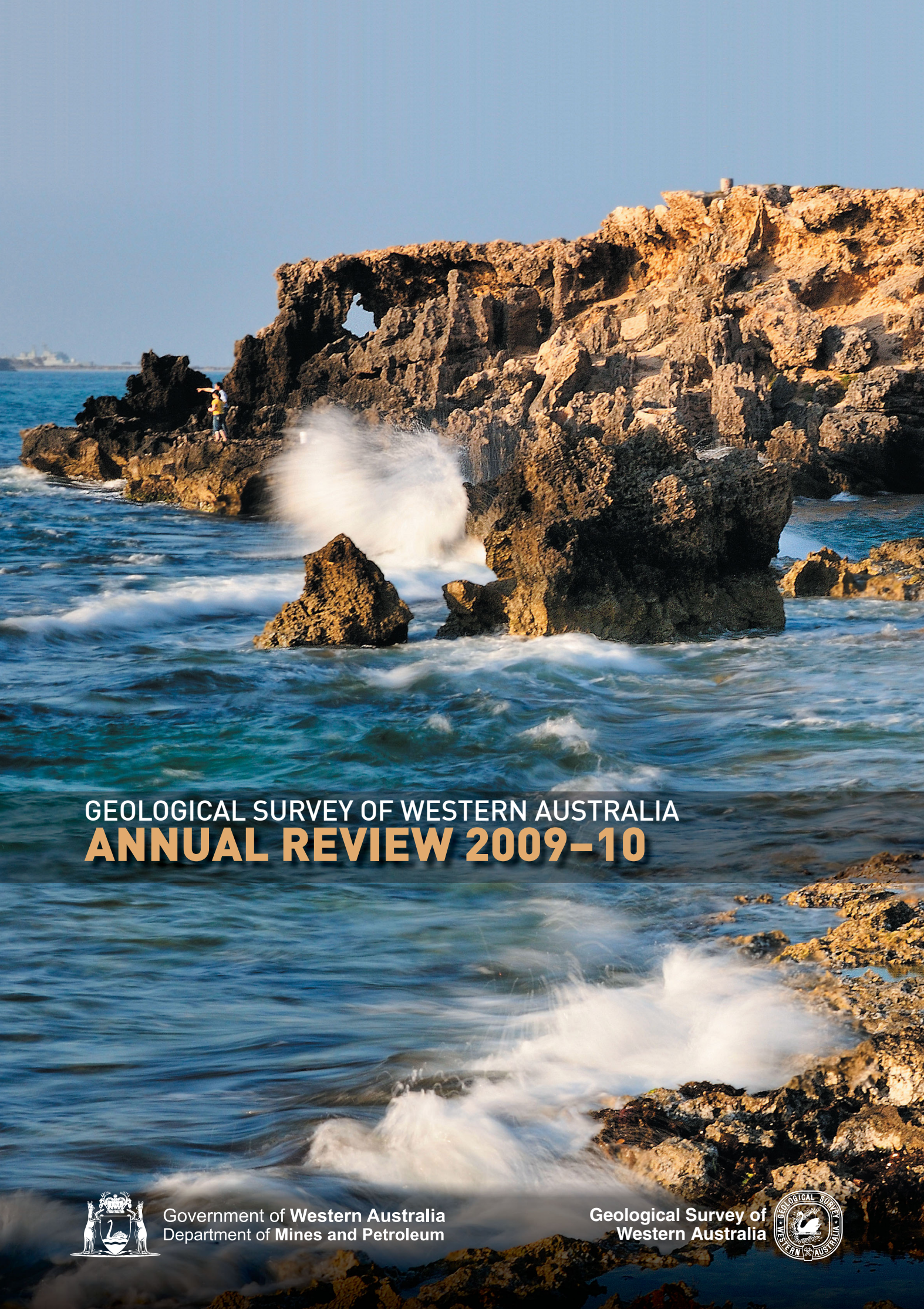

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REVIEW 2009–10

Government of **Western Australia**
Department of **Mines and Petroleum**

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REVIEW 2009–10

MINISTER FOR MINES AND PETROLEUM
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DIRECTOR GENERAL, DEPARTMENT OF MINES AND PETROLEUM
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EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Tim Griffin

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Cover
Eroded remnants of large-scale cross-stratification in Tamala Limestone, Point Peron
Photograph courtesy Alan Thorne

Frontispiece
Irregular folds in calc-silicate, mafic amphibolite and paragneiss in the Malcolm Metamorphics, Albany–Fraser Orogen, at Point Malcolm, east of Esperance
Photograph courtesy Catherine Spaggiari

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Geological Survey of Western Australia

GSWA mission statement

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

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

Our role is to elucidate the geological framework of Western Australia and to 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 GSWA 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 lie in field-based research, particularly regional geological mapping in the Precambrian and Phanerozoic provinces of the State. GSWA is a leader in the fields of structural geology, basin studies, carbonate sedimentology, mineralization studies, geochemistry, regolith studies, geochronology, paleontology, 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 repository of mineral and exploration reports, the GSWA is the custodian of an immense volume of information on the geology of the State and is the premier organization providing geoscientific expertise in Western Australia.

2009–10

Year in review


Tim Griffin

During the first half of 2010 there was more optimism that Australia's economy was recovering, although there is still doubt about the robustness of the world's economy. Commodity prices have climbed strongly from their lows in early 2009, but the number of mineral-related initial public offerings in the first half of 2010 remains subdued. In May 2010 the Australian Government's announcement of a resources rent tax that would apply to the mineral industry from 2012 had a dampening effect on resource investment sentiment. Such conflicting messages meant that total mineral and petroleum exploration expenditure (including in the offshore Commonwealth jurisdiction) in Western Australia declined marginally in 2009. However, this hid a significant decline in mineral exploration expenditure in 2009, although there are good signs of recovery in the first half of 2010.

At the end of 2009–10 all elements of the Exploration Incentive Scheme (EIS) had commenced. This includes the appointment of the first embedded researchers under the Western Australia Regional Researcher Initiative, and the signing of all agreements for exploration-related research undertaken in collaboration with WA:ERA, the Centre for Exploration Targeting, The University of Western Australia, Curtin University, and CSIRO. Particularly pleasing was the completion of a significant program of airborne geophysical surveys and deep seismic reflection surveys by the end of 2009–10. The first round of the Co-funded Industry–Government Drilling Program was a success, with several new discoveries being made. The second-round subsidy winners were announced at the end of June 2010.

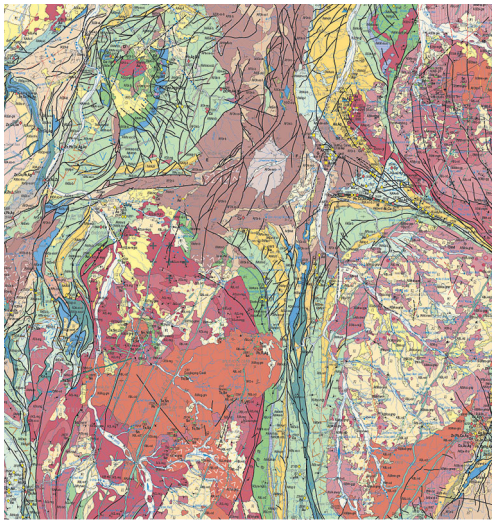
For GSWA, the execution of such a large additional geoscience program under EIS, on top of the recurrent program, is placing some strain on our systems and staff. The quality of our staff, and of the considerable investment that has been made in the development of our systems over the last few years, is shown by our ability to rise to the challenge of doubling our output with only eight additional Public Service employees.

GSWA publications

During 2009–10 GSWA published:

- 24 geoscience maps including 12 Geological Series maps at 1:100 000 and one at 1:250 000 scale
- 36 records, reports and other publications
- 22 digital information packages.

GSWA met or exceeded its 2009–10 planned achievements for the recurrent budget-funded program despite the fact that some managers were also involved in implementing major EIS projects. Series map production continued at a high level for the second year in a row, which reflects the mature stage several mapping projects have reached.

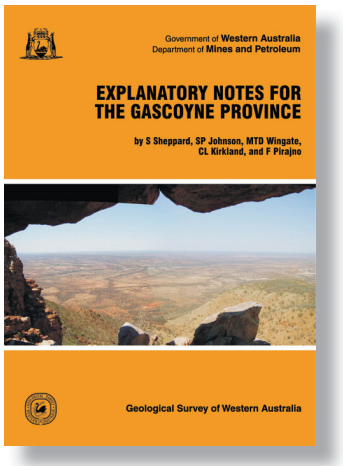


Part of the Marble Bar 1:250 000 Geological Series map

For the Pilbara mapping project, the Marble Bar 1:250 000 Geological Series map (third edition) is its final release. This map was compiled very differently from all previous 1:250 000 geological maps from the Pilbara. The new 1:250 000 geology was derived by a two-stage process involving simplification by 'rolling-up' up the 1:100 000-scale geology layers in the digital Pilbara Geological Information Series (GIS) package covering the area of the 1:250 000 sheet, followed by recompilation to further simplify areas still too complex for a 1:250 000-scale publication. This process achieved a much-improved consistency between the 1:100 000-scale GIS database and the geology of the 1:250 000 map sheet.

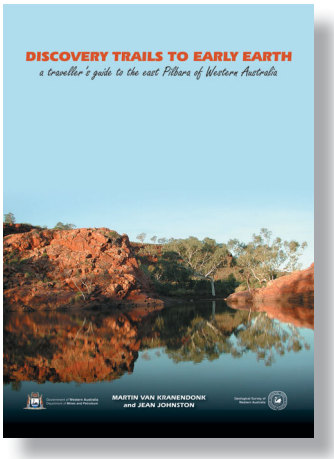
Seven 1:100 000 Geological Series maps were released for the Northeast Yilgarn mapping program. These, together with 'digital only' versions of three other 1:100 000-scale map sheet areas, are included in the latest release of the East Yilgarn GIS digital package, and complete the coverage of the Archean granite–greenstones up to the edge of the Gunbarrel Basin. Updated GIS packages were also released for the Murchison, west Musgrave, and western Capricorn Orogen, together with an updated Geological Exploration package for the west Arunta.

