamorphic grade with garnet present in metapelites close to the craton margin.

Late offset of the rotated boundary-parallel fabrics along a large west-northwesterly striking brittle structure and possible antithetic northeasterly trending structures characterize the D_{5d} event in northeastern YARDILLA (Fig. 2).

Deformation in Proterozoic rocks

Woodline Formation

Scattered outcrops of the Proterozoic Woodline Formation unconformably overlie Archaean rocks in northwestern YARDILLA and ERAYINIA (Jones, in prep. b), and consist of quartz sandstone, quartz conglomerate, and mudstone. The Woodline Formation is weakly deformed, with gentle upright folding and warping, and a weakly to moderately developed subvertical cleavage in places (Hall and Jones, in prep.). Beds predominantly have shallow dips and are well preserved, with clear younging indicators showing that beds are not overturned. Small-scale thrusts are present, but show only minimal movement with little effect on the stratigraphy. Southeast–northwest compression is suggested by generally northeasterly trending fold axes, consistent with Albany–Fraser Orogeny-related deformation (D_5) in the underlying Archaean rocks.

The Woodline Formation was thought by Myers (1995) to represent an allochthonous sequence thrust onto the Yilgarn Craton. However, the lack of strong deformation, the unconformable basal contact, and a Rb–Sr age of 1620 ± 100 Ma (Turek, 1966) suggest that deposition of these sedimentary rocks pre-dated the 1300–1100 Ma Albany–Fraser Orogeny (Nelson et al., 1995; Clark et al., 2000). Trough cross-beds and ripples in Woodline Formation rocks on ERAYINIA to the north indicate a predominantly northwest to southeast flow direction (Hall and Jones, in prep.). These sedimentary rocks could be similar in age to the Mount Barren Group in the southern part of the Albany–Fraser Orogen, recently dated at 1696 ± 7 Ma (Dawson et al., 2002), and suggest a prolonged history of tectonic activity along this margin.

Fraser Range

The Fraser Range in the southeastern corner of YARDILLA is composed of high-grade quartzofeldspathic gneisses and layered mafic intrusions of the Fraser Complex, which Myers (1990)

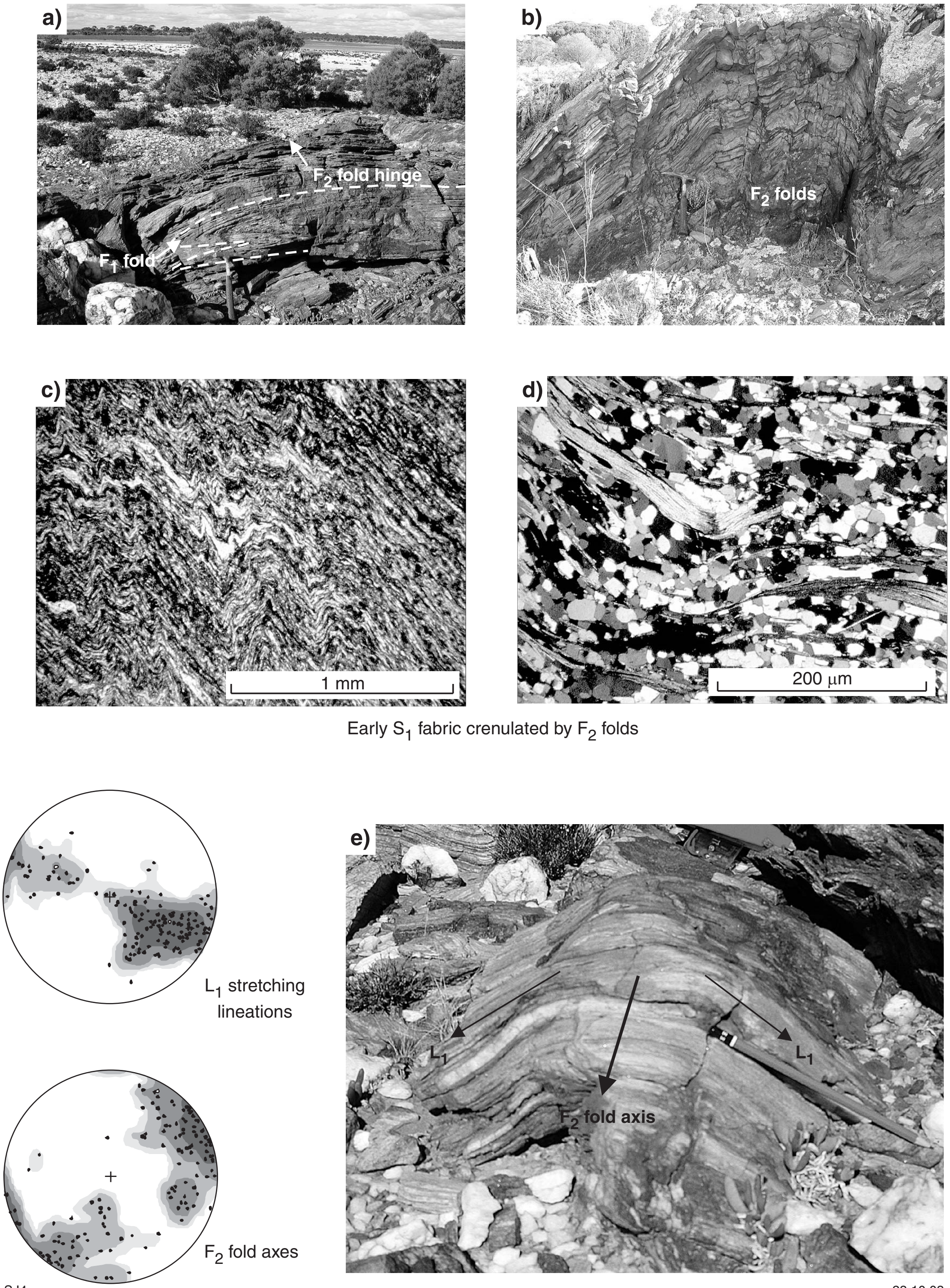

Figure 4. a) Isoclinal recumbent F_1 fold hinge, northeastern YARDILLA; b) upright F_2 folds, northeastern YARDILLA; c) S_1 foliation crenulated by F_2 folding in metasiltstone, northeastern YARDILLA; d) early S_1 fabric defined by aligned micas refolded by F_2 folds; e) stereoplots and photograph illustrating the L_1 stretching lineation being refolded by upright F_2 folds

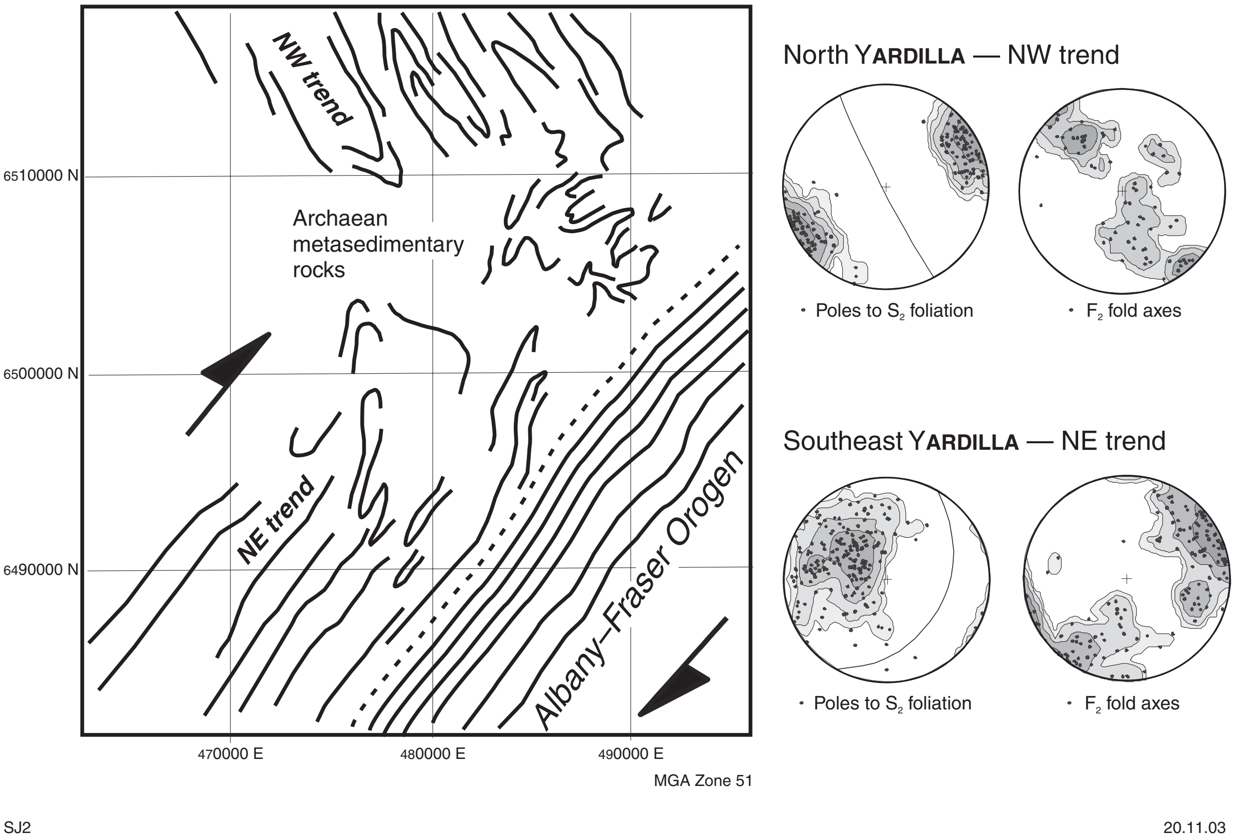

Figure 5. Map and stereoplots demonstrating the marked change from the regional north-northwesterly structural trend in northern YARDILLA *to the local northeast trend in the area adjacent to the suture zone. The foliation data and fold axes show a much greater spread in the lower stereoplots as a result of D_{5a} folding*

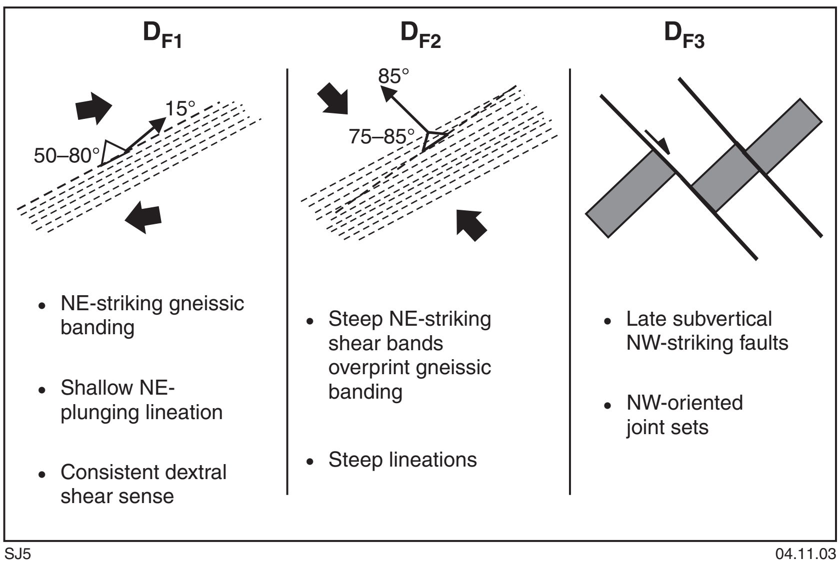

Figure 6. Deformation sequence in the Proterozoic gneisses of the Fraser Range

included in the Biranup Complex in the northwestern part of the eastern Albany–Fraser Orogen.

Three deformation events (D_{F1} to D_{F3}) were recognized in the gneisses of the Fraser Range (Fig. 6). D_{F1} is characterized by well-developed, northeast-striking, steeply dipping gneissic banding formed during northwest–southeast shortening (Fig. 7a). A weakly developed, gently to moderately northeast plunging lineation (L_{F1}) is associated with this fabric (Fig. 7d), and is defined by aligned feldspar augen in granitic augen gneiss. In places, asymmetric tails on augen (Figs 7b,c) provide good dextral shear sense indicators, suggesting a component of dextral shear during D_{F1}.

Subvertical to steeply northwest dipping, northeast-striking D_{F2} shear bands with steeply plunging lineations overprint the gneissic banding (Fig. 7e). Both reverse and normal shear sense have been recorded on these structures and further work is necessary to establish the dominant sense of shear. This event most likely marks a slight rotation in the stress axes, and may represent a reactivation of the pre-existing planar fabric during continued compression.

The youngest structures recognized in the Fraser Range are subvertical, planar, northwest-striking D_{F3} faults. Displacement on these structures ranges from centimetres to several hundred metres, and many structures are associated with abundant fault-parallel fracture sets.

Discussion

On YARDILLA, the marked change from the regional north-northwesterly trend to a local boundary-parallel trend in the area adjacent to the boundary between the Yilgarn Craton and Albany–Fraser Orogen is interpreted as the effect of continent–continent collision during the Mesoproterozoic Albany–Fraser Orogeny. The clockwise rotation of the Archaean rocks suggests a large component of dextral shear during the collision, and this is consistent with dextral shear sense indicators in the gneisses of the Fraser Range. The suture-parallel S_{5c} fabric in the Archaean rocks is near parallel to the D_{F1} gneissic banding in the Fraser Range and may be related to the same event. Renewed northwest–southeast compression and reactivation is suggested by the D_{F2} and D_{F3} overprinting structures in the Fraser Range and the crosscutting D_{5d} brittle structures in the Archaean rocks in northeastern YARDILLA.

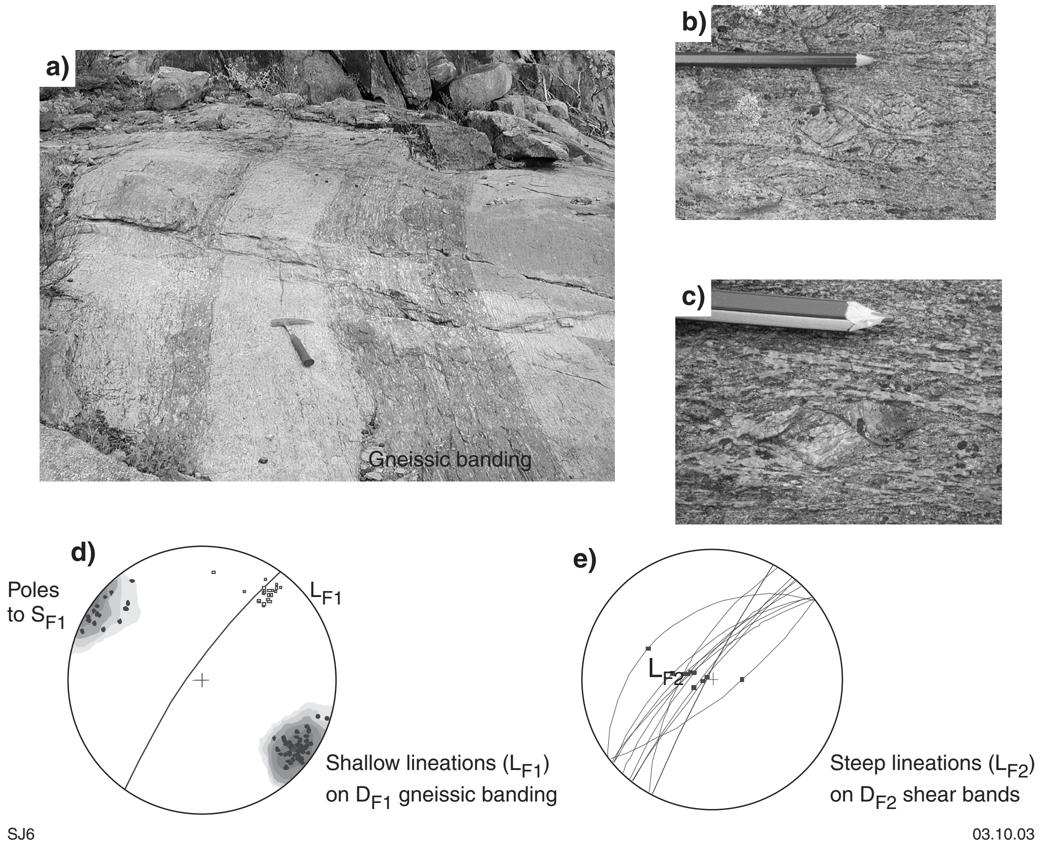

Figure 7. a) Gneissic banding in granitic augen gneiss, Fraser Range; b) and c) asymmetric augen indicating a dextral sense of shear; d) stereoplot illustrating the northeast-trending D_{F1} fabrics in the Fraser Range; e) stereoplot illustrating the northeast-trending D_{F2} fabrics with steep lineations