A number of Records and Reports were released detailing our understanding of the Proterozoic events in both the Capricorn Orogen and the Musgrave Province. This has involved the synthesis of extensive sets of geochronology, whole rock geochemistry, and isotope data, combined with a mature understanding of the regional geology. In the Capricorn Orogen, publications covered the 2005–1950 Ma Glenburgh Orogeny and the 1820–1770 Ma Capricorn Orogeny, as well as the geochronology of the Abra polymetallic deposit. In the Musgrave Province, publications detailed the age and geochemistry of the both the mafic and the felsic rocks. A Record on the Alcurra Suite discusses its relationship to the c. 1068 Ma Nebo–Babel intrusion, which is host to significant Cu–Ni–PGE mineralization, and the implications for further exploration. GSWA released a series of BSc Honours theses carried out as collaborative projects with Adelaide University, with GSWA providing field supervision and logistic support.



Explanatory notes for the Gascoyne Province were released in a new format representing a break from GSWA's tradition of publishing explanatory notes for individual map sheets. The new format notes are made up of two parts: a front-end containing a synthesis of the geological evolution of the Gascoyne Province, and a back-end consisting of detailed descriptions of each lithostratigraphic unit and tectonic event.

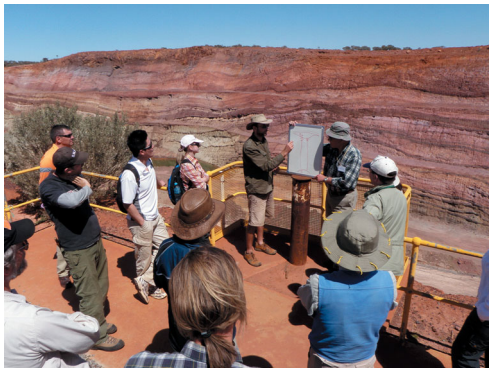
Year in review



GSWA also released a self-drive guide book that showcases to the general public some of Earth's ancient wonders to be seen in the rocks in the Pilbara region, and allows the reader to appreciate the formation of its landscape. Written by Martin Van Kranendonk and Jean Johnston, *Discovery Trails to early Earth — a traveller's guide to the east Pilbara of Western Australia* provides directions for five different trails all beginning from Marble Bar.

The delivery of GSWA information through GeoVIEW.WA continued to expand, with 75 valuable State-wide geoscientific and related datasets available that are updated on a regular basis. A new 'Base Imagery' category was added containing State-wide raster datasets and associated metadata, including radiometrics, magnetics, gravity, 1:250 000 geology mosaic, 1:100 000 geology mosaic, and 1:250 000 topography.

Geological mapping programs



The Windimurra vanadium mine

During 2009–10 mapping programs continued in the Yilgarn Craton, with field mapping completed on the Windimurra and Narndee Igneous Complexes in the Murchison Domain of the Youanmi Terrane. New SHRIMP geochronology has confirmed an age of c. 2800 Ma for the Narndee Igneous Complex, part of the Boodanoo Suite, and a c. 2810 Ma date for the Meeline Suite, a part of which is the Windimurra Igneous Complex. The extensive layered mafic–ultramafic intrusions, which host significant vanadium mineralization, collectively make up 40% by volume of the greenstones in the Murchison Domain, and also include the c. 2792 Ma Little Gap Suite, the c. 2750 Ma Gnanagooragoo Igneous Complex, and the 2735–2710 Ma Yalgowra Suite of layered gabbroic sills. All suites are demonstrably contemporaneous with packages of high-Mg tholeiitic lavas and/or felsic volcanic rocks and are consistent with genesis over a 100 million-year period in a mantle plume setting.

In the Eastern Goldfields, work has commenced on the implementation of a regional stratigraphy, regularizing existing stratigraphic nomenclature, and extending a consistent stratigraphic system across the whole of the Eastern Goldfields Superterrane. Mapping has been completed in the northeastern Yilgarn Craton leading to new interpretations with implications for the extent to which this stratigraphy can be applied, for crustal architecture and geodynamic evolution, and for prospectivity. Results suggest that the Burtville Terrane has affinities with the Youanmi Terrane to the west of the Kalgoorlie Terrane, and is a fragment that rifted off and was 'reaccreted' onto the proto-Yilgarn Craton. The inboard Kalgoorlie Terrane and the outboard Yamarna Terrane developed as adjacent rift basins that were closed during the reaccretion event.

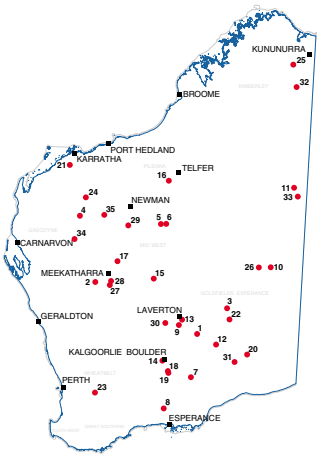
In the Gascoyne Province the east-southeasterly trending Chalba Shear Zone has been shown to control much of the intracontinental reworking recognized in the province. North of the shear zone new SHRIMP

titanate geochronology suggests that the province was pervasively reworked at medium metamorphic grade at c. 1280 Ma, during the Mesoproterozoic. South of the shear zone apparently similar reworking is 500 million years older, and took place during the 1815–1770 Ma Capricorn Orogeny.

In the basement to the Edmund Group in the Egerton Inlier, gold-bearing quartz veins are hosted by low-grade pelitic and psammitic schist, and minor metadolerite, mafic schist, psephite, and metadolostone. Mineralization is centred on the contact between metasedimentary rocks and a strongly foliated to mylonitic metadolerite. The basement rocks may correlate with the Padbury Group, or with the Bryah Group, which hosts recently discovered gold and copper mineralization at DeGrussa.

It has been recognized that the Albany–Fraser Orogen and the Musgrave Province in central Australia have been affected by similar tectonothermal events within the period between c. 1350 Ma and c. 1120 Ma. GSWA's ongoing work in both regions has enhanced our understanding of these events and is being used to test the possibility of a common tectonic link. The c. 1300 Ma Fraser Zone in the Albany–Fraser Orogen is dominated by metamorphosed gabbro and interlayered metamorphosed sedimentary rocks and granite. Its chronological counterpart in the Musgrave Province is the 1345–1293 Ma Wankanki Supersuite, a voluminous sequence of Andean-style continental arc granites and volcanic rocks. The Fraser Zone is interpreted as a lower crustal region of high-temperature metamorphism that was extensively intruded by sheets of gabbro while undergoing partial melting producing a wide spectrum of hybrid mafic to felsic magmas. This scenario is typical of lower crustal 'hot zones' thought to form the roots of active convergent margins, an environment also thought to have existed beneath the Musgrave Province during the formation of the Wankanki Supersuite.

Exploration Incentive Scheme

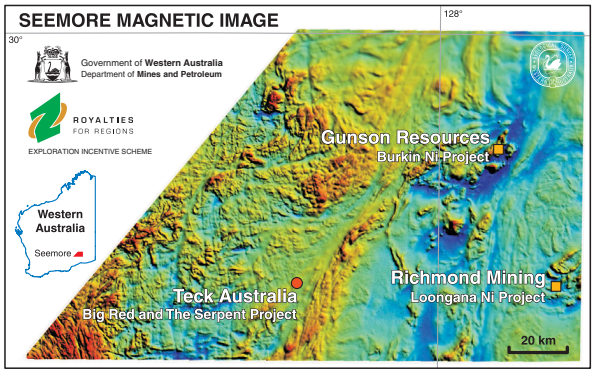


EIS Co-Funded drilling projects 2009–10

The first round of the EIS Co-funded Exploration Drilling scheme allocated $3.19 million for 35 projects across the State, of which 30 will be completed. Successes include Beadell Resources' West Musgrave gold discovery (60 m @ 0.9g/t from 13 m depth, including 5 m @ 4.7 g/t gold), which is project 10 on the adjacent map. Drillcore will also provide new insights into the geology of remote areas, including the basement to the Eucla Basin. An amount of $5.5 million is available for co-funded drilling in 2010–11. Following preliminary advertising in November 2009, applications opened in mid-February 2010 (for one month) and 62 successful applicants were announced in June 2010. Gold was the most sought-after commodity, followed by copper, uranium, and nickel.

As part of the Exploration Incentive Scheme (EIS), GSWA released nine regional airborne magnetic and radiometric surveys during 2009–10 totalling 907 000 line-km. The surveys were aimed at some of the most remote parts of Western Australia, covering the central and northern Canning Basin and the western Eucla Basin. The western Eucla Basin was flown at 200 m line spacing — half the usual spacing of GSWA's regional surveys. The images give a remarkably detailed picture of Proterozoic basement rocks buried beneath sand and relatively thin Cenozoic limestone. Ground gravity surveys were completed over the southern central Yilgarn, the eastern Albany–Fraser Orogen, and the northern Capricorn Orogen.

Year in review



EIS funding, in collaboration with AuScope (National Earth Science Infrastructure Program), ANSIR (National Research Facility for Earth Sounding) and Geoscience Australia, was used to acquire the Capricorn and Youanmi deep seismic lines for a total length of 1276 km across the Capricorn Orogen, and across the northwestern and central Yilgarn Craton. Acquisition started near Tom Price and ended at Leinster, providing an unparalleled view into the crustal architecture of the West Australian Craton. Magnetotelluric (MT) surveys were carried out in conjunction with the seismic surveys. Further MT surveys funded through EIS were carried out across the Southern Cross Domain of the Yilgarn Craton from Hyden to Norseman, and across the Musgrave Province.

The East Wongatha regolith mapping and regional geochemical survey was carried out in the East Yilgarn and adjacent Albany–Fraser Orogen under EIS. Regolith mapping was also undertaken in the Gascoyne Province. Following on from the purchase and release of the Terra Search surface and downhole geochemical database, the mineral drillhole database to store company data has been developed under EIS and is being tested. It is estimated that there are 7000 historical datasets to be entered plus 1000 new datasets per year. Improvement of GSWA mapping databases continued, with the emphasis on the Explanatory Notes database.

A new initiative under EIS with both the Centre for Exploration Targeting at UWA and CSIRO's Minerals Down Under Flagship is developing exploration targeting products for under-explored areas of the State, starting with the West Arunta and the eastern Albany–Fraser Orogen. A program in collaboration with GEMOC at Macquarie University is well under way to obtain Lu–Hf data from dated zircons, together with a program of obtaining whole-rock Nd isotope data from dated samples. Phosphate dating using SHRIMP is being expanded.

National Virtual Core Library

GSWA is a participant in the National Virtual Core Library (NVCL) as part of AuScope, which aims to deliver high-resolution images and mineral composition information for drillcore throughout Australia. Information will be generated using the HyLogging system, a new and innovative spectral scanning system developed by CSIRO. GSWA's HyLogger has been commissioned at the Perth Core Library and is housed in a custom-built container that ensures a dust-free and temperature-controlled environment. Two spectrometers covering the visible-near-infrared (VNIR) wavelengths and the shortwave-infrared (SWIR) wavelengths are used to scan the core and determine its mineralogy. A Thermal Infrared scanner is still to be delivered.

AuScope's NVCL HyLogging system at GSWA's core library

Current target minerals include the Fe oxide group, the Al(OH) group, the Mg(OH) group, the carbonate group, sulfates, some OH-bearing silicates, the Si(OH) group, and the ammonium-bearing group. More than 15 000 m of core has been scanned. The HyLogging system will provide new insights into alteration-mineral assemblages, vectors to mineralization, objective determination of lithostratigraphic units and their boundaries, and refined inputs to resource block-modelling and mineral-processing characteristics.

Geochemistry and regolith

In 2009–10 more than 700 multi-element geochemical analyses of rocks were carried out in support of GSWA mapping and mineralization studies. Although commercial laboratories can accurately and precisely determine the concentrations of most elements, particularly precious metal analytical data, Geoscience Australia's laboratory provides the best-quality data for some REE and high field strength elements at low-level concentrations.

No progress has been made with the collection of samples in the central and western desert regions and in the Kimberley for the National Geochemical Survey of Australia due to delays in obtaining Aboriginal Heritage clearances.

GSWA has reviewed its approach to regolith mapping to provide a standardized approach to the understanding and classification of regolith, and to the use of remotely sensed data in the production of regolith maps. During the year, GSWA contributed to a meeting held in Kalgoorlie on the Paleovalley Groundwater Project.

Geochronology and isotope geology

Some 90 samples were dated in 2009–10 as part of GSWA's ongoing programs, including samples from the Pilbara Craton, the Youanmi and Burtville Terranes of the Yilgarn Craton, the Gascoyne and west Musgrave Provinces, the Albany–Fraser Orogen, and the Edmund and Collier Basins. In addition to GSWA's ongoing zircon geochronology program, a program of phosphate dating continued in collaboration with Curtin University as part of an ARC Linkage grant.

Integration of results from whole-rock Sm–Nd and zircon Lu–Hf analyses, which are being obtained in part under EIS, provide a valuable complement to U–Pb geochronology by revealing the timing of mantle input into the crust, which may correspond to regional mineralization events.

Sampling granite in the Albany–Fraser Orogen for Hf analysis

The Geochronology Record Series is now published directly to the GSWA website, with the latest results accessible using GeoVIEW. WA or via Digital Paper. GeoVIEW. WA opens with a geochronology theme preloaded, and redesigned tables are now more intuitive, allowing U–Pb and isotope files to be downloaded as text files. GSWA's geochronology and isotope data are downloadable as a KMZ file for use in Google Earth.

Year in review

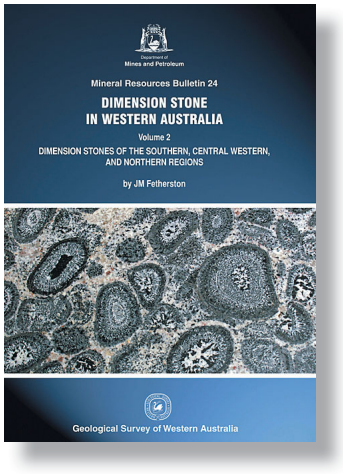
Petroleum geology

Studies in the Canning Basin have shown that it is 'cooler' than first evaluated. A study to determine potential for geothermal energy has begun in the Carnarvon Basin, incorporating legacy data related to temperature at basement, depth to basement, and thermal conductivity analysis.

Difficult access, extensive sand cover, and a perception of low prospectivity — despite producing oil and gas fields in the NT — make the western Amadeus Basin one of the least-known geological regions in Australia. A field-based reassessment of the thick Neoproterozoic section in Western Australia has commenced with early progress made in correcting some long-standing miscorrelations. Two Neoproterozoic glacial units are present, allowing correlation with mid-Neoproterozoic successions elsewhere in Australia and world-wide. Numerous stromatolite horizons are present and preliminary identifications fit well with lithostratigraphic and sequence stratigraphic correlations. Most of the stratigraphic units in the Northern Territory that have demonstrated or suspected source rock potential are now recognized in Western Australia. If not reservoirs in the Amadeus Basin, they may have provided hydrocarbon charge to the Canning Basin, which onlaps to the west.

Mineral occurrence mapping, commodity analysis, and mineral exploration information

A DVD covering mineral occurrences and exploration activities of the Peak Hill area was released by the Mineral Occurrence Mapping and Commodity Analysis Group. Mineral Resources Bulletin 24 entitled *Dimension stone in Western Australia: volume 2 — dimension stones of the southern, central western, and northern regions,* by JM Fetherston was released.



More than 3376 reports were added to the WAMEX database, with 7686 released to open-file. These included 3176 from the sunset clause release and 4490 covering expired tenements. Another 4336 reports (previously only available on microfiche) were scanned and are available online. During the year there were 21 120 visits to the WAMEX webpage, 86% from outside the department, and by 30 June 2010 55 890 reports were on open-file

The WAMEX3 database is being continually improved. Focus has been on better data management of individual components, such as drilling data, surface geochemistry, geophysics spectral data, and GIS datasets, including reorganizing pre-WAMEX3 data for the website.

Land use geoscience

For Land Use Geoscience, prospectivity studies of proposed conservation areas continued, including for the Great Western Woodlands. Geological advice was given to other government departments on land rezoning and subdivisions, reserve creation, and under Section 16(3) of the Mining Act. Strategic resource studies focused on construction materials for the rapidly growing South West region and on titanium–zircon mineralization.

The rocky limestone coast at Cape Peron

The coast is a dynamic environment responding to changes in sea level, sediment supply and transport, and wave and swell patterns. Shorelines in southwest Western Australia are wave-dominated and can be broadly categorized into rocky and sandy coasts. Of major concern in managing coastal environments is determining the response to predicted rises in sea level. Without good long-term planning, coastal communities and infrastructure are at risk of erosion and flooding. Mapping of the coastline in southwest Western Australia by GSWA, can be used to understand the present stability of coastal landforms and their susceptibility to erosion.

The future

The Exploration Incentive Scheme (EIS) has been running for 15 months and is producing a step change in the amount of quality precompetitive geoscience information available. It is an effective demonstration that WA is committed to attracting more exploration investment by reducing risk. The focus is on areas that are poorly understood geologically; both in under-explored regions, and deep in terranes already known to be mineralized.

Integration of the ongoing mapping programs with the EIS programs should be aimed at developing a mineral-systems approach that will be effective in generating new exploration targets, particularly under the soil and the thin sedimentary basins that cover much of WA's under-explored regions. GSWA is also expanding cooperative projects with Geoscience Australia and CSIRO, and with university earth science research centres.

The challenge for GSWA, together with its government and university research partners, is to assist explorers to make full use of the modernized and expanded products and datasets. The development of new concepts, skills, and technologies is aimed at creating a new generation of exploration targets, which can be tested either under the Government co-funded drilling scheme, or by attracting new investment.

This will be my last review of GSWA operations as I will shortly take up a new position elsewhere in the Department of Mines and Petroleum. My time with GSWA, beginning in 1980 at Kalgoorlie, has been professionally rewarding and very enjoyable. I thank all the GSWA staff who have assisted me over the last thirty years and who have contributed in a collaborative way to making the Geological Survey one of the world's leading geological surveys.

Tim Griffin
Executive Director

Overview of mineral exploration in Western Australia for 2009–10

by PB Abeysinghe and DJ Flint

Abstract

There were signs of recovery in commodity markets towards the end of 2009–10 following the economic downturn resulting from the global financial crisis of 2008–09. Statistical indicators for the year are mixed; some still show downward trends, whereas others show signs of recovery. In 2009–10, commodity prices generally improved leading to a resurgence in the mining sector, strengthening other related industries, and triggering positive effects in the employment sector. However, economic problems persisted in the United States and parts of Europe.

The Western Australian economy, with its reliance on mineral and petroleum exports, recovered quickly. In 2009–10, the value of mineral production in the State increased by 4% to a new record of A$52.1 billion (excluding petroleum). Iron ore, gold, and nickel, which form the backbone of the Western Australian mineral sector, accounted for 85% or A$44 billion of the value of minerals produced in 2009–10. A substantial increase in the gold price led to a significant increase in both production value (25.5%) and production quantity (20%) in 2009–10 compared to the previous year. The recovery of nickel prices also led to a significant increase in value (36%), although production quantity dropped marginally due to the earlier closure of some mines caused by the global financial crisis. In the iron ore sector, although the production increased by 25%, a significant drop in prices triggered by the global financial crisis resulted in a virtually unchanged value (A$33.7 billion) of production.

Across Australia, mineral exploration expenditure decreased marginally by 1.9% for the year, with drilling (metres drilled) at existing deposits recovering by 1.5% and drilling for new deposits increasing by 12% (comparable WA-specific data for metres drilled are not available).

In Western Australia, the trend was similar — mineral exploration expenditure during 2009–10 decreased by 2.6% (in 2009–10 dollar terms). The area held under granted Exploration Licences in Western Australia increased by 24% by the end of the year, with a moderate (5%) increase in the area under granted Mining Leases. The pro-uranium policy of the State Government continued to have a positive impact in the uranium sector with uranium exploration expenditure in the State increasing to A$55.4 million in 2009–10 from negligible amounts in the period from 1991 to 2006. A number of companies are planning to start new mines.

Numerous mineral discoveries are being made. This reflects technical success from the sustained, high levels of mineral exploration expenditure over many years and is despite the global financial crisis.

KEYWORDS: mineral exploration, exploration potential, exploration licences, exploration expenditure, mineral production, gold, iron, nickel, base metals, copper, lead, zinc, silver, diamond, heavy mineral sands, uranium, molybdenum, rare earth elements, vanadium, lithium, coal, tungsten, manganese, exploration drilling, Western Australia.

Overview

Significant observations for the Western Australian mineral industry during 2009–10 include:

- Mineral exploration expenditure in Western Australia marginally decreased (2.6%) from $1273 million* in 2008–09 to $1244 million in 2009–10 (Fig. 1, in 2009–10 dollar terms).
- Australian mineral exploration expenditure also marginally decreased (2%) from $2277 million in 2008–09 to $2233 million in 2009–10 (in 2009–10 dollar terms).
- Western Australia's share of the national exploration expenditure for minerals (excluding petroleum) marginally decreased to 55.7% in 2009–10 compared with the 2008–09 value of 56.1% (Fig. 1).
- Despite the negative effects of the global financial crisis in 2008–09, exploration expenditure for many commodities including gold, iron ore, base metals, and uranium are picking up.