Table 1. Summary table of deformation events in the Albany–Fraser Orogen

	Western Albany–Fraser Orogen				*Eastern Albany–Fraser Orogen*	
	Duebendorfer (2002)	*Beeson et al. (1988)*	*Holden (1994)*	*Harris (1995)*	*Myers (1995); Nelson (1995); Clark et al. (2000)*	*This study*
D_1	Subhorizontal (S_1) foliation and recumbent folds, no L_1 NW–SE shortening Coeval with peak granulite-facies metamorphism	Rare compositional layering (C_{1a}) preserved in hinge zones, no L_1 Dextral transcurrent with NW–SE shortening	Weak subhorizontal S_1 compositional banding, no L_1 Subvertical shortening dominates	S_{1a} axial-planar foliation to isoclinal folds; S_{1b} ductile extensional shear zones, no L_1 NW thrusting followed by extension (orogenic collapse) $D_1 \approx M_1 \approx 1190 \pm 8$ Ma (Black et al., 1992)	S_1 layer-parallel foliation, slightly precedes subhorizontal S_1/S_2 axial-planar fabric to recumbent folds; no L_1 NW–SE shortening, 1st phase of Stage I deformation (Clark et al., 2000)	None recognized
D_2	Upright NW-vergent folds and subvertical NE-striking foliation Sparse L_2 mineral elongation Dextral transpression	ENE-striking steep S_{2a} shears Sparse L_2 mineral elongation, 25–45°E pitch Open to isoclinal km-scale folds, overturned to NNW Dextral transcurrent with NNW–SSE shortening component	ENE-striking S_{2a} fabric, axial planar to variably plunging F_2 folds; subhorizontal L_2 Local S_{2b} LS-tectonite at granite contacts (no S_2 fabric at Herald Pt) Dextral shearing, NNW–SSE shortening	Upright F_{1c} open NE-trending folds, no S_{1c}; no L_2 NW-striking normal shear zones (S_{1d}); F_{1d} open folds NW–SE shortening followed by NE–SE extension (?) 1190–1170 Ma (Black et al., 1992)	NE-striking, steeply SE dipping S_3 fabric of Clark et al. (2000), axial-planar to upright, regional scale NE-trending folds — some dextral asymmetry No lineations reported NW–SE bulk shortening — last phase of Stage I deformation of Clark et al. (2000) 1315–1260 Ma (Black et al., 1992)	NE-striking, steeply dipping foliation, D_{F1} event (this study) Weak, shallow, NE-plunging (L_{F1}) lineation Dextral shear sense indicators Dextral transpression
$D_{2b?}$	?	?	?	?	Discrete NE-striking subvertical to steeply SE dipping shear zones (S_4 of Clark et al., 2000), axial planar to NW-verging isoclinal folds Steeply plunging lineations NW–SE shortening — early phase of Stage II deformation of Clark et al. (2000)	Subvertical NE-striking shears; steep, fine lineations — D_{F2} (this study) NW–SE shortening
D_3	Brittle–ductile conjugate WNW-striking dextral and NNE-striking sinistral shear zones; dextral shears dominate Dextral transpressive regime	Conjugate brittle–ductile shear bands (C_{2a}), variable sense of displacement Conjugate brittle–ductile shear bands (C_{2b}), WNW-striking dextral, NS to NNE-striking sinistral, no L_3 Dextral transpression with NNW–SSE shortening	S_3 shear zones and bands EW- to WNW-striking dextral, NNE-striking sinistral Subhorizontal L_3 Dextral transcurrent shearing	Conjugate brittle–ductile shears, no L_3 NW–SE shortening, minimum age $\approx 1182 \pm 12$ Ma (Black et al., 1992)	?	NW-striking subvertical brittle–ductile shears, D_{F3} (this study)
D_4	S_4 joints and extension fractures, conjugate NS and WNW NW–SE shortening	None reported	Extension fractures oriented at 316°	None reported	None reported	None observed

NOTE: The eastern part of the Albany–Fraser Orogen is the area east of Bremer Bay

The deformation sequence observed in the Fraser Range has many similarities to the deformation history recognized elsewhere in the Albany–Fraser Orogen (Table 1). Two thermotectonic stages between 1345 and 1260 Ma (Stage I) and 1214 and 1140 Ma (Stage II) have been proposed for the eastern part of the Albany–Fraser Orogen (east of Bremer Bay), based on structure, petrology, and geochronology (Clark et al., 2000). These authors suggest that an initial continent–continent collision at c. 1300 Ma was followed by intracratonic reactivation at c. 1200 Ma. However, a recent paper by Dawson et al. (2003) suggests that peak thermal metamorphism was at 1205 ± 10 Ma, post-dating peak dynamic metamorphism at c. 1260 Ma (Clark et al., 2000; Nelson, 1995) by at least 45 million years. Dawson et al. (2003) relate the peak thermal metamorphism to regional heating associated with the emplacement of 1215–1202 Ma dyke swarms and 1200–1180 Ma granites into the orogen and the adjacent Yilgarn Craton. They suggest three tectonic settings for the Albany–Fraser Orogen: a Stage I collision environment as a result of tectonic emplacement of the Albany–Fraser Province; an early Stage II anorogenic environment defined by a craton-scale thermal anomaly; and late Stage II reactivation of the orogen caused by renewed convergence.

Although regional Albany–Fraser Orogen D_1 structures (Table 1; Clark et al., 2000; Duebendorfer, 2002 and references therein) have not been recognized on YARDILLA, regional Albany–Fraser Orogen D_2 structures can be correlated with D_{F1} fabrics in the Fraser Range. The D_2 event is characterized by dextral transpression and is thought to represent the last phase of Stage I deformation (Clark et al., 2000).

In the Fraser Range, the steep, northeast-striking shear bands with steep lineations (D_{F3} structures) are similar to structures documented by Myers (1995) and Clark et al. (2000) as an early phase of Stage II deformation that involved renewed northwest–southeast shortening and reactivation. Reactivation is also suggested by the late, northwest-oriented D_{F3} faults in the Fraser Range and the D_{5d} brittle structures in the adjacent Archaean rocks. These structures may be related to the regional D_3 event recognized in western parts of the orogen (Duebendorfer, 2002). Regional D_4 extension fractures in the western parts of the orogen (Table 1) were not observed on YARDILLA.

Conclusion

Five deformation events (D_1–D_5) were recognized in Archaean rocks, with D_5 structures representing the local effect of collision along the Yilgarn Craton margin during the Albany–Fraser Orogeny. Initial folding and warping of Archaean rocks during D_{5a} was followed by clockwise rotation of D_1–D_{5a} structures from a regional north-northwesterly trend to a local boundary-parallel northeasterly trend, then by development of a boundary-parallel foliation (S_{5c}) associated with an increase in metamorphic grade, and subsequently by late, conjugate D_{5d} brittle faulting.

The three deformation events (D_{F1}–D_{F3}) observed in the Proterozoic gneiss of the Fraser Range are: well-developed D_{F1} gneissic banding associated with a shallow-plunging lineation and dextral shear sense indicators; steep, northeast-striking D_{F2} shear bands with steep lineations; and late, subvertical, northwest-striking D_{F3} faults.

The clockwise rotation of Archaean rocks adjacent to the boundary and D_{F1} dextral shear sense indicators in Fraser Range gneisses are consistent with dextral transpression during the regional Albany–Fraser Orogen D_2 event (last phase of the Stage I event of Clark et al., 2000). The near-parallel S_{5c} fabric in Archaean rocks and the D_{F1} gneissic banding in the Fraser Range may be related to the same event. The increasing metamorphic grade of Archaean rocks towards the boundary could represent uplift associated with the collision, with exposure of deeper crustal levels adjacent to the suture zone, or the thermal effects of deformation during the Albany–Fraser Orogen.

On YARDILLA, deformation associated with renewed northwest–southeast shortening and intracrustal reactivation (Stage II of Clark et al., 2000; Dawson et al., 2003), may be represented by the steep northeast-striking D_{F2} shear bands and subvertical northwest-striking D_{F3} faults in the Fraser Range, and by the late D_{5d} brittle structures in Archaean rocks.

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Program review

PETROLEUM SYSTEMS STUDIES AND PETROLEUM EXPLORATION DATA

Onshore petroleum systems studies

Objective: *To encourage and focus petroleum exploration within the onshore sedimentary basins of Western Australia by the production of original reports on the geology and hydrocarbon potential of those areas, utilizing and integrating GSWA data and open-file industry data.*

Highlights and activities 2002–03

Activities during 2002–03 focused on the Officer and Southern Carnarvon Basins, where current work programs are nearing completion. Elsewhere, a compilation of the leads and prospects for the northern Perth Basin was finalized and released during 2002–03, a preliminary report on the Nita and Goldwyer Formations of the Canning Basin was prepared, and field excursions to the Southern Bonaparte Basin and Devonian reef complexes of the northern Canning Basin were held. Promotional displays and presentations were made at several conferences, and a report on historic leads and prospects of the central Canning Basin, to accompany a data package, was released late in the year for a scheduled acreage gazettal.

In the Officer Basin, reprocessing of approximately 4300 km of seismic data was completed, with a significant increase in quality, and the data released to the industry. A record supplying technical data associated with the reprocessing was completed, and a regional evaluation and interpretation of the data is underway. A report on the geology and possible petroleum potential of the Waigen area, south of the Musgrave Complex, is in progress although subsurface information is virtually limited to a single drillhole, Vines 1, and remotely sensed data.
A geologically significant mineral exploration corehole in the southwest Officer Basin, WMC NJD 1, was logged, photographed, and re-assessed. The re-interpretation provides an important addition to the subsurface dataset for the basin. The upper part of the section appears to correlate well with that in Empress 1A, to the north, and an underlying pre-Officer Basin section provides control for the joint GSWA–GA seismic line extending into the Officer Basin over the NJD 1 location. A stratigraphic drillhole in the Gibson area, planned for 2002–03, has been postponed until 2003–04.

In the Southern Carnarvon Basin, reports on the Gascoyne Platform and the Bernier Ridge were completed, together with interpretive well completion reports for Yinni 1, Edaggee 1, and Boologooro 1, and a report summarizing and integrating GSWA work since 1994 on the Southern Carnarvon Basin. Although the studies of the Gascoyne Platform and Bernier Ridge focus on offshore areas, they have contributed significantly to understanding of the tectonic framework and evolution of adjacent onshore areas. The well completion reports, which have increased the biostratigraphic control of the Cretaceous section onshore, will also be useful references for offshore sections.

2002–03 publications and products

- Completion and release of 4300 km of reprocessed seismic data in Officer Basin;
- Report 86: *A summary of the geological evolution and petroleum potential of the Southern Carnarvon Basin, Western Australia*;
- Report 87: *Structure and petroleum prospectivity of the Gascoyne Platform, Western Australia*;
- Record 2002/18: *Stratigraphy and petroleum geology of drillhole WMC NJD 1, Officer Basin, WA*;
- Record 2003/4: *Leads and prospects within tenements of the northern Perth Basin, Western Australia, 2002*;
- Record 2003/7: *GSWA Yinni 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia*;

- Record 2003/8: *GSWA Edaggee 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia*;
- Record 2003/13: *Seismic data reprocessing, Officer Basin, Western Australia*;
- Record 2003/14: *Prospects and leads, central Canning Basin, Western Australia, 2003*;
- *Summary of petroleum prospectivity, onshore Western Australia 2003: Bonaparte, Canning, Officer, Perth, Southern Carnarvon, and Northern Carnarvon Basins*;
- A paper on Officer Basin seismic stratigraphy in the 2001–02 GSWA Annual Review;
- six external papers: three in the third Western Australian Basins volume (two on the Officer Basin, one on prospectivity of the northernmost Southern Carnarvon Basin), one each in the 2003 APPEA Journal (on play types and halotectonics in the Officer Basin), the PESA Journal (on Southern Carnarvon Basin geochemistry), and Palaeogeography Palaeoecology and Palaeobiology (on Permian glaciation in Western Australia).

Future work

A joint GSWA/industry workshop was held in late 2002 to ascertain future petroleum-related work directions for GSWA in the sedimentary basins within Western Australia. The workshop and follow-up discussions clearly indicated that in general work should be at a regional level, as with GSWA field-mapping programs, rather than at prospect or lead level. Programs should also show a mix of work in brownfields and greenfields areas. As a consequence, the basin studies group will increasingly focus on the onshore Canning Basin (as programs in the Southern Carnarvon and Officer Basins wind up). Initial products will consist of data packages assembled to assist later interpretive work — with an emphasis on trial seismic reprocessing and logging of available core from the pre-Permian section. These products will include records on post-mortems and correlations, historic leads, a geochemistry compilation, core descriptions, and a potential field interpretation through the southern Canning Basin.

In the Officer Basin, a regional re-interpretation of the reprocessed seismic data is already underway. The other major work will be the drilling of Lancer 1 in the Gibson Sub-basin, from which there will be basic and interpretive well completion reports.

A new state-wide interpretation of residual isostatic gravity is underway as a prelude to a revision of depth to basement for Phanerozoic basins, as well as a re-interpretation of potential field data acquired by Water Corporation over the southern Perth Basin.

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Petroleum exploration reports and data

Objective: *To administer the collection and storage of statutory petroleum exploration reports relating to tenements in Western Australia, and to ensure the efficient dissemination of information in these reports to industry. This work covers all aspects of the submission, management, and release of petroleum exploration data through WAPIMS (Western Australian petroleum information management system database).*

Highlights and activities 2002–03

The program of scanning well completion reports from hardcopy to PDF and TIFF file formats continued, with a total of 844 reports focusing on the Canning Basin being scanned and loaded onto the WAPIMS system for online web viewing.

As part of the WAPIMS database program well log curves for a further 550 wells — giving a total of 600 wells — were loaded into the system, enabling the public to view the data via the web.

Transcription of seismic field and processed data from the Canning Basin from nine-track reels to 3590 cartridges (3585 tapes from 12 surveys) was continued, to reduce the number of 'old' tapes in the archive and move these valuable data to new and more reliable media.

WAPIMS database

During 2002–03 a total of 38 166 new data items received from industry were loaded into the system, and core data for both the Kalgoorlie and new Perth core libraries has been entered onto WAPIMS.

Data release

During 2002–03, 257 edited and unedited reports were released. Industry requests were slightly higher than 2001–02, with 95 requests for loans of seismic and well, digital field, and processed data for 219 seismic surveys and 172 wells being supplied. In addition, 179 requests for sample drillcore or cuttings were processed.

Future work

- Upgrades to the WAPIMS public interface and ArcSDE component
- Continuation of the transcription program for seismic data
- Continuation of scanning well completion reports from the Canning and other basins

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MINERAL RESOURCES ASSESSMENT AND MINERAL EXPLORATION DATA

Mineralization and exploration assessment

Objective: *To promote prospectivity and encourage mineral exploration within the State for precious metals, base metals, ferro-alloys, and diamonds, 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 hardcopy reports and maps together with GIS-compatible databases on CD-ROM.*

Highlights and activities 2002–03

Two mineral prospectivity data packages on the north Kimberley and Arunta–Musgrave areas were released during the year. Compilation of databases and digitizing of spatial data for mineral occurrences and mineral-exploration activities was completed for the Paterson and Canning areas, and report writing for these areas commenced. Database compilation and digitizing also commenced on two new project areas: Earaheedy and Gascoyne. Updated CD-ROMs using data from the latest WAMEX releases since 1998 were completed for two earlier projects (north Eastern Goldfields and west Pilbara) and a CD update for the east Kimberley was in progress (Fig. 1).

Each data package contains a report that synthesizes information on the mineral prospectivity of an area, a CD-ROM, and a 1:500 000-scale map that shows mineral occurrences, mineralization styles, commodity groups, and geology. For project areas where there is limited open-file data (i.e. the Arunta–Musgrave, Canning, and Officer–Eucla areas) each package consists of a Record and a CD-ROM.

The CD-ROM for 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 Departmental database with mine sites and mineral resources); WAMEX (extract of Departmental database with index of open-file mineral exploration reports); TENGRAPH (extract of Departmental database with mining tenements and holders); geology (solid and regolith); Landsat; aeromagnetics; radiometrics; gravity; and topographic and cultural features.

A 1:500 000-scale map of the mineralization and geology of the entire Pilbara Craton was also released early in the year.

A poster display on diamond prospectivity in the Kimberley region was presented at the Australian Diamond Conference in December 2002.