* All $ figures in Australian dollars unless otherwise specified. All exploration expenditure figures and drilling statistics are compiled by the Australian Bureau of Statistics unless otherwise specified.

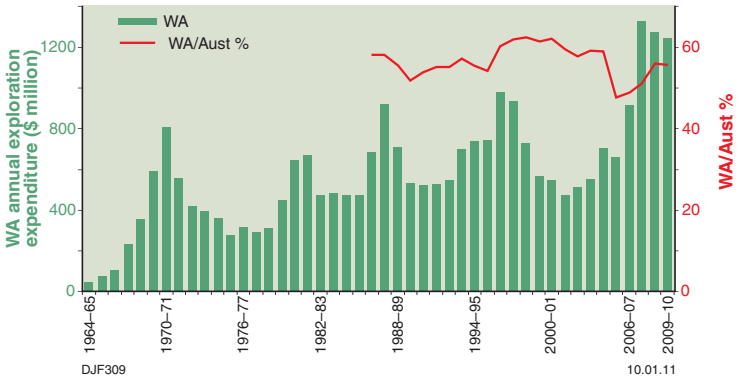


Figure 1. Mineral exploration expenditure in Western Australia, by year (2009–10 dollars)

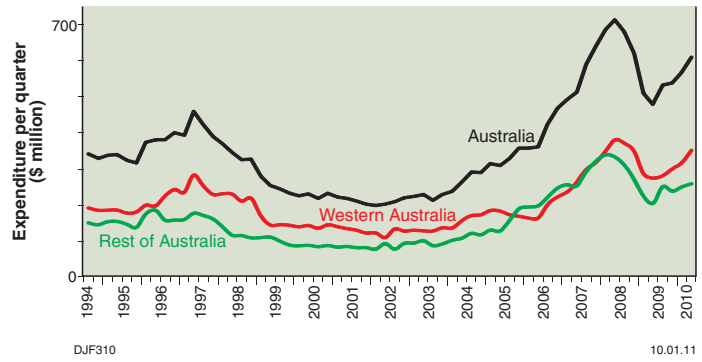


Figure 2. Mineral exploration expenditure in Australia, Western Australia, and rest of Australia (seasonally adjusted by quarter, June 2010 dollars)

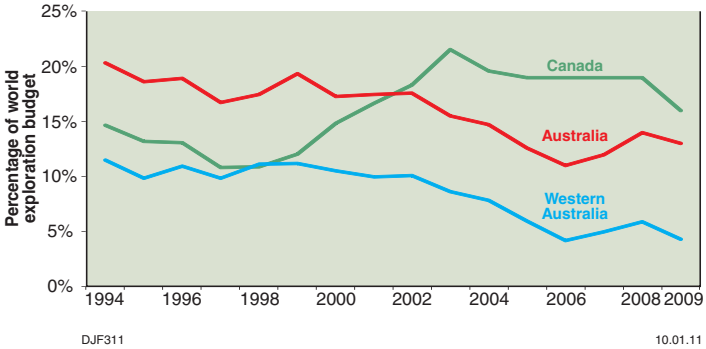


Figure 3. Non-ferrous mineral exploration expenditure — comparative market share of Canada and Western Australia since 1994 (source: Metals Economics Group (Canada), Australian Bureau of Statistics, and Department of Mines and Petroleum)

- Quarterly mineral exploration data indicate that exploration expenditure in Western Australia is still recovering, but at a moderate rate (Fig. 2).
- The main commodities being targeted are iron ore, gold, uranium, base metals, and nickel.
- The average gold price in 2009–10 increased by 25% (in US$ terms) compared to 2008–09. The gold industry in Western Australia is emerging from the shadow of the iron ore exploration industry and topped $100 million for the June 2010 quarter, reaching $109 million. This is the highest level of quarterly expenditure since 1998. This upward trend is likely to continue throughout 2010–11.
- The discovery of Doolgunna has boosted exploration for copper in Western Australia, which reached $15 million for the June quarter — probably an all-time record.
- Exploration expenditure for nickel in Western Australia is recovering from the disastrous effects triggered by the fall in nickel price in 2008–09. In 2009–10, nickel exploration expenditure was $195 million, but this is still well below the peak level of $295 million in 2007–08.
- Uranium exploration expenditure in Western Australia totalled $55 million in 2009–10 and is the highest since 1980 (in 2009–10 dollar terms).

During the last decade, the proportion of the world's non-ferrous mineral exploration expenditure in Australia has dropped from 19% to 13% (Fig. 3, based on data compiled by the Metals Economics Group of Halifax, Canada, <www.metalseconomics.com>), of which Western Australia's share has dropped from 11% to 4%. This decline for Western Australia is partly attributable to growth in exploration in iron ore in recent years, rather than the move of exploration activity offshore. The sharp decline from 2002 in both Western Australia and Australia appears to show little signs of recovery although there was a slight positive trend in 2008. The Canadian share of world's non-ferrous mineral exploration expenditure appears to have also decreased in 2009 to 16%. These trends suggest that Canada and Australia will continue to lose their dominance of the world's non-ferrous mineral exploration expenditure while the shares of other countries improve. Western Australia is actively working towards improving its competitiveness to attract

Overview

investment, including investment in greenfields exploration, by programs such as the Exploration Incentive Scheme (EIS). For more details on the scheme see Ellis (2010a,b).

Developments and mineral exploration highlights by commodity

During 2009–10, exploration for iron ore was again dominant (for the third year in succession) with 40% of the total, followed by gold, which increased to 28% of the total. These were followed by nickel and base metals whose share decreased to 21% of the total. Diamond exploration expenditure has dropped to less than 1% of the total (Fig. 4). The exploration expenditure trends for gold, iron ore, nickel, and base metals are shown in Figure 5.

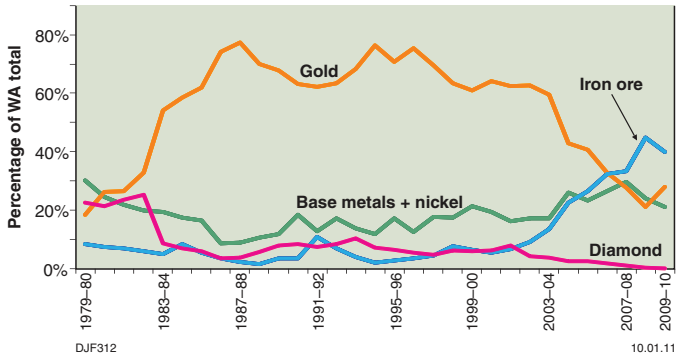


Figure 4. Exploration expenditure in Western Australia since 1979–80 (% of total, by commodity)

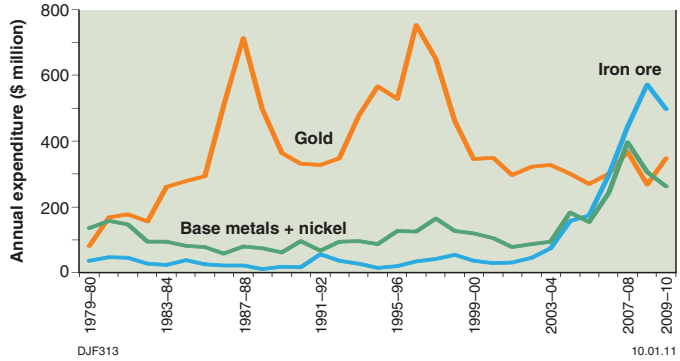


Figure 5. Gold, base metals + nickel, and iron ore exploration expenditure in Western Australia since 1979–80 (2009–10 dollars)

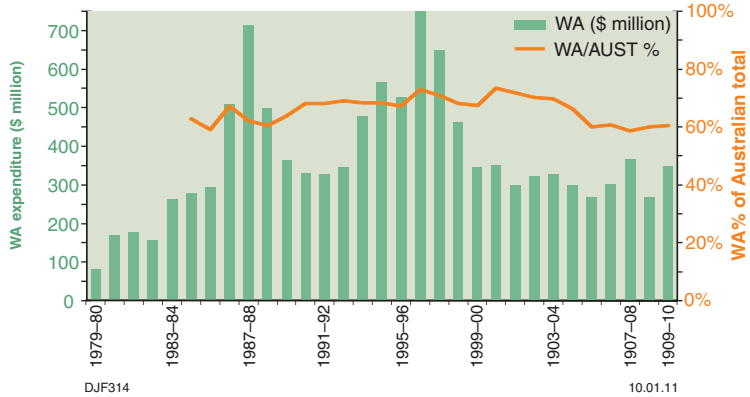


Figure 6. Gold exploration expenditure in Western Australia since 1979–80 (2009–10 dollars)

Gold

Trends in the gold industry in Western Australia during 2009–10 include:

- The international gold price, in Australian dollar terms, rose (6%), from an average of $1171/oz in 2008–09 to an average of $1236/oz in 2009–10. In US dollar terms, the increase during the same period was 25% from US$874/oz to US$1091. This has been a big boost to gold exploration in Western Australia, but has been partly moderated by the strength of the Australian dollar (which approached parity with the US dollar in 2009–10).
- Gold production in Western Australia increased by 21% to 27 446 kg, and the value increased by 26% to $1.3 billion. The top eleven gold producing mines during 2009–10 were the Super Pit (Kalgoorlie), Telfer, St Ives, Sunrise Dam, Jundee, Boddington, Kanowna Belle, Higginsville, Agnew, Kundana East, and Paddington.
- Gold exploration expenditure in Western Australia in 2009–10 increased by 30% to $349 million, reversing the negative trend of the previous year (Fig. 6).

Major developments in the gold industry include:

- In October 2009, Newmont Mining Corporation poured its first gold at the redeveloped Boddington mine and trucked its first shipment of copper concentrate from the mine to Bunbury port. Boddington will join

an exclusive global list of 1 million ounce-plus gold mines and is set to become Australia's largest gold operation. The mine is expected to produce around one million ounces (Moz) of gold annually for the first five years. The mine holds gold reserves of 20.1 Moz and has an expected mine life of more than 24 years (Jacoby, 2009a; Miningnewspremium.Net, 2010a).

- Ramelius Resources Ltd reached a milestone in June 2010 by achieving 100 000 ounces production at Wattle Dam gold mine, 25 km southwest of Kambalda. The underground high-grade ore has averaged around 30 g/t in the first two years of production, making it the highest grade gold producing underground mine in Australia (Ramelius Resources Ltd, 2010).

- With its feasibility study nearing completion, AngloGold Ashanti Ltd has plans to develop the 5 Moz Tropicana project, 340 km northeast of Kalgoorlie, into production by 2013 (Jacoby, 2010a).

During 2009–10, a number of companies announced the start of new gold operations or their intention to start operations in the near future. These include:

- Catalpa Resources Ltd had its first pouring of gold from its Edna May gold mine at Westonia in April 2010. Total measured, indicated, and inferred resource of the project is estimated at 52.1 Mt at 0.99 g/t Au for 1.656 Moz of contained gold. Of this the proved and probable reserves are estimated at 29.6 Mt at 1.06 g/t Au for 1 Moz of contained gold (Catalpa Resources Ltd, 2010a,b).

- A1 Minerals Ltd had the first gold pour in early March 2010 from its BrightStar project, 35 km southeast of Laverton. The company aims to produce 30 000 oz gold per annum over four years, based on gold resources of 1.7 Moz and reserves of 150 000 oz (A1 Minerals Ltd, 2009, 2010).

- Navigator Resources Ltd acquired the Bronzewing operation from View Resources in late 2009 and then announced pouring of the first gold in April 2010. The company has increased the resource at Bronzewing, and as at June 2010 resources were estimated at 13.65 Mt at 2.1 g/t Au for 946 000 oz of contained gold (Jacoby, 2009b; Navigator Resources Ltd, 2010; Batten, 2010a).

- Saracen Mineral Holdings Ltd poured the first gold bar in late January 2010 from its Carosue Dam operation near Laverton. The company hopes to produce 100 000–120 000 oz per annum (Saracen Mineral Holdings Ltd, 2010a,b).

- La Mancha Resources Inc. has poured the first gold from its White Foil openpit gold mine, 20 km west of Kalgoorlie. The company is on track to produce 13 000–16 000 oz gold for 2010 and is expected to produce 76 000 oz gold over its 27-month phase-1 mine life (Batten, 2010b).

- Focus Minerals Ltd recommissioned the Three Mile Hill gold treatment plant at its Tindals Mining Centre, near Coolgardie. The company aims to produce 80 000 oz gold in 2010 and more than 100 000 oz from 2011 onwards (Focus Minerals Ltd, 2010a).

- Integra Mining Ltd began construction at the Randalls gold project, 55 km east-northeast of Kambalda. The first phase of production at a rate of 90 000 oz per annum gold is due to start in September 2010 and phase 2 will see production rise to 100 000 oz per annum and then to 140 000 oz per annum (Integra Mining Ltd, 2010a,b).

- Avoca Resources Ltd remained confident that its goal of producing a total of 400 000 oz per annum from Higginsville and South Kalgoorlie by the 2013 financial year is achievable. The total measured, indicated, and inferred resources of Higginsville, South Kalgoorlie, and Frog Leg deposits are estimated at 85 Mt at 2.4 g/t Au for 6.7 Moz of contained gold (Avoca Resources Ltd, 2010).

On the resources side, a number of companies announced significant increases in the gold resources of their projects. These include:

- Apex Minerals NL announced a revised indicated and inferred mineral resource of 8.03 Mt at 6.6 g/t Au for 1.6 Moz of gold for its Wiluna mine (Apex Minerals NL, 2009).

- Korab Resources Ltd announced an increase of the global resource of the Melrose project, 95 km northeast of Leinster. The total measured, indicated, and inferred resource of the project consisting of Boundary, Bungarra, and Stirling deposits increased by 11% to 6.57 Mt at 1.61 g/t Au for 339 975 oz (Korab Resources Ltd, 2010).

Overview

- Australian Mines Ltd announced an increase of gold resources at the Mount Martin mine, 30 km southeast of Kalgoorlie, by about 50% to a total indicated and inferred resource of 4.67 Mt at 2.19 g/t Au for 328 000 oz (Australian Mines Ltd, 2010).

- Reed Resources Ltd announced an increase in gold resources at its Sand Queen gold mine, 100 km north of Kalgoorlie, to a total indicated and inferred resource of 534 000 t at 10.8 g/t Au for 186 000 oz of gold (Reed Resources Ltd, 2010a).

- Focus Minerals Ltd announced a maiden total indicated and inferred resource of 182 000 t at 3.7g/t Au for 21 600 oz for the Tindals deposit, and also updated indicated and inferred resources for the Cyanide project near the Tindals Mining Centre to 672 000 t at 5.5 g/t Au for 117 800 contained ounces. In addition, Focus Minerals announced a maiden probable reserve of 68 000 t at 8.6 g/t Au for 19 200 oz for the Mount deposit, about 80 km south of Tindals Mining Centre (Focus Minerals Ltd, 2010a,b,c,d).

In the exploration sector, a number of companies reported impressive gold intersections from various projects throughout Western Australia. These include:

- At the Wilber – Andy Well prospect, 45 km north-northeast of Meekatharra, Doray Minerals Ltd reported impressive gold intersections of 12 m at 21.47 g/t from 16 m, 8 m at 62.53 g/t from 60 m (including 4 m at 120.71 g/t from 60 m) — all in the same drillhole. Another drillhole intersected 9 m at 42.97 g/t from 45 m (including 3 m at 114.51 g/t from 48 m). Diamond drilling confirmed these with similar intersections (Doray Minerals Ltd, 2010a,b).

- Southern Gold reported multiple wide gold intersections at the Cannon and Georges Reward prospects at the boundary of the Bulong South project, 30 km southeast of Kalgoorlie. These include 66 m at 2.9 g/t Au (including 21 m at 4.5 g/t Au from 36 m) in hole BNRC057, 43 m at 3.4 g/t Au from 99 m in hole BNRC010. More high-grade intersections at Cannon prospect include 20 m at 4.75 g/t gold from 60 m in hole BSRC095 (including 4 m at 11.24 g/t Au from 63 m) (Southern Gold Ltd, 2009, 2010).

- Drilling at the Handpump prospect, 75 km east of Warburton, has confirmed the existence of a new gold mineralized system in the west Musgrave Province. Among the results are 15 m at 2.3 g/t Au from 31 m, (including 5 m at 4.7 g/t Au from 34 m), 7 m at 1.4 g/t from 3 m, and 11 m at 1.1 g/t from 24 m (Beadell Resources Ltd, 2010).

- At the Barlee gold project, about 140 km east of Paynes Find, Beacon Minerals Ltd had impressive gold intersections of 14 m at 45.32 g/t Au from 86 m (including 6 m at 102.66 g/t from 87 m) in one hole with another hole intersecting 10 m at 18.47 g/t Au from 69 m, including 4 m at 41.38 g/t Au from 71 m (Beacon Minerals Ltd, 2009a,b).

- Regis Resources Ltd had impressive intersections of 73 m at 3.61 g/t Au from 51 m and 69 m at 4.26 g/t Au from 42 m at the Garden Well prospect at the Duketon Gold project, 80 km north of Laverton (Regis Resources Ltd, 2009).

- Renaissance Minerals Ltd discovered shallow gold mineralization in its first drillhole at Mount Rankin, 15 km southwest of Southern Cross. The hole intersected multiple zones of gold, including 30 m at 1.08 g/t Au from 71 m (Renaissance Minerals Ltd, 2010).

- Drilling by Integra Mining Ltd at the Salt Creek deposit of the Randalls gold project, 55 km east-northeast of Kambalda, returned impressive intersections of 5 m at 129 g/t Au from 16 m (including 1 m at 627 g/t Au from 16 m) and 26 m at 2.13 g/t Au from 1 m. At Maxwell deposit (part of the same project) intersections include 4.6 m at 21.36 g/t Au from 189 m and 2.95 m at 39.29 g/t Au from 221 m (Integra Mining Ltd, 2009a, 2010b).

- Integra Mining Ltd reported 20 m at 1.58 g/t Au from 190 m in a diamond drillhole at KZ5 prospect in the Aldiss project, 90 km east-northeast of Kambalda (Integra Mining Ltd, 2009b).

- Integra Mining also made a gold discovery at their Majestic prospect, 45 km northeast of Kambalda, with intersections of 198 m at 1 g/t Au from 24 m to end of hole, including 20 m at 5.79 g/t Au from 104 m. Another hole, at the same prospect, intersected 64 m at 1.3 g/t Au (Integra Mining Ltd, 2010c).

- Convergent Minerals Ltd reported intersections of 12 m at 5.5 g/t Au from 168 m (including 1 m at 41.4 g/t from 176 m) in one hole and 6 m at 6.02 g/t Au from 182 m in another hole at the Blue Vein deposit, part of the Bounty gold project, 80 km south of Marvel Loch (Convergent Minerals Ltd, 2009).

- At Craiggiemore gold project near Laverton, Crescent Gold Ltd had intersections of 26 m at 9.6 g/t Au from 30 m in hole CMRC319, and 17 m at 4.3 g/t Au from 5 m in CMRC313, and 11 m at 5.1 g/t Au from 43 m in hole MMSRC089 (Crescent Gold Ltd, 2010a,b).

- Drilling by Silver Lake Resources Ltd at the Daisy Milano underground mine of the Mount Monger operation, about 35 km northeast of Kambalda, returned an intersection of 1.1 m at 680 g/t Au from 136 m, which includes 0.2 m at 3531 g/t Au (Silver Lake Resources Ltd, 2010; Batten, 2010c).

- Resource drilling at Edna May mine near Westonia returned 41.55 m at 1.5 g/t Au from 231.95 m, 53.4 m at 3.02 g/t Au from 182.9 m, and 70.1 m at 1.4 g/t Au from 210 m (Catalpa Resources Ltd, 2009).

- Anglo Australian Resources NL reported intersections of 6 m at 10.03 g/t Au including 2 m at 25.69 g/t Au at Dalray prospect near Feysville project, 25 km southeast of Kalgoorlie (Anglo Australian Resources NL, 2010a).

- Multiple gold zones were intersected in drillholes outside and adjacent to the current Golden Eagle proposed pit, 10 km south of the township of Nullagine. These include 8 m at 9.32 g/t Au from 45 m, including 1 m at 65 g/t Au, and 6 m at 7.28 g/t Au from 92 m, including 1 m at 16 g/t Au from 93 m (Millennium Minerals Ltd, 2010).

- Diamond drilling at Tregurtha and Hughes prospects of the Mount Jewell project, 60 km north of Kalgoorlie, extended the depth of gold mineralization. At the Tregurtha prospect, intersections include 20.35 m at 1.71 g/t Au from 159.2 m and 22.2 m at 1.95 g/t Au from 80.5 m, and at Hughes intersections include 11 m at 1.23 g/t Au from 159 m (Pioneer Resources Ltd, 2009).