A further enhancement to access open-file data is being introduced on GeoView to provide links between EXACT and WAMEX on the web. The distribution of exploration activities derived from WAMEX open-file reports was made available on GeoView in late 2002 where activities are displayed as points, lines, and polygons. Clicking on an activity activates an attribute box containing information on the activity type and the open-file report 'A' number. Alternatively, an area may be selected ('lassoed') to provide information on numerous activities and report numbers within that area of interest. Work is in progress to establish a hyperlink from report numbers in EXACT to WAMEX reports on the web.

2002–03 publications and products

- Report 85: *Mineral occurrences and exploration potential of the north Kimberley*;
- Record 2002/9: *Mineral occurrences and exploration activities in the Arunta–Musgrave area*;

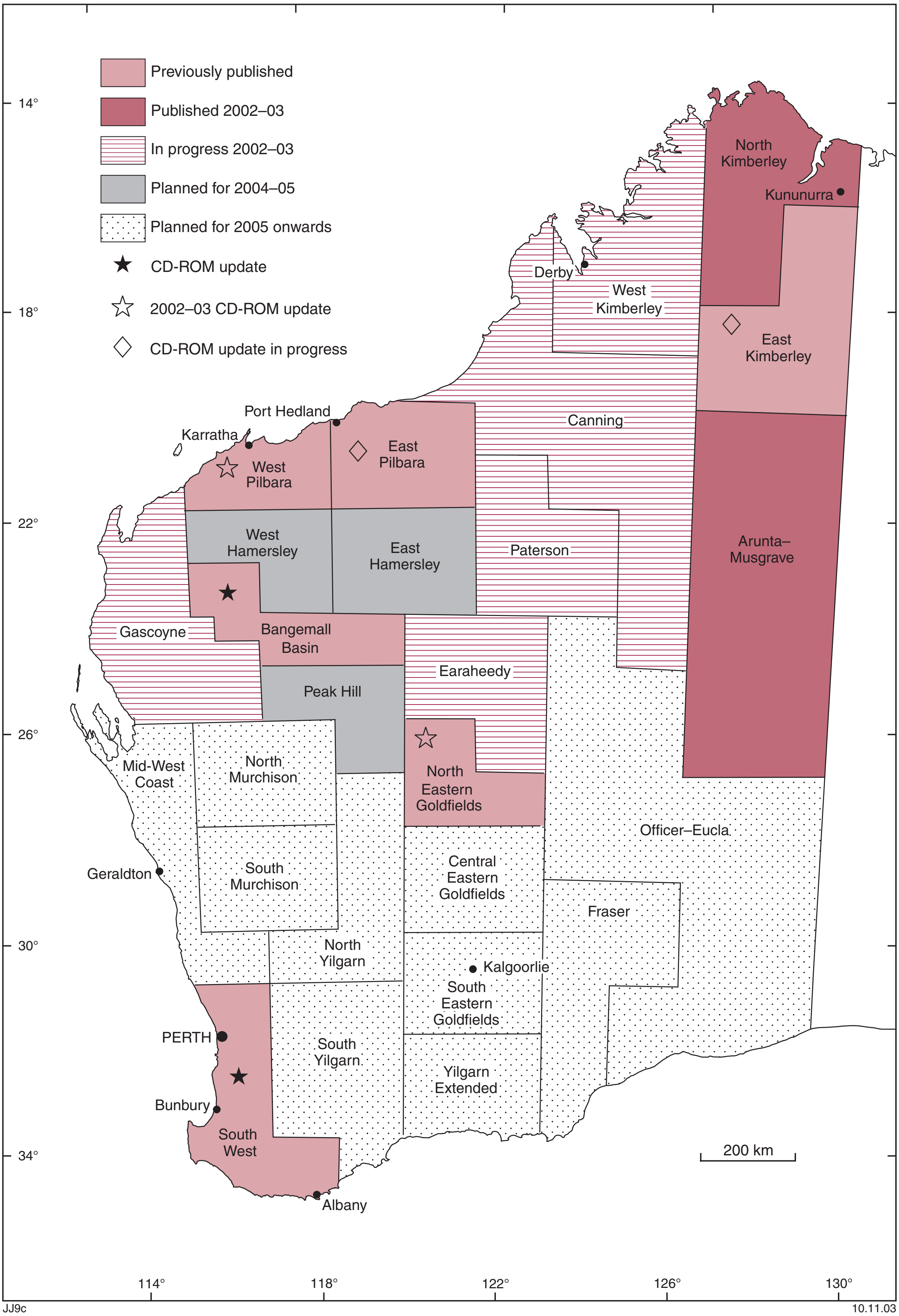

Figure 1. Progress of regional mineralization mapping projects

- CD-ROM updates: north Eastern Goldfields and west Pilbara;
- Mineralization and geology of the Pilbara Craton (1:500 000-scale map).

Future work

Two data packages for the west Kimberley area (Report 88) and Canning area are in preparation for release in late 2003. One data package for the Paterson area is in preparation for release in mid-2004. An update of the CD-ROM for the east Kimberley is in preparation for release in early 2004. Database compilation and digitizing will continue for the Earaheedy and Gascoyne areas, and will commence for the west Hamersley area (Fig. 1).

An update of mineral occurrences and mineral exploration activities will commence for the east Pilbara, using data from the latest WAMEX releases since 2001. The new digital data are planned for release on an updated CD-ROM in mid-2004.

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Commodity and industry analysis

Objective: *To provide statistics, expert analysis, and authoritative opinion on all commodities in the area of mineral exploration activity, mineral resources and reserves, and mining to a range of customers including: other Divisions of the Department of Industry and Resources, other Government agencies, the minerals industry, and the community at large. All these functions are supported through the maintenance and enhancement of Western Australia's mines and mineral deposits database (MINEDEX).*

2002–03 highlights, activities, and publications

- The ongoing data capture into DoIR's mines and mineral deposits database (MINEDEX) formed an important part of the function of this section. A total of about 250 ad hoc inquiries seeking information on mines, deposits, mineral resources, and mineral production were received from industry, the public, other Government agencies, and staff of DoIR.
- A draft GSWA Bulletin on tantalum in Western Australia was prepared.
- The Atlas of mineral deposits and petroleum fields (A4 booklet and A0 map) was published.
- Record 2002/19: *Mines and mineral deposits of Western Australia: digital extract from MINEDEX, May 2003 update* was published in CD-ROM format.
- Iron ore deposits of the Pilbara (August 2002 edition) was published as a map and CD.
- A paper entitled 'Declining greenfields exploration in Western Australia, 1996–2001' was published.
- Annual overviews on mineral exploration and development in Western Australia were compiled for publication by several organizations.

Future work

Future work planned for this group centres on providing enhancements to MINEDEX, particularly the online availability of historic gold production data via MINEDEX-on-the-web. Updates for the major resources map and the iron ore deposits compilation will be published, as well as the tantalum bulletin. A new map showing operating mines in Western Australia will be generated from the MINEDEX database. The annual overview of mineral exploration and development in Western Australia will be completed. A bulletin delineating the dimension stones in Western Australia will be compiled for publication in two volumes.

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Resource mapping and assessment

Objective: *To undertake detailed mineral resource and regolith–landform mapping in areas of the State that are likely to see significant development, and in which land use planning would benefit from the availability of digital and hardcopy geoscience datasets.*

Highlights and activities 2002–03

The published maps, reports, and assessments are based on the regolith–landform mapping system — involving the systematic collection of surface and near-surface material properties, and landform properties and patterns — combined with an appraisal of potential for extracting basic raw materials and data on minerals and mining activity.

Some additional field mapping was completed for the Kalgoorlie and Boulder 1:50 000 sheets (Fig. 2) in 2002, and the Inventory of features of mine sites, quarries, and pits was completed.

Compilation — and, hence, the planned release — of the Kalgoorlie and Boulder 1:50 000 sheets was deferred while new systems and procedures were implemented for the Inventory of abandoned mine sites, and field activities for the Kanowna and Golden Ridge 1:50 000 sheets were limited to acquiring mine site features.

Future work

The Kalgoorlie–Boulder regolith–landform resources map and mineral dataset on CD-ROM is expected to be completed in 2003–04, and will have an increased emphasis on mineral resource data. Field mapping in the Kanowna and Golden Ridge 1:50 000 map sheets is planned for late 2003–04, followed by publication of the digital dataset.

Digital remastering and revisionary fieldwork is still planned for Yallingup, with the work scheduled for 2004–05, leading to completion of a Cape-to-Cape dataset for this part of the South West region.

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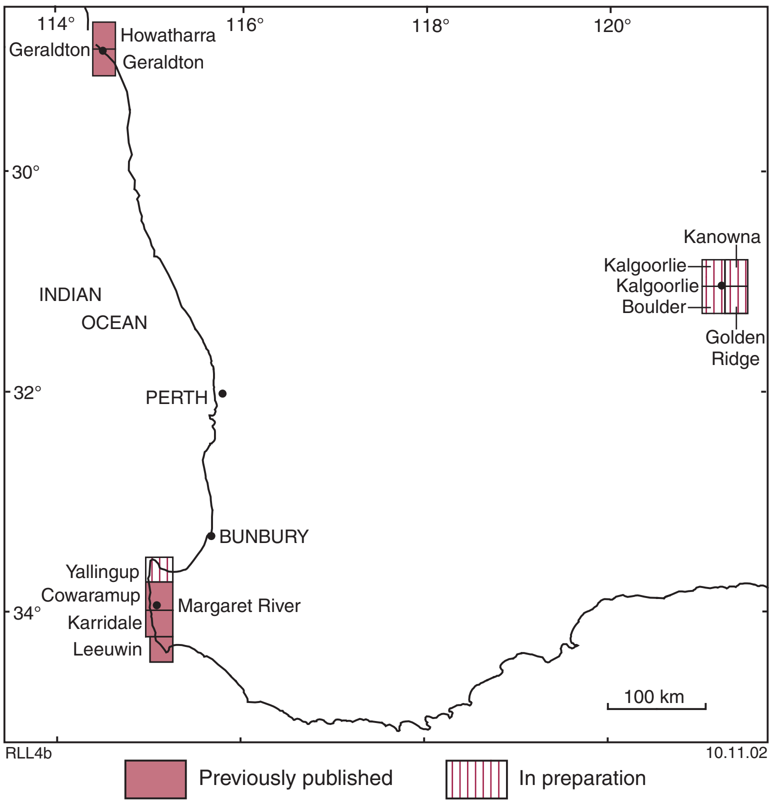
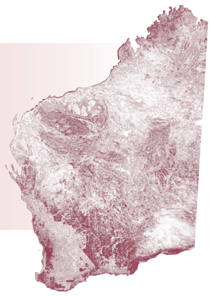


Figure 2. Progress of resources and regolith–landform mapping

Inventory of abandoned mine sites

Objective: *To accurately locate mine site features on historic mine sites in the State and document factors relevant to the safety and environmental hazards they pose. This will provide a sound basis for future planning of rehabilitation of features at abandoned mine sites.*



Highlights and activities 2002–03

The inventory, which commenced in 1999–2000, has the objective of locating mining-related features within historic mine sites in the State and documenting factors relevant to their safety and environmental impact. This information can be used to provide advice on rehabilitation or conservation of historic mine sites.

The field database on a hand-held computer is linked to satellite navigation equipment capable of locating mine site features such as shafts to an accuracy of around 10 m. The rate of data collection reflected productivity gains made using new equipment introduced in 2002, with more than 31 000 mine site features added to the inventory during the field season. The total number of features in the inventory stood at 94 130 at 30 June 2003 (Fig. 3). The total also includes some potential hazards completely or partially rehabilitated by mining tenement holders, with location data supplied to the Department by companies.

Priority for field inspection is being given to those sites within 10 km of towns and communities, and within 1 km of important access roads. About 35% of all historic mine sites are in this high-priority category. At 30 June 2003, approximately 75% of known high-priority production sites had been inspected during the program.

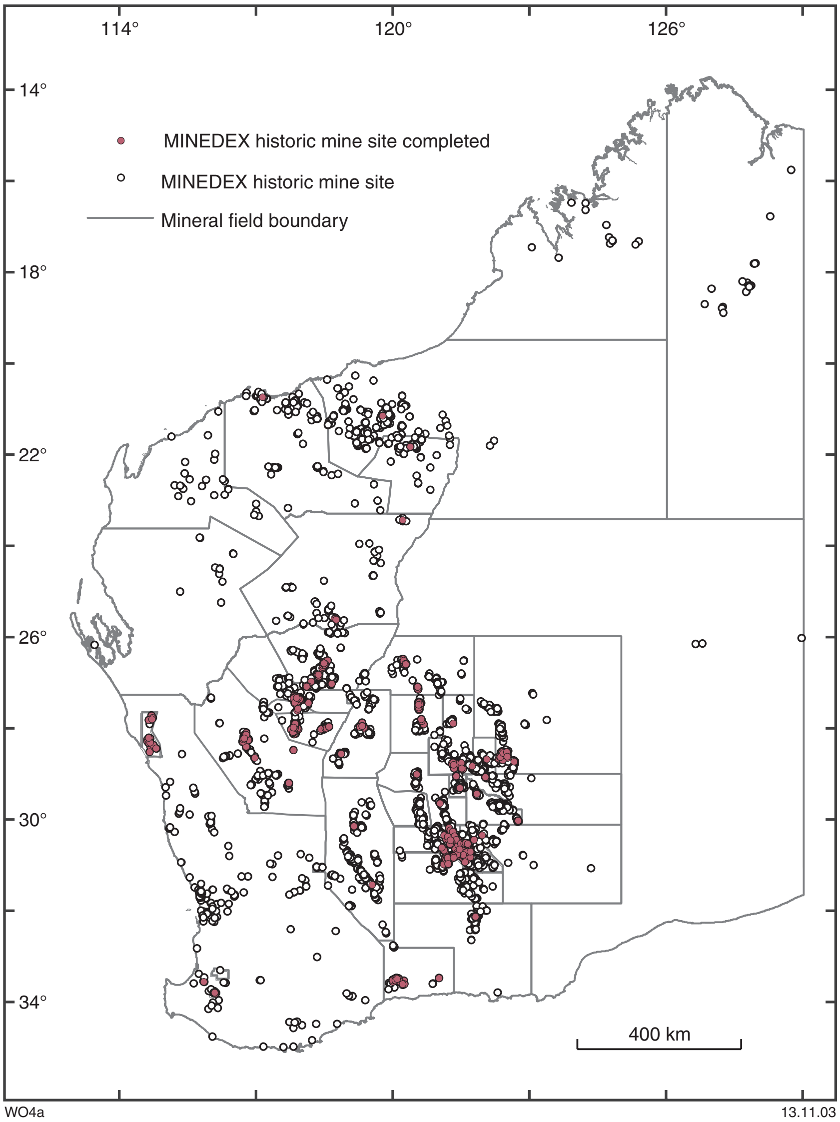


Figure 3. Status of the inventory of abandoned mine sites — MINEDEX sites completed as at 30 June 2003

Fieldwork during 2002 was conducted at high-priority sites around Kalgoorlie and Coolgardie and included surveying all sites for the four 1:50 000 map sheets centered on Kalgoorlie, that is, KALGOORLIE (3136-II), BOULDER (3135-I), GOLDEN RIDGE (3235-IV) and KANOWNA (3236-III). Fieldwork commenced in the Southern Cross area in 2003.

2002–03 publications and products

- Record 2003/9: *Inventory of abandoned mine sites: progress 1999–2002.*

Releases and planned work program for 2003–04

The field season of 2003–04 will allow the mapping team to capture attributes for approximately 40 000 features from up to 1300 historic mine sites in the Southern Cross, Westonia, Kambalda, and Norseman areas. An updated CD-ROM of digital data, including field photographs, is planned for release in late 2003, and there are plans to release a web-based version of the inventory database in 2004.

Work programmed for 2004–05 and beyond

For field seasons in 2004 and beyond the plan is to complete the inventory for Norseman, and start work on the Golden Quest Discovery Trail from Coolgardie to Leonora. Completing the inventory for the South West of WA and for Aboriginal communities in the Goldfields is also a priority for future fieldwork.

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Land access and resource assessment

Objective: *To provide geological advice with respect to land title and land use changes, and thereby protect access to land for future exploration and mineral resources extraction. This advice is provided to other divisions of the Department, other Government authorities, resource companies, and the community.*

2002–03 highlights and activities

Responsibility for this function was transferred from the disbanded Land Access Branch to the Geological Survey from 1 July 2002.

The primary function is to provide geological advice with respect to changes to the tenure and purpose of Crown land and Private land. During 2002–03 advice was given to 1048 requests for land title or land use changes. These included advice on land subdivision proposals, pastoral lease acquisitions for conservation purposes, and the creation of terrestrial and marine conservation reserves to ensure future resource access.

Detailed resource assessment studies, including reports, were carried out on:

- Geraldton to north Eastern Goldfields infrastructure corridor. This involved the assessment of the mineral potential of underlying tenements and negotiating appropriate deviations for the Gas Pipeline Working Group of the Department;
- Yakabindie Aboriginal heritage claim for the Department of Indigenous Affairs and Environment Australia;
- Proposed extensions to Mount Manning nature reserve for Department of Conservation and Land Management (CALM) and DoIR's Office of Major Projects;
- CALM pastoral leases that are proposed to be converted to conservation reserves.

Future work

Work will continue on examining land title and land use changes for potential conflict with land access for exploration or the sterilization of known and potential mineral resources.

The following resource assessment work is continuing for:

- Hope Downs railway project. This involves assessment of mineral potential of underlying tenements and negotiating appropriate deviations for DoIR's Office of Major Projects;

- Department of Defence and the Department of Premier and Cabinet regarding the future of the Lancelin Defence Training area and selection of alternative sites;
- Report on sand and gravel resources in the Kalgoorlie region for the Department of Planning and Infrastructure;
- Walpole Wilderness Gravel Study for CALM, Shire of Walpole, and WA Main Roads Department;
- Proposed expansion to the Kalgoorlie–Boulder townsite for the City of Kalgoorlie–Boulder.

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Industry and community liaison

Objective: To maintain or improve mineral, petroleum, and building materials access on all lands and marine areas in the State through provision of advice to Government authorities, the resources sector, and community groups. This advice being related to the importance of the sector to the sustainable well-being of society, to the interaction between resource access and planning processes, and the provision of geological information to achieve best planning outcomes for the State.

2002–03 highlights and activities

Responsibility for this function was transferred from the disbanded Land Access Branch to the Geological Survey from 1 July 2002.

Conservation issues

- As identified in the Government's Protecting Our Old Growth Forest Policy, the draft Southwest Forest Management Plan proposes a number of new conservation reserves that generally recognize and support maintenance of resource access. Negotiations are continuing to minimize potential future impacts on resource access, particularly in areas with high petroleum and mineral resource potential.
- Advice was provided on a number of management plans for particular reserves, such as at Woodman Point, the Mount Manning extensions, and the Dampier Archipelago. Comment was provided on the State's proposed Biodiversity Protection legislation and a policy on the State's CAR (Comprehensive, Adequate and Representative) Reserve System.

Community liaison

- Geological and resource information input went into a broad range of planning initiatives related to urban, rural, and community developments, such as Augusta–Walpole Coastal Planning, Great Southern Strategy, the Turquoise Coast Plan, Rottnest Island, Moresby Range, Batavia Coast, Ravensthorpe, East Gelorup – Boyanup and Serpentine–Jarrahdale. Advice was provided to a number of local Government authorities regarding extractive industry policies and projects.
- Watching briefs were maintained on the Perth Metropolitan, Peel, and the Greater Bunbury Regional Plans in relation to protection of access to titanium mineral deposits and construction materials. Information and advice was fed into the revision of Statement of Planning Policy 10 — Protection of extractive materials in the Perth Metropolitan region.
- Work towards final definition of a buffer surrounding the Bunbury Basalt quarries at Gelorup continued. It will be a very significant outcome in relation to future protection of quarries from conflicting land uses that is likely to be applied widely on a generic basis.

Planning initiatives

- Mapping of titanium mineral deposits in the northern Swan Coastal Plain was commenced to ensure resources are protected from conflicting land uses until mining and rehabilitation is completed. Similar mapping of the southern Swan Coastal Plain has been particularly effective in protecting deposits.

- Advice was provided to a Legislative Council Select Committee enquiring into State Government processes impacting on the rights of private property owners.

Geological initiatives

- GSWA is part of an inter-departmental committee considering protection of important Western Australian fossils from inappropriate collection. The Survey's role is to assist in protection and management of the State's geological heritage while ensuring that any consequential legislated protection does not unnecessarily conflict with access to resources.
- GSWA is creating Crown reserves over internationally important stromatolite fossil sites in the Pilbara region, the oldest fossils known on Earth.

Publications

Publications included an external paper on dating of zircons from sediments in the Frankland River, and the presentation of an invited paper on the Bunbury Basalt to a blasting conference in Perth.

Future work

Work on the above projects will continue as required, particularly the provision of geological advice and input to regional plans, and urban, rural, and community developments.

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Geoscientific advice relating to exploration

Objective: *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 2002–03

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 2820 mineral tenements (Table 1) was reviewed during 2002–03 (2091 in 2001–02) 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 during 2002–03 has decreased by about 12% to 5632. Anecdotal evidence suggests that this decrease is partly due to the tightening of departmental policy in respect to expenditure exemptions. Holders who think it now unlikely that their applications would succeed, may decide not to apply for expenditure exemptions and either surrender the tenement or wait for it to be forfeited.

Most referrals of applications for expenditure exemptions to the Geological Survey are in respect to applications under Section 102(2)(e) and (f) — that the tenement contains a deposit that is currently sub-economic or contains ore required for future operations. Referrals under 102(2)(b) — that time is required to evaluate work done on the tenement — are also common. In these cases, previous exploration data is reviewed to substantiate such claims.

Exemption applications recommended for refusal are referred if they require the assessment of work programs that have been lodged as part of a company's submission. Before an exemption application is finally recommended for refusal, an internal committee (Exemption Sub-committee) reviews the recommendation. The Geological Survey is represented on this committee to ensure that geoscientific issues are considered in any decision. The committee also considers whether a fine should be imposed in lieu of forfeiture where an expenditure

Table 1. Tenement reviews

	Number of tenement actions					
Geological advice provided	*1997–98*	*1998–99*	*1999–2000*	*2000–01*	*2001–02*	*2002–03*
Expenditure exemption	821	580	1 287	1 569	1 962	2 362
Extension of term of Exploration licences	27	48	82	394	411	369
Dealings in first-year Exploration licences	21	27	7	75	42	43
Iron ore authorization (Exploration licences)	13	9	22	16	32	30
Iron ore drop offs (Exploration licences)	10	27	22	2	0	0
Retention licence applications	5	3	3	6	6	5
Special prospecting licence applications	11	14	1	4	4	4
Other	48	65	22	2	4	7
Total	**956**	**773**	**1 446**	**2 068**	**2 091**	**2 820**

exemption has been refused. The number of exemption applications refused has increased to about 20% of total applications in 2002–03 (3% in 2001–02). This figure of 20% includes lapsed applications where tenements have been surrendered before the intent to refuse could be carried through. The increase in the refusal of expenditure exemptions reflects a more rigorous approach in determining such applications to ensure that ground is turned over and not kept unexplored for unreasonable periods.

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Mineral exploration reports and data

Objective: *To administer the collection and storage of statutory mineral 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 (Western Australian mineral exploration database).

Highlights for 2002–03

A project to link the tenements in the Departmental TENGRAPH database with the relevant data in the WAMEX database was completed in cooperation with the Mining Tenements section. Customers searching TENGRAPH can now directly access the WAMEX results screen containing the details of reports submitted on the (dead) tenements they are viewing in the TENGRAPH application.

Mineral exploration reports

During the year, 2076 mineral exploration reports (3478 volumes) were received, representing industry activity on 9229 tenements. The total number of volumes held is now 80 159. Gold is still the most commonly sought-after commodity, with over 75% of reports submitted relating to exploration programs for gold. Submission of data in digital form continues to increase, with some 70% of all reports submitted during the year containing some digital data.

Reporting standards

This year has been the seventh full year of required compliance with the ‘Guidelines for mineral exploration reports on mining tenements’ and the second year in which companies could submit data in digital format according to the Department’s requirements. The quality-control checking by Departmental staff found that the content of the hardcopy reporting has been improving, with a reduction to 11% in the number of reports not complying with the reporting guidelines. The submission of digital data is voluntary; however, about 70% of reports contain some digital data and about 55% of all reports submitted are totally digital. About 21% of reports submitted in digital form required some amendments or additional data.

The ‘Requirements for the submission of mineral exploration data in digital format’, which were developed in consultation with industry groups, have been adopted by the interdepartmental working group as the basis of national reporting requirements for the mineral exploration industry.

WAMEX database development

During the development of processes and data management systems for the core library, it was recognized that a review of the management and delivery of mineral exploration data was needed. This review now has the status of a project, with development of modules of the new database about to commence.

Data release

During the year 1037 reports were released to open file bringing the total number of open-file mineral reports to 31 826.

Future work

- Redevelopment of the current WAMEX database and development of the core library database
- Continue the implementation and refinement of the ‘Requirements for the submission of mineral exploration data in digital format’
- Continuation of scanning to PDF files (rather than microfiching) of mineral exploration reports prior to release to open file, and scanning of reports previously released to open file in microfiche format
- Provision of both scanned and generated files of mineral exploration data via the web-based WAMEX interface
- Progressive capture of metadata for digital files that were submitted prior to the compliance requirements for digital data
- Progressive acquisition in digital format of legacy tabular data previously submitted in hardcopy reports
- Development of a link to the WAMEX database through GeoVIEW.WA.

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REGIONAL GEOSCIENCE MAPPING

Regolith mapping and geochemistry

Objective: *To document the distribution and composition of regolith over Western Australia, and present these data as digital datafiles and maps to the mineral exploration industry. To acquire and collate geochemical data in a central repository, and disseminate these data, in order to enhance the prospectivity of the State.*

Highlights and activities 2002–03

A 1:500 000-scale map of regolith distribution in Western Australia has been compiled from existing geological and regolith maps, and made available via GSWA's web-based GEOVIEW.WA software application. The coverage is based on GSWA's regolith classification scheme, classifying regolith in terms of nine subdivisions. Using gridding software, the map can be simplified for viewing at a variety of scales. The data can be used for formulating or interpreting regional regolith geochemical surveys, and used in conjunction with the interpreted bedrock geology map of the State to further constrain regolith composition. An interpretive regolith map of the BELL ROCK 1:100 000-scale map sheet was commenced, as a precursor to regional mapping in the west Musgrave area.

The regional regolith mapping program is shown on Figure 4.

The Large Igneous Province (LIP) project, commenced in 2002, has shown that rocks of 1070 Ma age extend from the central west of the State into the Northern Territory and South Australia, placing this LIP in the same size category as other well-documented LIPs such as the Deccan Traps. It is likely that the LIP is related to plume activity centred beneath the Musgrave Complex. A presentation about the LIP was given at the Australian Geological Convention in Adelaide, and a GSWA report was commenced on the extent and geochemistry of the LIP.

Implementation of DataShed software as the database to house geochemical data was continued, including migration of the system to an Oracle platform, ongoing importation of various geochemical datasets, and development of a simple viewing and data extraction tool for GSWA staff. Approximately 13 000 soil and lag analyses were acquired from WMC Exploration for incorporation into the database.

2002–03 publications and products

- WILUNA 1:250 000 regolith materials map
- 1:500 000 regolith map of Western Australia, available on GEOVIEW.WA.

Future work

During 2003–04, GSWA will continue the population of the corporate geochemical database using the DataShed software. Interpretive regolith maps will be compiled for areas of future 1:100 000-scale mapping in the Musgrave area. The GSWA report on the Large Igneous Province will be completed.

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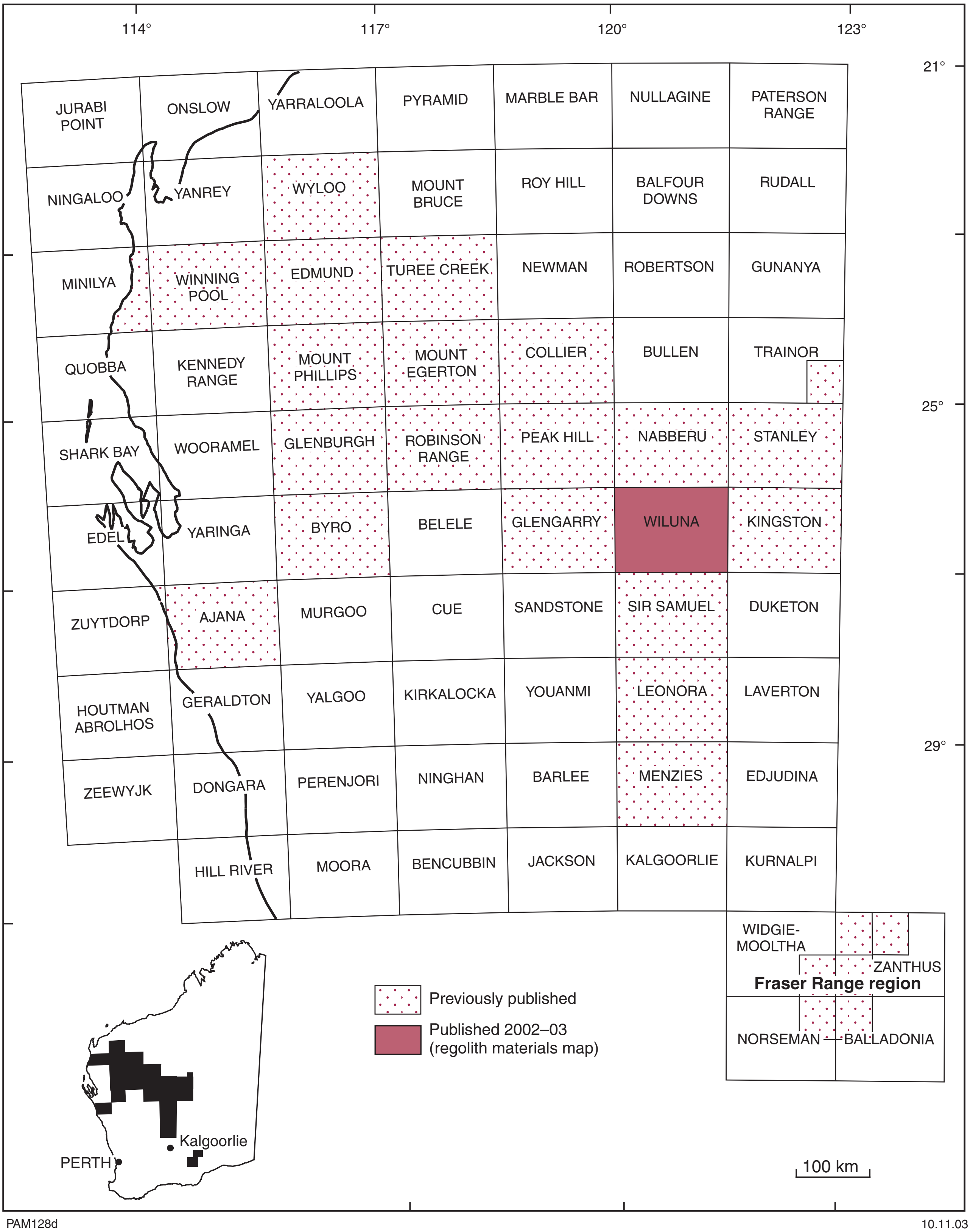

Figure 4. Progress of the regional regolith and geochemical mapping program

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 2002–03

During 2002–03 work continued on writing Explanatory Notes for the Dixon 1:100 000 map sheet.

Future work

Bulletin 143 on the geology of the King Leopold and Halls Creek Orogens will be completed ready for release the following year. Writing of Explanatory Notes for Turkey Creek and McIntosh 1:100 000 map sheets will commence.

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Lennard Shelf project

Objective: *To prepare comprehensive accounts and maps of the Devonian reef complexes of the northern Canning Basin and their associated terrigenous clastic deposits.*

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 its associated deposits.

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 wide-spread interest to geoscientists and the general public.

Seven maps of the outcrop belt, at scales of 1:250 000, 1:100 000, 1:50 000, and 1:25 000, and a report on the subsurface geology, have been published.

Highlights and activities 2002–03

A field excursion for the International Palaeontological Congress was conducted in the area in July 2002, and a guidebook for the excursion was published. P. E. Playford delivered a keynote address to the West Australian Basins 3 Symposium in October 2002, which was published as 'Paleokarst, pseudokarst, and sequence stratigraphy in Devonian reef complexes of the Canning Basin, Western Australia' in the proceedings of the symposium.

Compilation of Bulletin 145 on the Devonian reef complexes of the Canning Basin has continued, and the manuscript is scheduled for completion in 2004.