- Drilling by Corvette Resources Ltd at the Stingray prospect of the Plumridge project, 60 km south of the 5 Moz Tropicana project, returned impressive intersections of 3 m at 40.33 g/t Au from 97 m at Camaro prospect and 8 m at 10.0 g/t Au from 119 m at Stingray (Corvette Resources Ltd, 2009).

- Independence Group reported multiple intercepts in single drillholes at the Boston Shaker prospect, 0.5 km northeast of the 5 Moz Tropicana project. Intersections include 12 m at 4.9 g/t Au from 93 m and 16 m at 3.5 g/t Au from 119 m in hole TFRC3294, as well as 5 m at 3.9 g/t Au from 48 m and 17 m at 3.0 g/t Au from 58 m in hole TFRC3293 (Independence Group NL, 2010a).

- At the Boudie Rat pit of the Quinns project, 90 km northwest of Menzies, Wild Acre Metals Ltd had gold intersections of 8 m at 7.36 g/t Au from 113 m and 2 m at 3.81 g/t Au from 68 m (Wild Acre Metals Ltd, 2010).

- Drilling by Pacrim Energy Ltd at the Golden Terrace deposit of the Redcliffe Gold project, 40 km north-northeast of Leonora, returned 69 m at 5.03 g/t Au including 15 m at 10.05 g/t Au and 35 m at 5.48 g/t Au (Pacrim Energy Ltd, 2009).

- Dourado Resources Ltd reported drill intersections of 14 m at 1.83 g/t from 29 m, 6 m at 12.23 g/t from 54 m, and 13 m at 3.17 g/t from 45 m at the Sabbath deposit, 10 km north-northwest of Meekatharra (Dourado Resources Ltd, 2010).

- Drilling by Hannans Reward Ltd at the Sunday deposit, 80 km east of Leonora, returned intersections of 4 m at 16.68 g/t Au including 1 m at 78.97 g/t Au (Hannans Reward Ltd, 2009).

- Eleckra Mines Ltd reported impressive intersections of 3 m at 136 g/t Au from 192 m (including 1 m at 404 g/t Au from 192 m) and 1 m at 105 g/t Au from 104 m at the Central Bore prospect of the Yamarna gold project, 140 km east-northeast of Laverton (Eleckra Mines Ltd, 2010).

- Alchemy Resources Ltd reported intersections of 18 m at 5.25 g/t Au from 5 m, 33 m at 2.78 g/t Au from 91 m, and 22 m at 2.07 g/t Au from 27 m at the Wilgeena deposit, 15 km east-southeast of Peak Hill (Alchemy Resources Ltd, 2010).

Overview

Iron

Highlights in Western Australia during 2009–10 include:

- Iron ore production from Western Australia increased by 25% (79.5 Mt) to 396 Mt, but the value virtually remained unchanged at $33 billion, reflecting lower unit prices following the global financial crisis.
- Western Australian iron ore exploration expenditure peaked in 2008–09, and dropped by 13% (to $497 million) in 2009–10, but at that level is still the second highest on record (Fig. 7).
- Iron ore exploration in Western Australia attracts the highest expenditure of any mineral commodity, and since 2007–08 has surpassed gold exploration expenditure (Figs 4, 5), accounting for 40% of the total exploration dollars spent in Western Australia. About 215 companies are currently exploring for iron ore in Western Australia.
- Numerous mines, targeting zones of supergene enrichment, were either being developed or were at an advanced feasibility stage. Mine development work for the State's first two magnetite projects — Cape Preston and Karara — has also commenced.
- Following several years of intense capital investment in project expansion in the Pilbara, Western Australia's iron ore production is likely to increase significantly over the next 5 to 10 years.
- Overseas companies (predominantly Chinese) continued to greatly increase their direct ownership or involvement (e.g. through long-term off-take agreements) in the Western Australian iron ore industry, with all seeking to secure long-term supplies.

Companies exploring for iron ore in Western Australia continue to target numerous mineralization styles, including: channel iron deposits (CID); supergene-enriched hematite over Archean (Marra Mamba) to Paleoproterozoic (Brockman) banded iron-formations (BIF); primary magnetite in BIF (taconite ores) of the Pilbara and Yilgarn Cratons; titanomagnetite in cumulate-layered mafic–ultramafic intrusives (e.g. at Balla Balla in the Pilbara Craton); magnetite in BIF within the Mesoproterozoic gneiss terrane of the Albany–Fraser Orogen

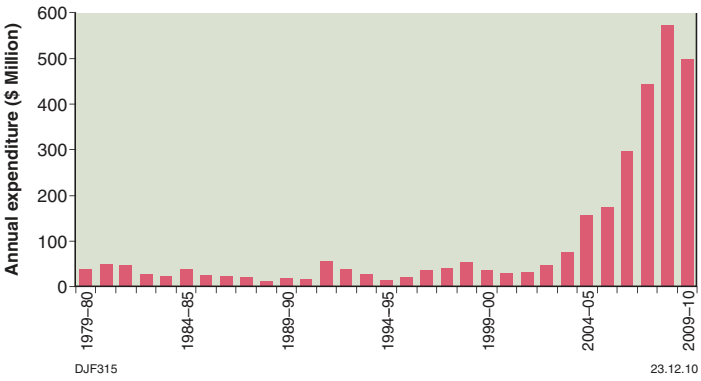


Figure 7. Western Australian iron ore exploration expenditure (2009–10 dollars)

(Southdown and Splinter); clastic hematite in Paleoproterozoic–Mesoproterozoic sedimentary rocks of the Kimberley Basin (Cockatoo Island, Koolan Island, and Irvine Island); hematite iron ore mineralization in the Midwest region; and granular iron-formation deposits in the Paleoproterozoic Earaheedy and Yerrida Basins. There was ongoing interest by numerous companies in primary magnetite mineralization within BIF horizons throughout the Yilgarn Craton, with this now even extending into the Eastern Goldfields Superterrane at Norseman and even east of Kalgoorlie at Steeple Hill. In addition, the northern edge of the Yilgarn Craton attracted interest too, with magnetite schists at Beyondie within the Marymia Inlier.

The unprecedented iron ore boom of the past three years continued but at a less frantic pace. The major producers in the Pilbara are still expanding their existing operations and planning new projects, whereas junior companies were still willing to explore in undeveloped and greenfields areas.

Major developments in the iron ore sector include:

- BHP Billiton Ltd's expanded Newman mining hub was officially opened in November 2009 and this will continue to be the centre of its iron ore mining, crushing, and screening activities in the eastern Pilbara region. BHP's Mount Whaleback iron ore operation will now be equipped to mine, crush, and screen the ore onsite, rather than at Port Hedland, before the product is shipped. BHP Billiton has also allocated US$1.93 billion (A$2.2 billion) in funding to expand its iron ore operations in the Pilbara. This represents initial expenditure for the Rapid Growth project 6, which is expected to increase capacity at BHP's Western Australian iron ore assets to 240 Mt a year in 2013 (Jacoby, 2009c, 2010b).

- Rio Tinto Ltd will increase the capacity of Cape Lambert port to 180 Mt by 2016 from its current 80 Mtpa rate. This will be achieved through the construction of a new 1.8-km jetty and four-berth wharf that will run parallel to the existing jetty (Winter, 2010; Rio Tinto Ltd, 2010a).

- Rio Tinto started producing iron ore from the Mesa A/Warramboo mine, near Pannawonica, in February 2010. The mine will have an initial production of 20 Mtpa increasing to 25 Mtpa by 2011 and has reserves totalling 249 Mt of pisolite (CID) ore, giving the project an 11-year mine life (Rio Tinto Ltd, 2010b; Batten, 2010d).

- Under an agreement with the Western Australian government, BHP Billiton and Rio Tinto will pay higher royalties for all their Pilbara iron ore production from the start of July 2010. This removes some concessionary rates that BHP Billiton and Rio Tinto have enjoyed since the early State Agreement Acts were first negotiated in the 1960s and 1970s, and brings those producers into line with the royalty rates applicable in later State Agreements and the Mining Act 1978. About 40% of the Western Australian production for 2009–10 enjoyed concessionary royalty rates. Royalty rates for these early State Agreement projects will change from 3.75% to 5.625% for fine ore and to 7.5% for lump ore (Jacoby, 2010c).

- Fortescue Metals Group Ltd's mining operations at Cloudbreak and Christmas Creek, situated about 50 km apart in the Chichester Ranges in the Pilbara region, were progressing satisfactorily. The expansion of the Chichester Hub was in full swing with the commissioning of the Christmas Creek plant scheduled for March quarter 2011 (Fortescue Metals Group Ltd, 2009, 2010a,b).

Developments in the direct shipping ore (DSO) projects include:

- Atlas Iron Ltd shipped over 1 Mt of iron ore in its maiden year of operations at the Pardoo DSO project, 115 km east of Port Hedland. The ore was shipped through Fortescue Metals Group's Port Hedland port facility (Atlas Iron Ltd, 2009).

- Atlas Iron has also begun mining at the Wodgina DSO iron ore project, 110 km south of Port Hedland, and is now on target to achieve a combined rate of 6 Mtpa from its Wodgina and Pardoo DSO mines (Atlas Iron Ltd, 2010a,b).

- Mount Gibson Iron Ltd announced the recommencement of construction and development work at its Extension Hill DSO project, 65 km southwest of Paynes Find. Construction and development is scheduled to be completed by the first half of 2011, incurring $80 million of capital expenditure. The company has executed life-of-mine sales agreements with each of Shougang Concord International Enterprises Company and APAC Resources for all the production from Extension Hill (Mount Gibson Iron Ltd, 2010).

- Full-scale mining has begun at the Sinosteel Corporation's Koolanooka – Blue Hills project, 165 km east-southeast of Geraldton, and the first hematite DSO (from Koolanooka) was shipped from Geraldton in mid-2010. Sinosteel plans production of 1 Mt during calendar year 2010, rising to 1.5 Mtpa in 2011, with a seven-year mine life (Miningnews.Net, 2010; Jacoby, 2010d).

- Gindalbie Metals Ltd finalized a second long-term off-take contract with Ansteel covering the life-of-mine hematite production from the Karara project (95 km south of Yalgoo), which is scheduled to start in mid-2011 at a rate of 3 Mtpa (Gindalbie Metals Ltd, 2010a).