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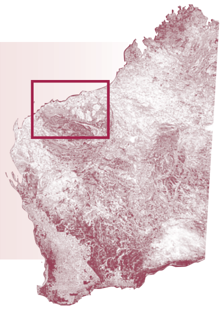
Pilbara Craton project

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.*



The Pilbara project commenced in 1995, field investigations will be completed in 2003, and all products will be released by the end of 2005. The project is a National Geoscience Accord (NGA) project with Geoscience Australia. By 2005 the project will have resulted in the detailed remapping of a 70 000 km^2 area, publication of 31 new 1:100 000-scale maps, new editions of seven 1:250 000-scale maps, and various non-series maps at 1:50 000 and 1:250 000 scales (Fig. 5). An additional four 1:100 000-scale maps (Rocklea, Isabella, Braeside, and Pearana) and two 1:250 000-scale maps (Mount Bruce and Roy Hill) were mapped as parts of earlier projects immediately prior to commencement of this project. Explanatory Notes describing all aspects of the geology of individual sheets accompany all published maps. GSWA Reports, papers in international journals, and contributions to a number of geological conferences have presented both regional syntheses and the results of specialized research.

Highlights and activities 2002–03

Geological mapping was completed on the Coongan, Nullagine, Noreena Downs, Warrie, and Mount Marsh 1:100 000 map sheets, and continued on the Yilgalong and Marble Bar 1:100 000 map sheets, and on the Port Hedland 1:250 000 map sheet. Mapping from the 1:100 000 program, combined with interpretation of data from remote sensing, was used to compile the Pyramid 1:250 000 sheet and a special 1:250 000 map of the West Pilbara Granite–Greenstone Terrane. Complete geological coverage of all granite–greenstones in the northern part of the Pilbara Craton has now been achieved.

Members of the Pilbara mapping team made a major contribution to the Archaean Biosphere Drilling Project (ABDP), an international collaborative project between GSWA, the NASA Astrobiology Institute (through Pennsylvania State University), Kagoshima University (Japan), and the University of Western Australia. The main objectives of the ABDP were to recover 'fresh' Archaean rocks (mostly sedimentary rocks), and use them to conduct systematic palaeontological and biogeochemical investigations to increase our understanding of the early Earth, including: a) the biosphere, especially the types and distribution of organisms in the oceans, lakes, and on land; b) the climate; c) the chemistry of the atmosphere and oceans; and d) the geochemical fluxes of O, C, S, Fe, and other elements in the atmosphere – oceans – continents – oceanic crust – mantle system. As part of the research requirements of the principal scientific investigators, GSWA's main roles were to identify the best lithostratigraphic targets for diamond drilling, select and mark out precise drilling sites, obtain the necessary land-access approvals, organize and supervise earthworks and water supplies, and to assist in arranging export approvals for core samples required in Japan and USA. Six diamond drillholes, ranging in depth from 150 to 300 m, were drilled. Fifty per cent vertical splits of all core are now permanently stored at the Perth Core Library.

2002–03 publications and products

- Tambourah 1:100 000 Explanatory Notes;
- Pinderi Hills 1:100 000 Explanatory Notes;
- Dampier – Barrow Island and Yarrie 1:250 000 Explanatory Notes;
- Split Rock 1:100 000 map sheet;
- Eastern Creek 1:100 000 map sheet;
- Pardoo 1:100 000 map sheet;
- De Grey 1:100 000 map sheet;
- Whim Creek and Mallina Basin special 1:250 000 map.

Future work

The 2003–04 year will see the publication of the Mount Edgar, Carlindie, Nullagine, Coongan, Noreena Downs, and Lamil

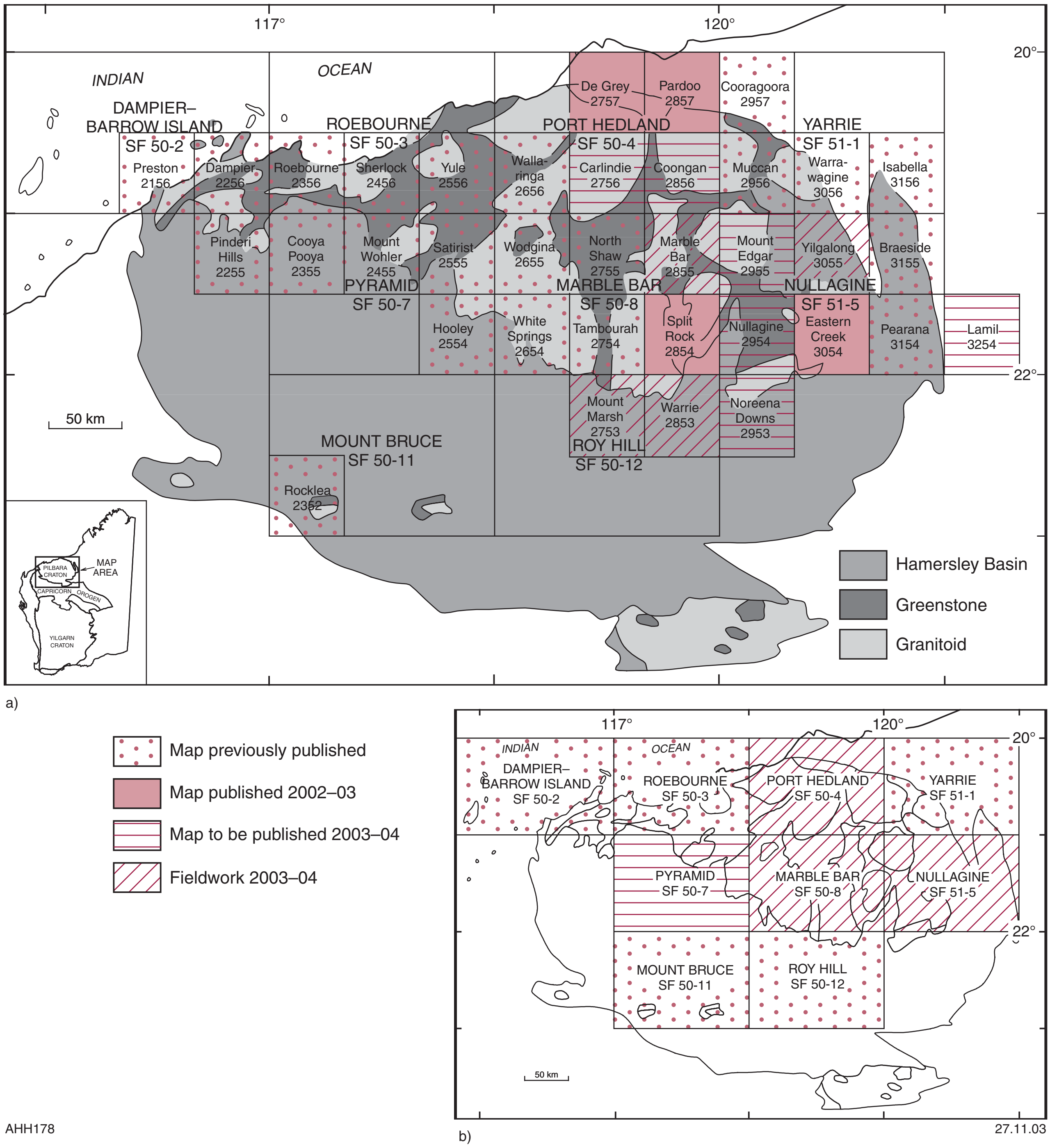


Figure 5. Progress of recent regional mapping in the Pilbara Craton: a) 1:100 000 sheet areas; b) 1:250 000 sheet areas

1:100 000 maps, the PYRAMID 1:250 000 map, the North Shaw – Tambourah 1:50 000 map, and the West Pilbara Granite–Greenstone Terrane 1:250 000 map. Explanatory Notes for the SPLIT ROCK, EASTERN CREEK, PRESTON, WODGINA, COOYA POOYA, DE GREY – PARDOO, and WHITE SPRINGS 1:100 000 maps will be released. Mapping will be completed for the YILGALONG and MARBLE BAR 1:100 000 maps, and on the PORT HEDLAND, MARBLE BAR, and NULLAGINE 1:250 000 sheet areas. This will complete all geological mapping for the project.

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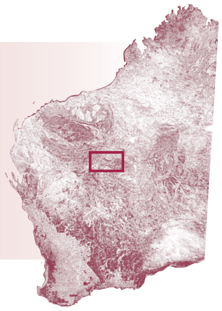
Earaheedy Basin project

Objective: *To increase geoscientific knowledge of the Earaheedy Basin and adjacent areas 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.*



Work in the Earaheedy Basin commenced in 1997 and is now nearing conclusion. Since 1997, ten 1:100 000-scale geological maps have been published (Fig. 6) and four sets of Explanatory Notes.

The Earaheedy Basin contains the Earaheedy Group and lies at the easternmost end of the Capricorn Orogen. Basement to the exposed Earaheedy Basin is the Archaean Yilgarn Craton and, to the west, the Yerrida Basin. The regional structure is an asymmetric east-plunging syncline with a vertical to locally overturned northern limb, due to compressive movements from the northeast that created a zone of intense deformation along the exposed northern margin of the Earaheedy Basin. This zone of deformation, named the Stanley Fold Belt, is characterized by reverse faults and shear zones that consistently dip steeply to the north, the development of slaty cleavage and phyllitic rocks, and the presence of metamorphic minerals (e.g. muscovite, sericite, and chlorite). The intensity of deformation gradually decreases southward, but abruptly decreases to the north.

The Palaeoproterozoic Earaheedy Basin contains the Earaheedy Group, a 5 km-thick succession of shallow-marine clastic and chemical sedimentary rocks that is divided into two subgroups — the Tooloo Subgroup and the overlying Miningarra Subgroup. The age of the Earaheedy Group is stratigraphically constrained by the age of the underlying Mooloogool Group (Maraloou Formation, c. 1.84 Ga), and by the Malmac (2.6 Ga) and Imbin (1.99 Ga) Inliers. Given these age constraints on the Earaheedy Group, deposition of the group was essentially synchronous with the Capricorn Orogeny.

Highlights and activities 2002–03

During the year, mapping was completed on COLLURABBIE, and was continued on WINDIDDA and VON TREUER. This mapping encompassed tectonic units such as the Glenayle and Prenti Dolerites, which intrude c. 1200 Ma sedimentary rocks of the Collier Basin and correlative units, as well as the Earaheedy Group. This work led to the recognition that these mafic rocks belong to a much wider unit, in which coeval and compositionally similar rocks can be traced as far as the western parts of the Edmund Basin and the Musgrave Complex, along a strike length of more than 1000 km, thereby constituting a large igneous province (LIP). Recent dating by SHRIMP (U–Pb; baddelyite) indicates that the LIP was emplaced at c. 1070 Ma. This discovery may have important economic implications, and the LIP is still under investigation in cooperation with researchers from UWA and Curtin University.

Three papers were accepted by international journals and two more submitted.

2002–03 publications and products

- NABBERU 1:250 000 geological map sheet;
- Record 2003/3: *Age and palaeomagnetism of dolerite intrusions of the southeastern Collier Basin, and the Earaheedy and Yerrida Basins, Western Australia;*
- Record 2003/6: *Interpretation of geophysical data over the Shoemaker impact structure, Earaheedy Basin, Western Australia.*

Future work

Work planned for 2003–04 includes the continuation of field mapping for VON TREUER, WINDIDDA and CARNEGIE (1:100 000 geological series maps). New compilations will include LEE STEERE, VON TREUER, WINDIDDA, and CARNEGIE. The Explanatory Notes for NABBERU – GRANITE PEAK will be published. A final GSWA Report on the geology and mineralization of the Earaheedy Basin will be prepared.

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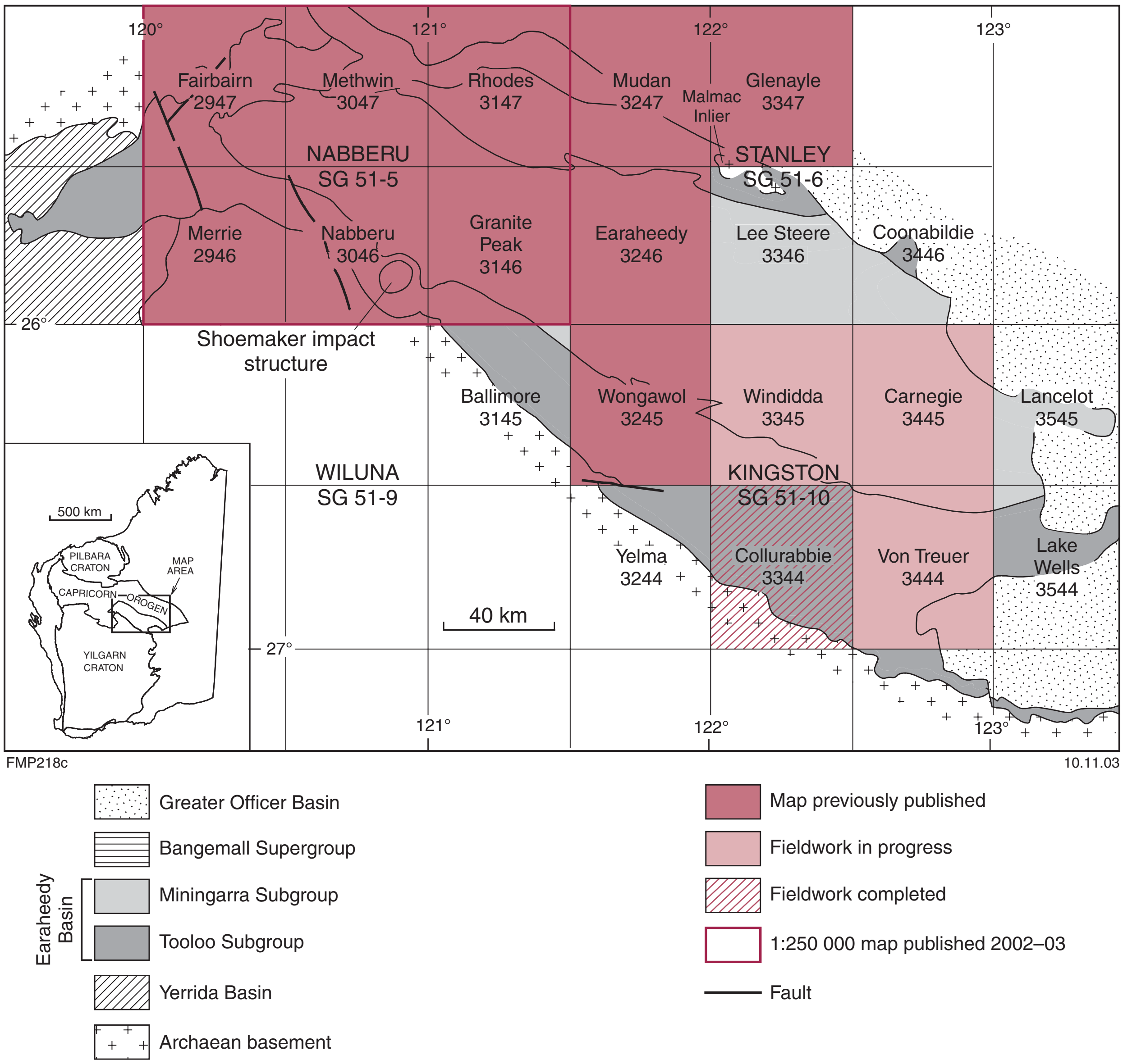
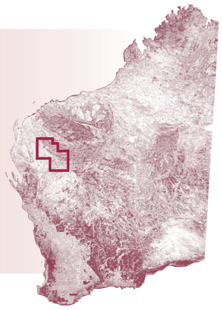


Figure 6. Progress of 1:100 000-scale geological mapping for the Earaheedy Basin project

Capricorn Orogen project

Objective: *To increase the knowledge of the Capricorn Orogen (Bangemall Supergroup and Gascoyne Complex) 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.*



Highlights and activities 2002–03

Fieldwork carried out in the northwestern part of the Capricorn Orogen during 2002–03 has involved detailed mapping of the Bangemall Supergroup rocks on Kenneth Range and Mount Phillips and Gascoyne Complex rocks on the Mangaroon 1:100 000 map sheet areas (Fig. 7). In addition there has been collaboration with university staff engaged in detailed geoscientific studies within the Capricorn Orogen.

On Kenneth Range the mapping has further highlighted the influence of the northwest-trending Talga Fault on Edmund Group sedimentation. Shallow-marine shelf facies siliciclastic and carbonate rocks dominate the stratigraphy to the northeast of this structure, whereas to the southwest generally finer grained, deeper marine facies are more abundant. It is also apparent that the base of the Discovery Formation truncates the Muntharra Formation and a wide range of units in the underlying Kiangi Creek Formation. This supports the results of earlier mapping and indicates that this surface probably represents a major depositional break within the Edmund Group.

New data from a c. 1070 Ma sill on Kenneth Range indicates intrusion was into wet or inhomogeneously

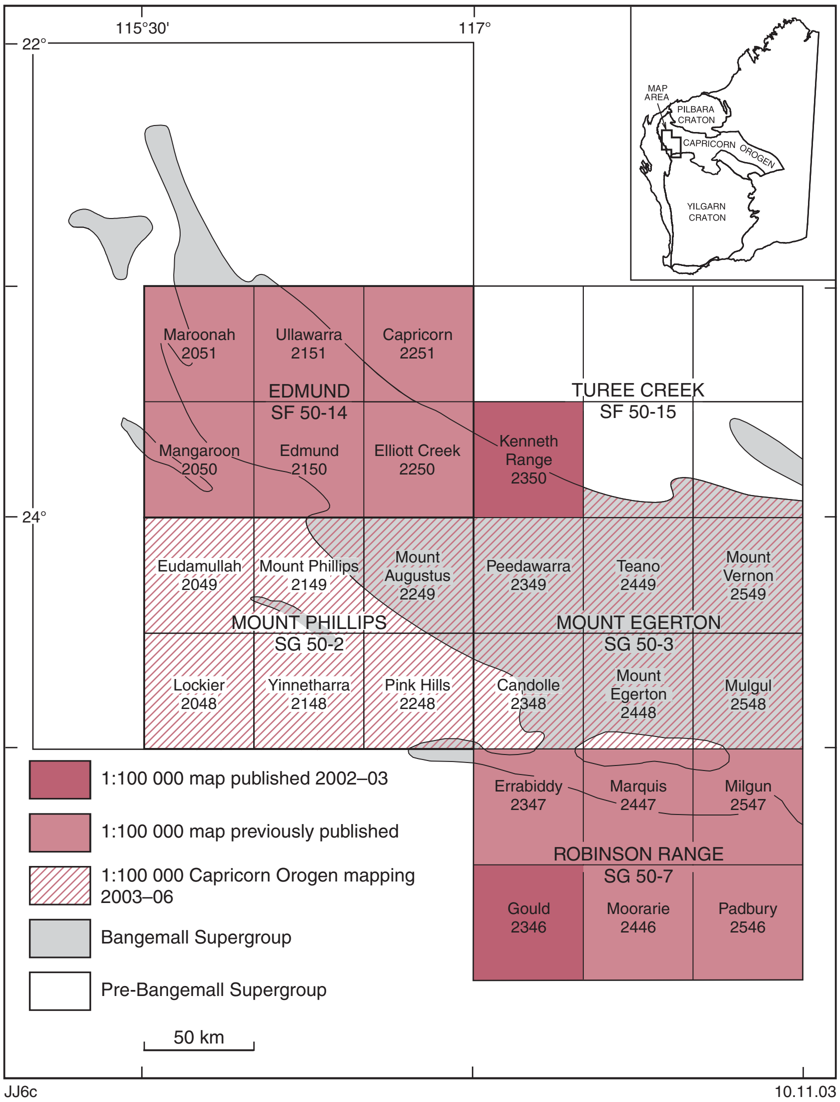


Figure 7. Progress of recent mapping for the Capricorn Orogen project

lithified sediments, resulting in the formation of localized peperite and associated fluidized sediment. The fluidized horizon is interpreted to affect the upper Edmund Group and basal Collier Group, suggesting that the significance of the intervening regional unconformity requires further investigation.

Enigmatic bedding-plane markings resembling a ‘string of beads’ have been observed at many localities in the Backdoor Formation (Collier Group) on KENNETH RANGE. Although their origin is the subject of ongoing debate, they are widely regarded as being the impressions of megascopic multicellular organisms. In addition to the ‘string of beads’, recent mapping has revealed two other potentially important bedding-plane markings: the first is a series of fine wrinkles that resemble the texture of elephant skin, and is interpreted as the external mold of subtidal microbial mats; the second are small conical to elongate impressions, closely associated with the beads and wrinkles, to which the strings are interpreted to have been attached during growth. The antiquity of these structures, between 1400 and 1070 Ma, has significant implications for the evolution of multicellular life.

On MANGAROON, mapping of the Gascoyne Complex rocks has better defined the extent and character of a 1680–1620 Ma orogenic event (Mangaroon Orogeny), more than 100 m.y. younger than the Capricorn Orogeny. The Mangaroon Orogeny comprises 1680–1650 Ma deformation and regional metamorphism up to granulite facies, accompanied by voluminous granite intrusion. After this time granite intrusion and activation and reactivation of faults or shear zones continued until about 1620 Ma. Preliminary SHRIMP U–Pb results from detrital zircons suggest that sedimentary protoliths to migmatites in the northern Gascoyne Complex were deposited some time after c. 1740 Ma and, thus, are not time equivalents of the Ashburton Formation as previously supposed. There is no evidence for terrane accretion or continent–continent collision processes during the Mangaroon Orogeny; rather the orogeny probably reflects intracratonic activity.

During the year substantial progress has been made on Ar–Ar dating by S. A. Occhipinti at Curtin University of Technology for a PhD study on the tectonothermal evolution of the southern Capricorn Orogen. Samples of mica separates from high-strain zones in the northern Yilgarn Craton, Errabiddy Shear Zone, and southern Capricorn Orogen show that the region cooled through about 300°C by 1000–900 Ma. In September 2002, D. Bray commenced an MSc project on the origin and possible economic significance of tourmaline nodules in c. 1800 Ma granites on the GLENBURGH 1:250 000 sheet area. The study is a collaboration between GSWA and the University of Saskatchewan in Canada.

An excursion guide P*roterozoic geology of the Capricorn Orogen, Western Australia — a field guide* (GSWA Record 2003/16) was prepared for a field trip associated with the ‘SGTSG Kalbarri 2003’ conference held in September 2003 (sponsored by Geological Society of Australia’s Specialist Group in Tectonics and Structural Geology). GSWA staff have also prepared several papers for a forthcoming special issue of Precambrian Research on the Capricorn Orogen. A paper on the relationship between c. 1800 Ma granites of the Yarlarweelor Gneiss Complex and regional tectonism was published in the journal Lithos.

Office-based activities have included the compilation of geological data for KENNETH RANGE, MANGAROON, and MAROONAH map sheets, database entry for the EDMUND, KENNETH RANGE, MANGAROON, and MAROONAH map sheets, and analysis of field data.

2002–03 publications and products

- KENNETH RANGE 1:100 000 map sheet;
- GOULD 1:100 000 map sheet.

Future work

Work to be carried out during 2003–04 includes the mapping and compilation of Bangemall Supergroup and Gascoyne Complex rocks on the EUDAMULLAH, MOUNT PHILLIPS, and MOUNT AUGUSTUS 1:100 000 map sheets. The major aims of this work are to further test and implement the revised stratigraphy for the Bangemall Supergroup on MOUNT PHILLIPS and MOUNT AUGUSTUS; to identify and sample suitable targets for U–Pb zircon geochronology, provenance studies, and geochemistry; and to better understand the relationship between the different Gascoyne Complex rock units on the MOUNT PHILLIPS 1:250 000 map sheet. Explanatory Notes for the second edition ROBINSON RANGE 1:250 000 map sheet will be published during 2003–04. Compilation of a second edition GLENBURGH 1:250 000 map sheet will also commence during this period.

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West Musgrave Complex project

Objective: *To increase geological knowledge of the western part of the Musgrave 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, geochemistry, geophysics, geochemistry, remote sensing, and metallogeny.*

Highlights and activities 2002–03

The 2002–03 period saw no fieldwork on the West Musgrave project, although it is anticipated that fieldwork will commence towards the end of the 2003 field season. Airborne aeromagnetic and ratiometric data covering the FINLAYSON, HOLT, BATES, COOPER, BLACKSTONE, and BELL ROCK 1:100 000 map sheets has been acquired, as has digital orthophotography at a 1.2-m and 10-m pixel resolution. A digital, georeferenced dataset covering the BELL ROCK 1:100 000 sheet is being assembled, and will be gradually expanded to incorporate the entire project area. To date, the dataset incorporates Landsat, aeromagnetic, radiometric, and gravity imagery, as well as relocated data from previous relevant mapping projects including earlier geological mapping at 1:250 000 scale.

Work published during 2002–03

- West Musgrave Total Magnetic Intensity image, 1:250 000 scale (covers parts of SCOTT and COOPER 1:250 000 sheets)
- West Musgrave Ternary Radiometric image, 1:250 000 scale (covers parts of SCOTT and COOPER 1:250 000 sheets)

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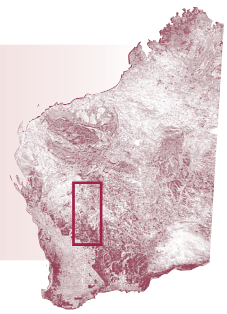
Central Yilgarn (Southern Cross) project

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 2002–03

In 2002–03, fieldwork and compilation of the LAKE MASON, ATLEY, MONTAGU, and RAYS ROCKS 1:100 000 sheets was completed; and field mapping commenced on the SANDSTONE and YOUNO DOWNS 1:100 000 sheets (Fig. 8).

A paper detailing the stratigraphic correlations in the Marda–Diemals greenstone belt has been submitted for external publication. Another paper, describing results of geochronological studies of detrital zircons in quartzites in the central Yilgarn, was prepared for external publication. Fifteen new SHRIMP U–Pb isotopic ages were acquired and published.

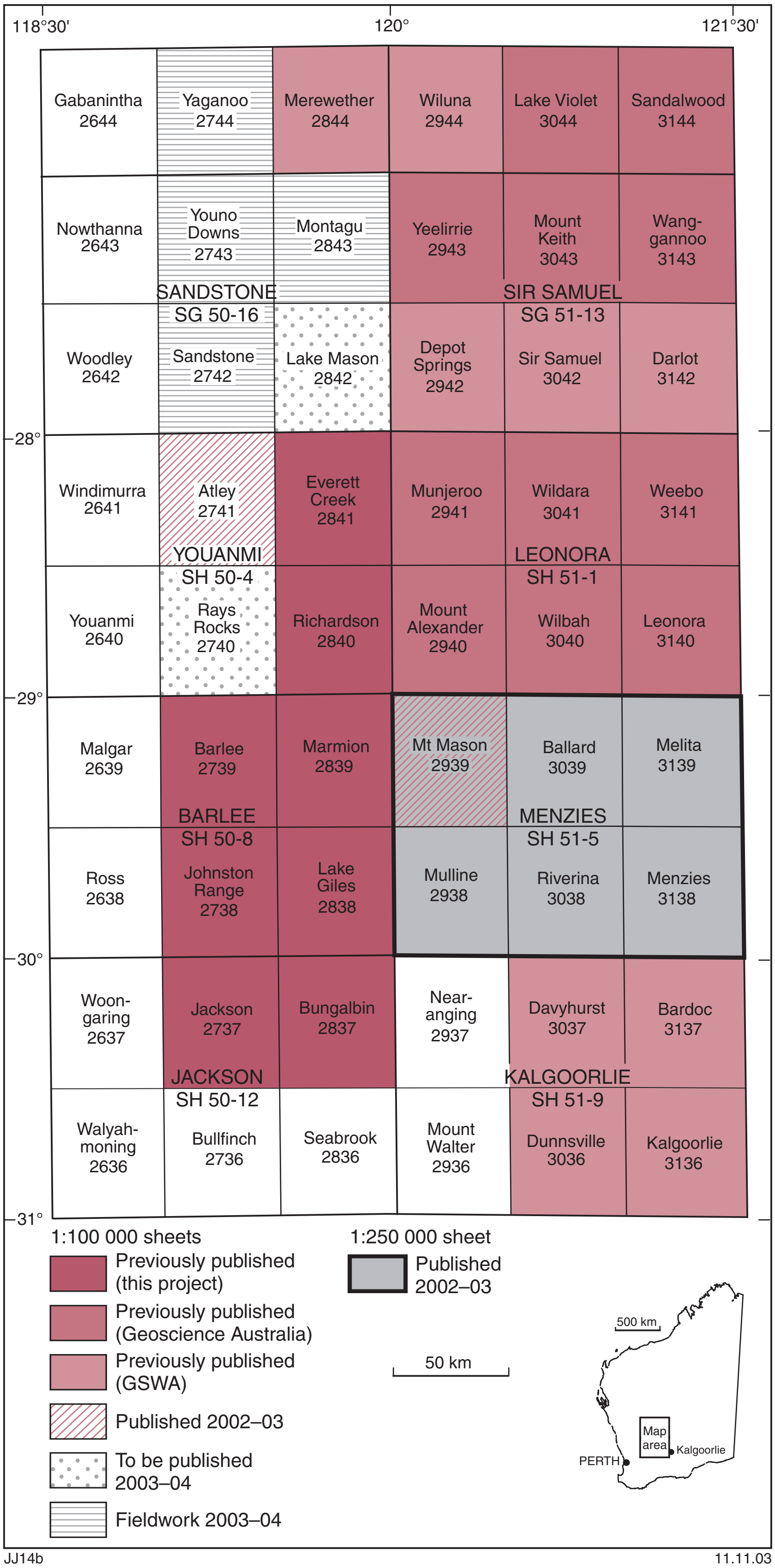


Figure 8. Progress of recent geological mapping for the Central Yilgarn (Southern Cross) project

Recent mapping has allowed stratigraphy to be established for greenstone belts away from the Marda–Diemals greenstone belt. However, no simple regional stratigraphic model for this lower (mafic–ultramafic–metasedimentary) greenstone succession has become apparent. Although containing broadly similar assemblages, greenstone belts have different arrangements of greenstone packages that cannot easily be correlated. A lack of suitable material for SHRIMP U–Pb zircon geochronology means that absolute ages of greenstones in the lower succession are unknown, so it is difficult to test proposed stratigraphic correlations.

The 2.73 Ga upper greenstone succession in the Marda–Diemals greenstone belt (felsic volcanic rocks of the Marda Complex and metasedimentary rocks of the Diemals Formation) differs in age from other felsic successions in the region and appears to represent an isolated volcanic centre.

2002–03 publications and products

- EVERETT CREEK 1:100 000 Explanatory Notes;
- BARLEE 1:100 000 Explanatory Notes;
- BUNGALBIN 1:100 000 Explanatory Notes;
- ATLEY 1:100 000 map sheet;
- MOUNT MASON 1:100 000 map sheet;
- MENZIES 1:250 000 map sheet.

Future work

The RAYS ROCKS and LAKE MASON 1:100 000 sheets will be published in 2003–04, and the SANDSTONE and MONTAGU sheets will be compiled. Fieldwork on the YOUNO DOWNS and YAGANOO 1:100 000 sheets will be completed in 2003–04, and those sheets will be compiled and published in 2004–05. Explanatory notes will be published in 2003–04 for the MARMION and RICHARDSON 1:100 000 sheets, and for the MENZIES 1:250 000 sheet.

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East Yilgarn project

Objective: *To increase geoscientific knowledge of the east Yilgarn Craton by the collection, synthesis, and dissemination of geological information, particularly through the development of seamless geoscience databases, and production of geological maps and supporting publications based upon integrated field and laboratory studies that include mapping, petrology, geochronology, geophysics, geochemistry, remote sensing, and metallogeny.*

The East Yilgarn project covers the highly mineralized Eastern Goldfields Granite–Greenstone Terrane and the southern part of the Southern Cross Granite–Greenstone Terrane that together comprise the eastern part of the Archaean Yilgarn Craton (Fig. 9). The project is based in the Kalgoorlie regional office, which includes the Joe Lord Core Library.

Highlights and activities 2002–03

Explanatory Notes for the third phase (Leonora–Laverton) of the seamless East Yilgarn digital geoscience database were released and all three phases of the database have been combined into a single seamless coverage of most of the Eastern Goldfields. The combined database includes a reinterpretation of the regolith, which is accompanied by an explanatory Record 2003/11. The combined East Yilgarn geoscience database now incorporates fifty-six 1:100 000 geological outcrop maps that stretch from Wiluna in the north to Norseman in the south. It is considered a preliminary release as further refinements are still in progress. The themes included are 1:100 000 outcrop geology and structures, mineral location and resource data (MINEDEX), tenement and geographic information, Landsat images, aeromagnetic and gravity images, and 1:500 000 interpretative geology. The data is supplied in GIS software-compatible formats, together with GeoVIEWER.WA, a free software package that allows powerful interactive visual access to the database.