- At the Spinifex Ridge iron ore project, 50 km northeast of Marble Bar, mining of hematite DSO began with the aim of shipment by December 2010. The deposit is estimated to contain a probable reserve of 4.334 Mt at 59.2% Fe, 1.8% Al_2O_3, 8% SiO_2, 0.13% P, 122 ppm S, with 4.9% LOI, which is derived from an indicated resource of 5.31 Mt at 58.4% Fe, 1.6% Al_2O_3, 9.3% SiO_2, 0.145% P, 122.7 ppm S, with 4.7% LOI. In addition, the deposit has an inferred resource of 2.3 Mt at 57.92% Fe, 0.8% Al_2O_3, 13.4% SiO_2, 0.114% P, 52 ppm S, with 2.8% LOI (Moly Mines Ltd, 2010a).

Developments in the magnetite sector include:

- CITIC Pacific Ltd has begun development activities for production of iron ore from the huge magnetite deposit (greater than 2 billion tonnes (Bt) of resources) of the Sino Iron project at Cape Preston in the Pilbara. The openpit mine is expected to be 5.5 km long,

3 km wide, and eventually 600 m deep. The project will have the capacity to produce 28 Mtpa of magnetite concentrate for over 25 years. Project construction is estimated to cost about $5 billion. The infrastructure requirements related to the project are massive and include development of a new port (Cape Preston), power station (450 MW, powered by gas from the Reindeer field), and a desalination plant with a capacity of 51 GL H_2O per annum. The construction workforce is about 4500 people, whereas the operational workforce will be about 850 people (CITIC Pacific Ltd, 2010a,b).

- Gindalbie Metals announced the finalization of a long-term off-take contract with its joint venture partner, Ansteel, covering the life-of-mine production from the Karara iron ore project, 95 km south of Yalgoo. The contract is valued at more than US$65 billion, and covers the total magnetite concentrate production from the Karara operations. Stage One production, based on a rate of 8 Mtpa of magnetite concentrate, is scheduled to be commissioned in late 2011. Capital development costs total about $2 billion (Gindalbie Metals Ltd, 2010b).

- Grange Resources Ltd's Southdown magnetite project near Albany has taken a major step towards construction after the project received conditional environmental approval from the Western Australian Government for the mine and associated infrastructure. The project received another boost after Grange secured a 25% increase in interim pricing for its iron ore pellets and received notification of Commonwealth approval for the Albany port expansion (Jacoby, 2009d; Miningnewspremium.Net, 2010b).

- Crosslands Resources, joint venture owner of Jack Hills project, 140 km west-northwest of Meekatharra, has secured non-binding Letters of Intent from north Asian steel mills to purchase more than 50 Mtpa of magnetite and hematite concentrate products from the Jack Hills Expansion project (Murchison Metals Ltd, 2010a).

A number of companies in Western Australia have either announced maiden resource estimates or upgraded existing resources. Some of these include:

- The resources at Fortescue Metals Group Ltd's Solomon Hub deposits in the Pilbara region increased to 2.8 Bt at 56.3% Fe. This includes Brockman mineralization at Firetail, CID and colluvial–detrital iron deposits at Kings, and predominately CID deposits at Serenity (Fortescue Metals Group Ltd, 2010b,c).

- The proved and probable ore reserves of the Balla Balla magnetite project, 5 km west of Whim Creek, have grown from 207 Mt to 238 Mt (at 44.7% Fe, 0.62% V_2O_5, and 3.7% TiO_2), with more than 79% being classified in the proved ore reserve category (Aurox Resources Ltd, 2009a).

- The total measured, indicated, and inferred resource at Jack Hills, 140 km west-northwest of Meekatharra, increased to 3 Bt at 31.7% Fe, more than 67% of which is in the measured and indicated categories (Murchison Metals Ltd, 2009).

- The total inferred mineral resource of the Hardstaff Peninsula iron ore deposit on Irvine Island, 135 km north of Derby, has increased to 294 Mt based on updated resource estimates for both the Yampi Member and Wonganin Sandstone. The Yampi Member is estimated to contain an inferred resource of 90 Mt at 46% Fe, 32.4% SiO_2, 0.68% Al_2O_3, 0.12% S, and 0.02% P, whereas the Wonganin Sandstone is estimated to contain an inferred resource of 204 Mt at 23% Fe, 59% SiO_2, 3.94% Al_2O_3, 0.1% S, and 0.03% P (Pluton Resources Ltd, 2010).

- A maiden resource of 143 Mt at 52.6% Fe (55.6% calcined iron) has been estimated for the Winmar iron ore deposit, 35 km west-southwest of Wittenoom (Cazaly Resources Ltd, 2010).

- Giralia Resources NL announced an upgraded inferred resource of 161.4 Mt at 56.2% Fe, 6.3% SiO_2, 2.6% Al_2O_3%, with 9.6% LOI for the McPhee Creek Main Range deposit, 37 km north of Nullagine (Giralia Resources NL, 2009, 2010a).

- A maiden inferred mineral resource of 13.3 Mt at 56% Fe, 7% SiO_2, 4% Al_2O_3, 0.06% P, 0.2% S, 0.13% TiO_2, with 7% LOI has been estimated for the Jabiru prospect, at the Mount Padbury project, 110 km north-northwest of Meekatharra (Montezuma Mining Company Ltd, 2010a).

- Flinders Mines Ltd has increased its resources at the Pilbara Iron Ore project in the central Pilbara from 550.1 Mt at 55.6% Fe to

658.3 Mt at 55.4% Fe, which consists of an indicated resource of 156.6 Mt at 56.5% Fe and an inferred resource of 501.7 Mt at 55.0% Fe (Flinders Mines Ltd, 2010a).

- A maiden inferred resource of 453 Mt at 23.1% Fe (no cutoff), 37% SiO_2, 15.8% Al_2O_3, 0.04% P, with 8.7% LOI has been estimated for the Spearhole channel iron deposit at Prairie Downs, 50 km west-southwest of Newman (Dynasty Metals Australia Ltd, 2010).

- Midas Resources Ltd reported a maiden indicated resource of 11.5 Mt at 53.1% Fe, 0.042% P, 7.75% SiO_2, 5.57% Al_2O_3, with 9.86% LOI (50% Fe cutoff grade) for its West Pilbara deposit, 110 km west of Tom Price (Midas Resources Ltd, 2010).

- Warwick Resources Ltd estimated a maiden inferred resource of 19.1 Mt at 55.1% Fe, 6.6% SiO_2, 4.1% Al_2O_3, 0.06% P, with 9.3% LOI for the Western Creek iron ore project near Newman. The resource includes a DSO component of 10.8 Mt at 58% Fe (Warwick Resources Ltd, 2009a).

- Golden West Resources Ltd reported an upgraded measured, indicated, and inferred resource of 141.1 Mt 58.77% Fe, 0.06% P, 2.81% Al_2O_3, 8.67% SiO_2, with 3.82% LOI for the Wiluna West hematite project (Golden West Resources Ltd, 2009).

- Atlas Iron Ltd estimated a maiden inferred resource of 20.8 Mt at 57.1% Fe, 6.6% SiO_2, 2.6% Al_2O_3, 0.07% P, 0.03% S, with 8.5% LOI for the Wishbone deposit at the Warrawanda project, 50 km southeast of Newman (Atlas Iron Ltd, 2010c).

- Giralia Resources estimated a maiden inferred resource of 186.8 Mt at 30.9% Fe for the Yerecoin magnetite project, 120 km north-northeast of Perth (Giralia Resources NL, 2010b).

- Iron Ore Holdings Ltd announced a maiden inferred resource of 23.4 Mt at 58.5% Fe for its Fingers deposit at Koodaideri South, 45 km southeast of Wittenoom (Iron Ore Holdings Ltd, 2010).

- Macarthur Minerals Ltd released an initial inferred mineral estimate of 4.4 Mt at 54.2% Fe, 0.067% P, 10.65% SiO_2, 4.89% Al_2O_3, with 7% LOI for its Banjo and Moonshine North DSO iron ore project located at Lake Giles, about 100 km west-southwest of Menzies (Macarthur Minerals Ltd, 2010).

In addition to the above resource estimates, some of the other iron ore exploration successes include:

- Significant intersections of massive hematite from exploration drilling at the Brindal prospect, 2.5 km south of the main Jack Hills orebody, 140 km west-northwest of Meekatharra. Intersections include 100 m at 67.5% Fe from 62 m in hole MHRC1120, 72 m at 68.5% Fe from 58 m in hole MHRC1043, and 64 m at 68.3% Fe from 50 m in hole MHRC1006 (Murchison Metals Ltd, 2010b).

- Atlas Iron discovered the new DSO prospect, Hercules, at its Wodgina operation, 110 km south of Port Hedland. Drill intersections include 52 m at 59.5% Fe from surface in hole WDRC1446 and 46 m at 59.3% Fe from 2 m in hole WDRC1506. The company has also had significant intersections at Dragon (70 m at 59.7% Fe from surface in hole WDRC1221) and Avro (38 m at 59.9% Fe from 34 m in hole WDRC1451) prospects of the same project (Atlas Iron Ltd, 2010d).

- Warwick Resources Ltd (now part of Atlas Iron) reported significant intersections including 42 m at 60.1% Fe from 44 m depth from step-out drilling at the Wishbone deposit of the Warrawanda project, 50 km southeast of Newman (Warwick Resources Ltd, 2009b).

- Hemisphere Resources Ltd obtained significant intersections including 16 m at 58.2% Fe, 5.08% SiO_2, 2.96% Al_2O_3, 0.06% P, with 7.67% LOI at Yandicoogina South prospect, 6 km south of Rio Tinto's Yandicoogina iron ore mine (Hemisphere Resources Ltd, 2010).

- Hawthorn Resources Ltd reported significant intersections of magnetite mineralization including 70 m at 35.9% Fe from 36 m and 62 m at 38.7% Fe from 28 m at Mount Bevan, 100 km west of Leonora (Hawthorn Resources Ltd, 2010).

- Flinders Mines Ltd announced high-grade intersections outside the current resource boundary at Delta (South Pilbara iron ore project). Intersections include 42 m at 58.8% Fe from 2 m, 24 m at 58.3% Fe from surface, 30 m at 59.2% Fe from 6 m (Flinders Mines Ltd, 2010b).