Mapping and compilation of YARDILLA was completed, with geological interpretations presented at the GSWA open day.

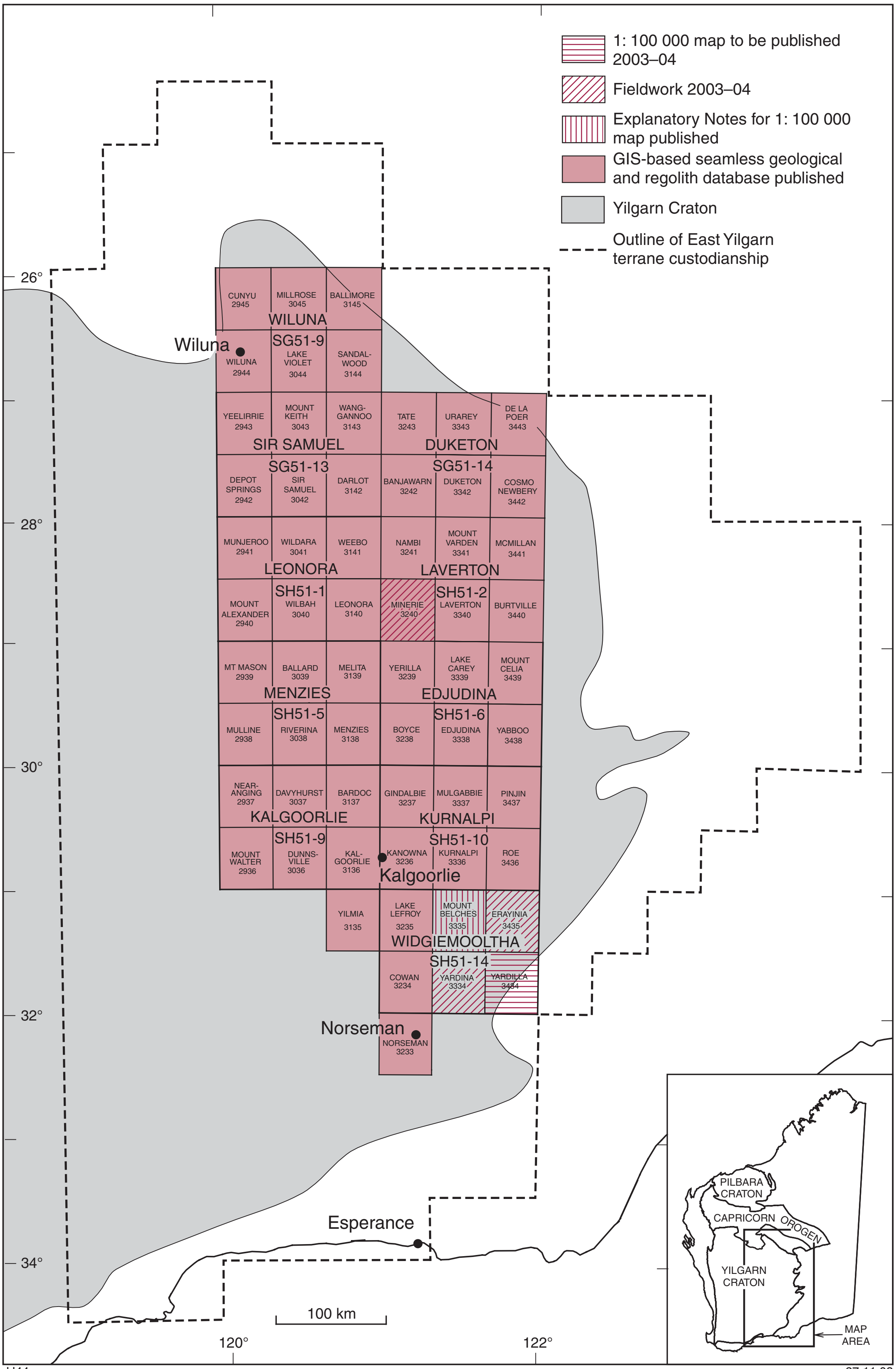

Figure 9. Progress of recent geological mapping in the east Yilgarn region and progress towards the GIS-based seamless digital database

The Joe Lord Core Library that is part of the regional office facility in Kalgoorlie–Boulder has continued to assist the mining and exploration industry through the acquisition, storage, and display of drillcore. Industry and university research projects have made use of the core, and detailed sampling for metallogenic studies has been undertaken.

The regional mapping geologists at the Kalgoorlie regional office of the Geological Survey provide advice to the general public, mining companies, and others on the geology of the East Yilgarn. Delegations from India and Victoria included the Kalgoorlie office on tours of Western Australia conducted to learn about the highly regarded relations between the mining industry and government in this state.

In October 2002 the annual combined GSWA and GA open day was held in Kalgoorlie. Of particular interest was the presentation of the Leonora–Laverton–Neale seismic traverse — with interpretations of the faults transecting the entire crust at Leonora, Laverton, and Yamarna. As in previous years, recent activities of GSWA and GA in the Yilgarn Craton were presented in posters, displays, and a series of talks.

Talks about the outcrop geology and models of the geological setting of the north Eastern Goldfields seismic line were presented at two GA–GSWA–pmd*CRC workshops, with notes published in GA records.

2002–03 publications and products

- Report 84: *East Yilgarn geoscience database: 1:100 000 geology of the Leonora–Laverton region, Eastern Goldfields Granite–Greenstone Terrane*
- Record 2003/11: *East Yilgarn geoscience database — 1:100 000 reinterpretation of the Eastern Goldfields regolith*
- 1:100 000 geological data package: *Combined East Yilgarn geoscience database, Eastern Goldfields (Preliminary edition)*

Future work

In 2003–04, the first edition of the Combined East Yilgarn Geoscience Database will be released, with a revised GSWA rock classification and coding scheme, and additional aeromagnetic and Landsat images.

The YARDILLA 1:100 000 sheet will be published in a new digital format on CD that includes field notes, photographs, petrography, and explanatory notes. Mapping and compilation of the ERAYINIA, MINERIE, and YARDINA 1:100 000 sheets will be completed, with publication planned for early in the following year.

Other releases in 2003–04 will include:

- Explanatory Notes for the LEONORA 1:250 000 geological sheet
- a GSWA Record and dataset on metamorphism in the Kalgoorlie region
- a GSWA Record on the nickel laterite deposits of the Eastern Goldfields
- a mineral occurrence dataset for the WOOLGANGIE and YILMIA 1:100 000 map sheets
- a GSWA Report on gold mineralization in the Edjudina–Kurnalpi–Kanowna area.

Field mapping will commence on BULDANIA, COWALINYA, and NEARANGING 1:100 000 map sheets in 2003–04.

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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 project.*

Highlights and activities 2002–03

Almost 70 samples from throughout Western Australia were dated, with typical precision of ±6 Ma, by the SHRIMP U–Pb zircon and monazite techniques for incorporation into GSWA geological maps and projects. Additional samples from the Pilbara Craton were dated by the Ar–Ar technique. GSWA Record 2003/2 documents all results from the geochronology work undertaken during calendar 2002.

Cathodoluminescence images of the minerals analyzed for U–Pb geochronology were acquired for all samples analyzed during 2002. These images will in future be incorporated into the annual GSWA geochronology publication. To facilitate more detailed assessment of the geochronology analytical results, it is also planned to incorporate into future geochronology publications the digital reflected and transmitted light images of the minerals analyzed.

2002–03 publications and products

- Record 2003/2: *Compilation of geochronology data, 2002* was prepared for printing.

Future work

Further geochronology work in the Pilbara, Southern Cross, Gascoyne, and Bangemall regions is in progress for 2003–04.

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Geoscientific specialist support

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 2002–03

Organizational and planning matters took up much of the year, particularly in relation to the Archaean Biosphere Drilling Project, and in answering numerous enquiries (from geo-scientists to tourists) seeking advice about sites to visit and information on fossil-collecting constraints. Twenty-six geoscientists (mainly from overseas) visited the section this year seeking advice or to examine material. Eleven talks were presented, and information was provided for 22 media items. Four scientific papers were published and two more were submitted: a further three are at an advanced stage of publication. Work continues on updating the collection and managing fossil loans, and on collaborative projects both internally and externally. Kath Grey was awarded the Geological Society of Australia (WA Division) Gibb Maitland Medal in March 2003 for her contributions to the understanding of the State's geology, particularly her work on Proterozoic stromatolite biostrati-graphy.

2002–2003 publications

- Record 2002/17: *3.45 billion year-old stromatolites in the Pilbara region of Western Australia — proposals for site protection and public access;*
- three external publications on aspects of late Neoproterozoic successions.

Future work

2003–04 will see the transfer of the palaeontological collection from Dianella to Carlisle, allowing the collection to be housed in the same area for the first time in 15 years. The palaeontologist will also transfer to Carlisle to maintain and catalogue the collection. Publications will include: a monograph on terminal Proterozoic biostratigraphy; a Handbook of stromatolites and related structures; reporting on the biostratigraphy of the new Officer Basin drillhole, Lancer 1; other publications on aspects of Proterozoic biostratigraphy.

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Geoscientific specialist support

Geophysics

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

Regional airborne geophysics

GSWA and GA contracted UTS Geophysics to acquire approximately 68 000 line km of new magnetic and radiometric data in the west Tanami area. The new data were merged with previously flown private company data and existing GA data to provide complete coverage of the southern half of GORDON DOWNS, the complete BILLILUNA sheet, and the northern half of LUCAS at survey line spacings from 200 to 400 m.

A separate high-resolution survey (50 m line spacing, 40 m flying height) was flown over the Wolfe Creek Crater as part of the regional survey.

Fugro Airborne Surveys was contracted by GSWA and GA to acquire 45 000 line km of new magnetic and radiometric data in a survey in the west Musgrave area. With the incorporation of private company data, this survey provides coverage over the southern part of the SCOTT and northern part of the COOPER 1:250 000 sheets.

The located and gridded data from all surveys were made available for public access, together with hardcopy magnetic and radiometric images.

Airborne geophysical survey register and data repository

During 2002–03, 68 new airborne survey datasets, containing approximately 172 000 line km of magnetic, radiometric, digital elevation, and electromagnetic data, were received for inclusion in the MAGIX data repository. About 2.9 million km of private data from almost 570 surveys are now held in the repository.

Most companies submitting data have agreed to make public the location and basic specifications of their surveys; this information is available through the GeoVIEW.WA system on the Department's website.

Regional gravity surveys

A regional gravity traverse was carried out across the major greenstone belts in the Sandstone area. A total of 91 stations with variable 250–1000 m spacing were collected to assist in evaluation of the 3D geometry of the greenstones.

2002–03 publications and products

- Interpretation of data from the Morton Craig, South Dongara, and Pilbara gravity surveys
- South Dongara gravity images
- West Musgrave regional airborne geophysical survey digital dataset and images
- West Tanami regional airborne geophysical survey digital dataset and images
- Wolfe Creek airborne geophysical survey digital dataset

Future work

New data acquisition is programmed for the Murchison region, with planned surveys and data purchases to complete the coverage over ROBINSON RANGE, BELELE and, possibly, CUE.

Other activity includes lithostructural interpretations of the airborne survey datasets acquired in 2002–03 for the west Musgrave and west Tanami regions, and interpretations of other regional gravity and magnetic data to support the Survey's field mapping projects.

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Logistics support and core libraries

Objectives:
- *To manage core library facilities in both Perth and Kalgoorlie to service the needs of industry and GSWA*
- *To manage field support services, including transport and other equipment, and provide field assistants and communication links for all GSWA field parties*
- *To manage inventory services for all GSWA publications, including maps, Bulletins, and Reports*
- *To promote and monitor safety both in the field and throughout the logistical support areas in Perth and Kalgoorlie.*

Perth and Kalgoorlie Core Libraries

The new core storage facility in Perth was officially opened in April 2003. This facility at Carlisle, with an 8640-pallet capacity (equivalent to about 1200 km of core), will hold mineral and petroleum core and cuttings, geochemical samples including rock pulps, and GSWA rock collections. It will provide industry with the most advanced system of drillcore storage in Australia.

An audit of all material was carried out during the relocation of core and cuttings from the old Dianella and Morley stores and from the Star Street facility to Carlisle. The Perth Core Library was closed for several months while this task was undertaken.

A program to collect valuable historical core is currently underway. Core has been collected from significant drilling projects from the Kimberley and Pilbara regions. This material will be available for inspection at the Perth Core Library by December 2003.

The Kalgoorlie J. H. (Joe) Lord Core Library, with a capacity to warehouse 2880 pallets (equivalent to about 400 km of core), currently holds more than 900 pallets of mineral core. During the last 12 months 195 clients viewed and/or sampled core or cuttings at the Perth and Kalgoorlie facilities. Clients spent 1129 hours viewing core and cuttings, and took 811 samples for further analysis. More than 139 pallets of mineral exploration core and 16 pallets of petroleum core and cuttings were accessioned into the collection.

With the new Perth Core Library now fully operational there has been a notable increase in general enquiries for both acquisition of core and for client inspection/sampling. An increase in both identifying and collecting core for archiving and client viewing is envisaged over the next 12 months.

Field support

The GSWA specialized 4WD fleet is managed from the division's Carlisle depot. The policy of flying to remote locations, and servicing of vehicles in regional areas, has improved the efficiency of the depot operations. However, this was offset by the need for a greater degree of urgency, and tight turnaround times, as a result of the thirty per cent reduction of the 4WD fleet. Overall significant savings were made and all geologists' field requirements were met.

Base-level field staff requirements have been maintained and provision of additional field assistants by an employment agency continues to allow flexibility in meeting short-term needs. Some difficulties were met with provision of field staff for the Kalgoorlie office and, despite an agency contact in Kalgoorlie, locally based field assistants were in short supply.

Continuous improvement of work practices in regard to field safety remains a high priority. Communication procedures have been improved with the introduction of satellite telephones; however, the technology required to receive text messages directly into a database from satellite phones is still unavailable. The high-frequency radio communications base at the Carlisle depot continues to be the focus for monitoring safe operations in the field. There were no significant safety issues during the year.

Future work

The publications inventory is to be relocated to the archive storage sheds by November 2003. Plans for the shift have been finalized and include layout and rationalization of stock that will provide a more efficient service.

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Geoscience information products

Objectives:
- *Provide a quality and timely editing and publishing service for geoscientific manuscripts, maps, and database products produced by Geological Survey geoscientists*
- *Provide the infrastructure for the management of geoscientific data*
- *Develop and coordinate geoscientific database policies and standards*
- *Promote Geological Survey products and services through displays, advertising, and other promotional events*
- *Monitor product sales and develop marketing strategies to ensure products are reaching the appropriate market*
- *Provide information and advice for the general public on all aspects of Western Australian geology*

2002–03 publications and products

The Geoscience information products group continued to produce high-quality geological and geophysical maps, printed and digital reports, and digital data packages.

Geological and geophysical maps

Thirty-six maps and images at various scales were published (see Appendix: Planned achievements and publications released, p. 109), including:

- seven 1:100 000 geological series maps
- two 1:250 000 geological series maps
- one 1:250 000 regolith materials series maps
- seven project maps at various scales
- nine geophysical images at various scales
- ten miscellaneous plates.

Geoscientific digital data packages

Twenty-seven geoscientific digital data packages were released in 2002–03 (Appendix, p. 109), including:

- one Combined East Yilgarn Geoscience Database package (preliminary)
- one atlas of 1:250 000 geological series map images
- one annual update for the Pilbara iron ore resources package
- two mineral occurrences and exploration potential data packages
- updates of two mineral occurrences and exploration potential data packages
- three well completion report data packages
- three acreage release data packages
- one geoscience of WA promotional CD
- two petroleum initiatives promotional CDs
- two updates of MINEDEX, one with a spatial search facility
- one State regolith coverage at 1:500 000 scale
- three airborne geophysical data packages
- five miscellaneous data packages.

Geoscientific reports

Thirty-six manuscripts were edited, illustrated, and published (Appendix, p. 109), including:

- Four Explanatory Notes for series maps
- Twenty-two Records and Reports
- One Mineral Resources Bulletin
- Nine miscellaneous publications including the GSWA Annual Review 2001–02.

Other activities

Promotional activities

Publication of Fieldnotes (the GSWA quarterly newsletter first published in January 1996) continued during 2002–03 and provided a medium for informing our customers about our activities, and promoting newly released maps, publications, and datasets.

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. Media releases describing GSWA products, services, and new publications were prepared and issued during the year, in cooperation with the Corporate Communications Branch of DoIR.

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

- 16th Australian Geological Convention (Adelaide, July)
- Diggers and Dealers Conference (Kalgoorlie, August)
- AIG Structural Geology Conference (Kalgoorlie, September)
- Good Oil Conference (Fremantle, September)
- Earth Science Week (Perth, October)
- Australian Ni Conference (Scarborough, October)
- Western Australian Basins 3 Symposium (Burswood, October)
- Mining 2002 (Brisbane, October)
- Diamond Conference (Scarborough, December)
- North American Prospectors Expo (NAPE; Houston, January)
- ASEG 2003 (Adelaide, February)
- PDAC 2003 (Toronto, March)
- APPEA 2003 (Melbourne, March)
- AAPG 2003 (Utah, May).

In addition to the above, DoIR and GSWA held three events to promote communication with our customers.

These were:

- Petroleum Open Day — showcasing recent work by the Department and issues of interest to petroleum explorers (Perth, October)
- Open day and display of recent work in the Eastern Goldfields (Kalgoorlie, October)
- GSWA 2003 (Perth, April).

Of these events, GSWA 2003 was a highlight, with the promotion of GSWA's online databases and other services and the launch of GeoVIEWER.WA, a CD-based tool that provides improved access to CD-based data.

The promotion of Western Australia's prospectivity overseas continued in 2002–03 with GSWA representatives attending and assembling display material at PDAC 2003 in Toronto, at the North American Prospectors Expo in Houston, and at the AAPG conference in Utah.

GeoVIEWER.WA

GeoVIEWER.WA harnesses leading-edge geographic information system (GIS) technologies to improve customer access to CD-based data through visualization, query, and integration tools. It is an underlying 'viewing tool plug-in' on which all future GSWA CD-based data can be distributed. As an easy-to-use interface it meets the changing needs of customers, including exploration geologists, prospectors, and the community to create a customized view of geoscientific data on their PC.

The implementation of GeoVIEWER.WA allows GSWA to move away from the standard map-centric structure, to a data-centric approach in the delivery of geoscience and associated data. By making the geoscientific data readily accessible, these CD data can be integrated with local data and incorporated into decision-making processes, thereby promoting mineral and petroleum exploration in Western Australia.

The benefits of GeoVIEWER.WA include:

- Easy to use
- Add your own data layers from the CD or a hard drive
- Apply transparency to see one data layer over another
- Change data layer symbology
- Query and search tools
- Pan and zoom on the map extent
- Scalable architecture to easily extend the functionality.

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Appendices

Planned achievements and publications released

Major planned achievements for 2002–03

The GSWA program for 2002–03 was an ambitious project-based program of work designed to promote Western Australia's exploration potential. The programmed planned achievements for 2002–03 were:

- release of 30 geoscientific maps at various scales;
- publication of 50 geoscientific Bulletins, Reports, Explanatory Notes, Records, and other papers;
- publication of 19 digital geoscience datasets;
- 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 2002–03, changing priorities resulted in the completion of a slightly different mix of published output for the year than was originally planned. Thirty-six maps and 36 books were published, and 27 digital datasets were released, which again reflected the changing technology and a greater volume of geoscience data being provided in digital form. In particular, provision of data in digital form, either on CD or via the internet, again grew during the year, and GSWA's new digital visualization, query, and integration tool, GeoVIEWER.WA, was released. In overall terms, GSWA publication milestones for 2002–03 were met. The total combined number of published products released was 99, which matched our stated target.

Provision of statutory information services to industry via the WAMEX and WAPIMS database systems continued through the year. Work continued on enhancements to both systems, which now allow the delivery of digital reports and data to customers via the worldwide web.

In addition, in 2002–03 GSWA completed construction of the Perth Core Library, a modern facility that complements the Kalgoorlie Core Library opened in 2001.

Despite a challenging year marked by amalgamation with another Government agency and a reduction in working hours, GSWA staff managed to achieve a marginal increase in real productivity measured on a cost basis.

Maps, books, and datasets released in 2002–03

Geological series maps	
1:100 000 Geological Series	SPLIT ROCK by L. Bagas, M. J. Van Kranendonk, and M. Pawley DE GREY by R. H. Smithies PARDOO final by R. H. Smithies EASTERN CREEK by T. R. Farrell GOULD by I. M. Tyler and S. A. Occhipinti ATLEY by S. F. Chen MOUNT MASON by S. Wyche
1:250 000 Geological Series	MENZIES by S. Wyche NABBERU (second edition) by R. M. Hocking
1:250 000 Regolith geochemistry	Regolith materials, WILUNA, W.A., by P. A. Morris
1:500 000 maps	Archaean geology of the Mallina and Whim Creek Basins, by R. H. Smithies Iron ore deposits of the Pilbara region, August 2002 Mineralization and geology of the north Kimberley, by I. Ruddock Mineralization and geology of the Pilbara Craton, by I. Ruddock
Geological maps at other scales	Major resource projects map 2002 (1:3 000 000) W.A. mineral deposits and petroleum fields 2003 (various scales) Gascoyne Platform by R. P. Iasky, C. D'Ercole, K. A. R. Ghori, A. J. Mory, and A. M. Lockwood (10 plates) W.A. Atlas of mineral deposits and petroleum fields 2003 (various scales)
Geophysical images	West Musgrave Total Magnetic Intensity image (1:250 000) West Musgrave Ternary Radiometric image (1:250 000) Tanami Total Magnetic Intensity image (1:500 000) Barlee Total Magnetic Intensity image (1:250 000) Barlee Ternary Radiometric image (1:250 000) Jackson Total Magnetic Intensity image (1:250 000) Jackson Ternary Radiometric image (1:250 000) Tanami Total Magnetic Intensity image (1:250 000) Tanami Ternary Radiometric image (1:250 000) West Tanami Total Magnetic Intensity map (1:500 000)
Mineral Resources Bulletin	21 **Silica resources of Western Australia**, by P. B. Abeysinghe
Reports	84 **East Yilgarn Geoscience Database: 1:100 000 geology of the Leonora–Laverton region, Eastern Goldfields Granite–Greenstone Terrane**, by M. G. M. Painter, P. B. Groenewald, and M. McCabe 85 **Mineral occurrences and exploration potential of the north Kimberley**, by I. Ruddock 86 **A summary of the geological evolution and petroleum potential of the Southern Carnarvon Basin, Western Australia**, by R. P. Iasky and K. A. R. Ghori 87 **Structure and petroleum prospectivity of the Gascoyne Platform, Western Australia**, by R. P. Iasky, C. D'Ercole, K. A. R. Ghori, A. J. Mory, and A. M. Lockwood

Records

2002/1 **Geological Survey work program for 2002–03 and beyond**

2002/9 **Mineral occurrences and exploration potential of the Arunta–Musgrave area**, by P. B. Abeysinghe

2002/16 **Morton Craig gravity survey, southwestern Officer Basin, Western Australia**, by S. I. Shevchenko

2002/17 **3.45 billion year-old stromatolites in the Pilbara region of Western Australia — proposals for site protection and public access**, by K. Grey, A. H. Hickman, M. J. Van Kranendonk, and M. J. Freeman

2002/18 **Drillhole WMC NJD1, western Officer Basin, Western Australia: stratigraphy and petroleum geology**, compiled by R. M. Hocking

2002/19 **Mines and mineral deposits of Western Australia: digital extract from MINEDEX — an explanatory note, 2002 update**, by R. W. Cooper, D. J. Flint, and S. Searston

2003/3 **Age and palaeomagnetism of dolerite intrusions of the southeastern Collier Basin, and the Earaheedy and Yerrida Basins, Western Australia**, by M. T. D. Wingate

2003/4 **Leads and prospects within tenements of the northern Perth Basin, Western Australia, 2002**, by C. D'Ercole, A. Pitchford and A. J. Mory

2003/5 **GSWA 2003 Seminar: Promoting the prospectivity of Western Australia — extended abstracts**

2003/6 **Interpretation of geophysical data over the Shoemaker impact structure, Earaheedy Basin, Western Australia**, by P. J. Hawke

2003/7 **GSWA Yinni 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia**, by M. Dixon, D. W. Haig, A. J. Mory, J. Backhouse, K. A. R. Ghori, and P. A. Morris

2003/8 **GSWA Edaggee 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia**, by M. Dixon, D. W. Haig, A. J. Mory, J. Backhouse, K. A. R. Ghori, R. Howe, and P. A. Morris

2003/9 **Inventory of abandoned mine sites: progress 1999–2002**, by W. R. Ormsby, H. M. Howard, and N. W. Eaton

2003/10 **Geophysical investigation of the Wolfe Creek meteorite crater**, by P. J. Hawke

2003/11 **East Yilgarn Geoscience Database — 1:100 000 reinterpretation of the Eastern Goldfields regolith**, by A. Riganti and P. B. Groenewald

2003/13 **Seismic data reprocessing, Officer Basin, Western Australia**, by A. P. Simeonova

Explanatory Notes
1:100 000 Geological Series

Geology of the Barlee 1:100 000 sheet, by A. Riganti
Geology of the Pinderi Hills 1:100 000 sheet, by A. H. Hickman
Geology of the Bungalbin 1:100 000 sheet, by S. F. Chen
Geology of the Tambourah 1:100 000 sheet, by M. J. Van Krandonk

Miscellaneous

GSWA Annual Review 2001–02

Overview of the mineral sector in Western Australia in 2001–02, by D. J. Flint and S. M. Searston

Summary of petroleum prospectivity, onshore Western Australia 2003: Bonaparte, Canning, Officer, Southern Carnarvon, and Northern Carnarvon Basins

Fieldnotes v. 24

Fieldnotes v. 25

Fieldnotes v. 26

Fieldnotes v. 27

Supplement to Catalogue of GSWA maps and publications (September 2002)

Ministerial Inquiry into greenfields exploration in Western Australia: Phase 2

GeoVIEW.WA Users Guide

Digital products

Mineral occurrences and exploration potential of the West Pilbara — 2002 update

Iron ore deposits of the Pilbara region, August 2002 — 1:500 000 digital data package

State regolith south of 26th parallel, preliminary edition

State regolith north of 26th parallel, preliminary edition

North Perth Basin Specific Area Gazettal data package

Wolfe Creek airborne magnetic and radiometric data

Second East Canning Specific Area Gazettal data package

West Musgrave geophysical survey

Mineral occurrences and exploration potential of the north Eastern Goldfields — 2002 update

Atlas of 1:250 000 Geological Series Map Images (and update CD)

Drillhole WMC NJD1, western Officer Basin, Western Australia: stratigraphy and petroleum geology (Record 2002/18)

Mines and mineral deposits of Western Australia: digital extract from MINEDEX, 2002 update (Record 2002/19)

Mineral occurrences and exploration potential of the north Kimberley (Report 85)

Combined East Yilgarn Geoscience Database (1:100 000): Eastern Goldfields Granite–Greenstone Terrane

West Tanami aeromagnetic data (Phase 1 and Phase 2)

Publications, maps, and datasets for explorers 2003 — mini CD

Western Australian Petroleum Acreage Release, March 2003

Inventory of abandonded mine sites: progress 1999–2002 (2003/9)

Geological evolution and petroleum potential of the Southern Carnarvon Basin, Western Australia (Report 86)

Structure and petroleum prospectivity of the Gascoyne Platform, Western Australia (Report 87)

GSWA Yinni 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia (Record 2003/7)

Mineral occurrences and exploration potential of the Arunta–Musgrave area (Record 2002/9)

GSWA Edaggee 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia (Record 2003/8)

Petroleum promotional data — mini CD

Major planned achievements for 2003–04

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 2002–03 include:

- release of 32 geological maps at various scales;
- publication of 52 geoscientific Bulletins, Reports, Explanatory Notes, Records, and other papers;
- publication of 22 digital data packages.

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 2002–03

The following GSWA staff published papers in external journals during the year, and gave talks and seminars at a variety of venues.
Note: GSWA authors are in italics

ABEYSINGHE, P. B., 2002, Ceramic clay in Western Australia: AUSTCERAM 2002, Perth, W.A., October 2002, Refereed Proceedings and Conference Program; Australasian Ceramic Society (WA Branch) and Industrial Minerals Centre Australia, p. 279–280.

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BLEWETT, R., CHAMPION, D., CASSIDY, K., GOLEBY, B., BELL, B., *GROENEWALD, B.*, NICOLL, M., and WHITAKER, A., 2002, Implications of the northern Yilgarn seismic to Leonora–Laverton 3D model: Northeastern Yilgarn Seismic Workshop, August 2002, Perth, W.A., Workshop Notes; Geoscience Australia, p. 104–116 (unpublished).

BORDORKOS, S., SANDIFORD, M., and *VAN KRANENDONK, M.*, 2002, Conductive incubation and its role in the formation of dome-and-keel structure in the Archaean East Pilbara Granite–Greenstone Terrane, *in* Geoscience 2002: Expanding Horizons *edited by* V. P. PREISS: 16th Australian Geological Convention, Adelaide, S. A., July 2002; Geological Society of Australia, Abstracts Volume, no. 67, p. 44.

CARLSEN, G. M., SIMEONOVA, A. P., and *APAK, S. N.*, 2003, Petroleum systems and exploration potential in the Officer Basin, Western Australia: APPEA Journal, v. 43, p. 473–494.

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EYLES, N., *MORY, A. J.*, and BACKHOUSE, J., 2002, Carboniferous–Permian palynostratigraphy of West Australian marine rift basins: resolving tectonic and eustatic controls during Gondwanan glaciations: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 184, p. 305–319.

FREEMAN, M. J., ELITH, N., and BLAIR, D., 2002, Landuse planning – Environmental study: Bunbury (Powerpoint presentation): Drill Blast & Mine Mill Optimisation Conference, Presentations (CD), Perth W.A, July 2002; International Institute for Research, 41p.

GOLEBY, B. R., BLEWETT, R., *GROENEWALD, B.*, CASSIDY, K., CHAMPION, D., KORSCH, R. J., WHITAKER, A., JONES, L. E. A., BELL, B., and *CARLSEN, G.*, 2002, Seismic interpretation of the Yilgarn Craton: Northeastern Yilgarn Seismic Workshop, August 2002, Perth, W.A., Workshop Notes; Geoscience Australia, p. 76–103 (unpublished).

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GREY, K., 2003, 'Was it life as we know it?': Astrofest, Trinity College, Perth, W.A., talk given 8/2/03.

GREY, K., HILL, A. C., WALTER, M. R., and CALVER, C. R., 2003, Neoproterozoic biotic diversification: 'Snowball Earth' or aftermath of the Acraman Impact: Geological Society of Australia (W.A. Division) May monthly meeting; West Australian Geologist, no. 473, May 2003, p. 3.

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List of acronyms and abbreviations

AAPG	American Association of Petroleum Geologists
ABS	Australian Bureau of Statistics
AGSO	Geoscience Australia, formerly Australian Geological Survey Organisation
AMEC	Association of Mining and Exploration Companies (Inc.)
AMIRA	Australian Mineral Industries Research Association Limited
ANZMEC	Australian and New Zealand Minerals and Energy Council
ANU	Australian National University
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, now Geoscience Australia
CME	Chamber of Minerals & Energy of Western Australia Inc.
CSIRO	Commonwealth Scientific Industrial Research Organisation
DLI	Department of Land Information
DoIR	Department of Industry and Resources, formerly MPR
EXACT	Western Australian mineral exploration activities database
GA	Geoscience Australia, formerly Australian Geological Survey Organisation
GeoVIEW.WA†	GSWA's integrated geoscience information system
GeoVIEWER.WA	GSWA's CD-based visualization, query, and integration tool
GIS	Geographic Information System
GPS	Global Positioning System
GSA	Geological Society of Australia
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
MAGIX	Mineral Airborne Geophysics Information eXchange
MERIWA	Minerals and Energy Research Institute of Western Australia, formerly WAMPRI
MINEDEX	DoIR's mines and mineral deposits information database
MPR	Department of Mineral and Petroleum Resources, now DoIR
NASA	National Aeronautics and Space Administration
NGA	National Geoscience Accord
PDAC	Prospectors and Developers Association of Canada
PESA	Petroleum Exploration Society of Australia
pmd*CRC	Predictive Mineral Discovery Cooperative Research Centre
REGOCHEM	GSWA's regolith and geochemistry database
SHRIMP	Sensitive high-resolution ion microprobe
TENGRAPH†	DoIR's electronic tenement-graphics system
UWA	University of Western Australia
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
WASM	Western Australian School of Mines

Note: † GeoVIEW.WA, WAMEX, WAPEX, and TENGRAPH are registered Trade Marks of DoIR

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