Overview

Nickel

Broad trends for the nickel industry in Western Australia during 2009–10 include:

- The international nickel price in 2009–10 increased (25%) to an average of $21 984/t from an average of $17 626/t in 2008–09.
- Recovery of the nickel price led to an increase (by 36%) in the value of nickel production from Western Australia to $4.1 billion in 2009–10, although the production quantity decreased marginally (<1%) to 177 thousand tonnes (kt) of contained nickel.
- Recovery of the nickel price is leading to the re-opening of a number of nickel sulfide as well as nickel laterite mining operations. However, many of the nickel mines that were put on care and maintenance during the global financial crisis are yet to be re-opened.
- Nickel exploration expenditure in Western Australia decreased by 23% to $195 million, relative to the previous year (Fig. 8).

Key points in the nickel sulfide sector include:

- Western Areas NL announced the first shipment of nickel concentrate to China from Flying Fox and Spotted Quoll – Tim King Pit mines at Forrestania. Production at Flying Fox began in December 2007 and that from Spotted Quoll – Tim King Pit began in late 2009. During 2009–10, both mines performed beyond expectations (Western Areas NL, 2010a).
- During the 2010 March quarter, the first development ore from the Lounge Lizard nickel deposit was mined. A total of 2295 t at 3.7% Ni was treated through the Cosmic Boy treatment plant and sold to Western Areas (Kagara Ltd, 2010a).
- Mincor Resources NL re-opened the Miitel mine, 40 km south-southwest of Kambalda, and discovered the N10 and N29 orebodies. Mincor has also identified significant new mineralized channels at the South Miitel deposit, the Burnett Zone at the North Miitel deposit, and a new ore shoot 'Terrace Surface' at the Mariners mine (about 5 km south of Miitel), immediately south of the newly discovered N10 orebody (Mincor Resources NL, 2009, 2010).
- In July 2009, Independence Group announced a maiden indicated resource of 401 00 t at

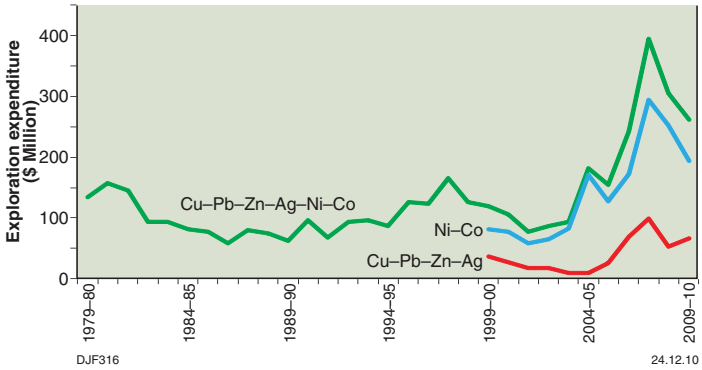


Figure 8. Western Australian nickel, cobalt, and base metal exploration expenditure (2009–10 dollars)

6.9% Ni and an inferred resource of 55 000 t at 8.3% Ni for the Moran deposit. Mine development has begun with first ore mined at a head grade of 4.6% Ni in the June 2010 quarter (Independence Group NL, 2009, 2010b).

- Nickel sulfide, copper, and PGE mineralization has been discovered at Rosie Prospect (2.5 km southwest of the initial Bulge C2 discovery), 120 km north-northwest of Laverton. Intersections include: 41 m at 0.44% Ni, 0.18% Cu, 623 ppb Pt, and 447 ppb Pd from 40 m in hole TBAC126; 60 m at 0.52% Ni, 619 ppm Cu, 102 ppb Pt, and 110 ppb Pd from 36 m in hole TBAC127; and 20 m at 1.32% Ni, 0.23% Cu, 1.54 g/t Pt+Pd from 184 m in hole TBRC070 (South Boulder Mines Ltd, 2009, 2010).
- High nickel, copper, and platinum–palladium values were returned in eight drillholes at the Olympia prospect of the Collurabbie project, about 200 km north of Laverton. Intersections include 2.74 m at 2.03% Ni, 1.06% Cu, 2 g/t Pt+Pd from 218.6 m in hole CLD196; 5.32 m at 1.05% Ni, 0.89% Cu, 1.74g/t Pt+Pd from 226.27 m in hole CLD199; and 3.82 m at 1.74% Ni, 1.05% Cu, 2.37 g/t Pt+Pd from 153.88 m in hole CLD1202 (Falcon Minerals Ltd, 2010).
- The Western Areas and Troy Resources NL joint venture discovered a number of nickel mineralized zones in a greenfields area about 20 km south-southeast of Sandstone. Drilling returned 26.2 m at 0.4% Ni from 60.3 m, including a narrow interval of semi-massive sulfide that analysed 0.2 m at 4.1% Ni from 86.3 m (Western Areas NL, 2010b).
- Western Areas reported an intersection of 88.3 m (true width 20–30 m) 200 m north

and below the New Morning deposit at Forrestania, which consists of several zones of disseminated and localized stringer sulfides separated by bands of granite and footwall sedimentary rocks from 868.4 m. Preliminary Niton (portable XRF analyser) estimates returned spot values up to 2% Ni for the disseminated sulfides and peak values up to 6% Ni and 3% Cu for the stringer sulfides (Western Areas NL, 2010c).

Key points in the nickel laterite sector include:

- First Quantum Minerals plans to re-open the Ravensthorpe operation in the first half of 2011, which was put on care and maintenance by BHP Billiton in January 2009. This will be followed by a nine-month ramp-up to the nominal production capacity of 39 000 tpa nickel (Miningnewspremium.Net, 2010c).

- The total combined resource base of the Kalgoorlie Nickel project of Heron Resources Ltd was updated to a total estimated measured, indicated, and inferred resource of 959 Mt at 0.74% Ni and 0.045% Co (7.1 Mt of contained nickel metal, 0.43 Mt of contained cobalt metal). Heron is currently identifying potential partners (Heron Resources Ltd, 2009, 2010).

- Metals X Ltd is reviewing funding options and opportunities for the development of the Wingellina project, which is one of the largest undeveloped nickeliferous limonite accumulations in the world. The deposit is estimated to contain a total measured, indicated, and inferred resource of 183.2 Mt at 0.98% Ni and 0.08% Co (Metals X Ltd, 2008, 2010).

- Norilsk's Cawse nickel laterite operation, 50 km northwest of Kalgoorlie, which was put on care and maintenance during the global financial crisis, is yet to be re-opened.

Base metals (copper–lead–zinc–silver)

Broad trends in the base metal sector in Western Australia during 2009–10 include:

- Copper–lead–zinc–silver exploration expenditure in the State increased by 25% from $54 million in 2008–09 to $67 million in 2009–10 (Fig. 8, 2009–10 dollars).

- There were significant increases in base metal prices in 2009–10 compared to 2008–09, with copper, lead, and zinc increasing by 18% (to $7568/t), 23% (to $2371/t), and 26% (to $2340/t) respectively.

- Copper production in the State in 2009–10 increased by 17% (from 127 328 t in 2008–09 to 148 553 t in 2009–10). The value increased by 74% to $1137 million. The increased copper production was due to increased output from the major producers — Nifty and Telfer mines (in the Paterson Orogen) and Golden Grove (Yilgarn Craton). The new Boddington gold–copper mine (Yilgarn Craton) also had significant production, with more than 15 000 t of copper contained in concentrates.

- Lead production in the State marginally increased (3%), from 25 203 t in 2008–09 to 25 918 t in 2009–10. The Magellan lead mine that was put on care and maintenance in April 2007 re-started in early 2010. The only other producing lead mine was Golden Grove. The value of lead production from Western Australia increased by 41% to $59 million.

- Zinc production in the State decreased by 40% (from 142 062 t in 2008–09 to 85 532 t in 2009–10) and the value of production decreased by 12% to $202 million. The production decrease was due to the closure of the Pillara mine and to decreased zinc production at Golden Grove.

Sandfire Resources NL continued to have exploration successes at its Paleoproterozoic volcanogenic massive sulfide (VMS-style) Doolgunna copper–gold project, 60 km east of Peak Hill. The discovery of DeGrussa, Conductor 1, and other deposits in the Doolgunna project in mid-2009, is the best base metal discovery in Western Australia in recent times. In early 2010, Sandfire published maiden resources for the DeGrussa and Conductor 1 deposits, which were then updated in July 2010 along with a maiden resource for the Conductor 4 deposit. As at July 2010, the total indicated and inferred resources of all these deposits are estimated at 9.62 Mt at 5.5% Cu, 1.8 g/t Au, and 14 g/t Ag for 533 000 t of contained copper, 559 000 oz of contained gold, and 4.3 Moz of contained silver. The company has also discovered Conductor 5 (Sandfire Resources NL, 2010a,b).

Other key points for base metal projects in Western Australia include:

- Ivernia Inc. re-commenced lead mining at Magellan and expects to produce 60 000 t

contained lead in concentrate in 2010. From 2011 onwards, the company plans to process 1.9 Mtpa of ore producing on average approximately 85 000 tpa of contained lead in concentrate (Ivernia Inc., 2010).

- The Boddington gold–copper operation, which began production in December 2009, was performing well. The production of copper and gold until the end of June 2010 amounted to 15 768 t and 464 000 ozs respectively (Newmont Mining Corporation, 2010a,b,c).
- In December 2009, Venturex Resources Ltd announced a maiden resource for the Evelyn deposit of the Liberty–Indee base metals project, 30 km south of Whim Creek. The total indicated and inferred resource was estimated at 708 000 t at 1.9% Cu, 3.6% Zn, 0.35 g/t Ag and 0.8 g/t Au (Venturex Resources Ltd, 2009).
- In late 2009 Fox Resources Ltd announced plans to return to nickel and copper production at Radio Hill, 35 km south of Karratha. The company is currently developing a base metals heap-leaching operation with the aim of establishing an initial five-year mine life, with commissioning expected in early 2011 (Fox Resources Ltd, 2010a).
- Fox Resources also announced a positive preliminary economic evaluation of its Sholl B2 deposit, 6 km north of Radio Hill in the Pilbara. Sholl B2 is a key contributor to Fox's developing heap-leach operation. The new evaluation highlighted a potential mine life of 10 years at Sholl B2 and Radio Hill (Fox Resources Ltd, 2010b).
- A scoping study by CBH Resources Ltd of the Panorama project in the Pilbara shows that it is possible to have an economically viable underground operation producing total contained metals of 185 000 t zinc, 70 000 t copper, and 880 000 oz silver during an initial mine life of around seven years (CBH Resources Ltd, 2009).
- Minerals and Metals Group (MMG) has plans to develop an openpit at its existing underground mining operations at Golden Grove. The openpit is expected to produce around 240 000 t of copper concentrate containing 59 000 t of contained copper metal in concentrate from 2011–14 (Jacoby, 2010e).
- Jabiru Metals Ltd approved the development of the Bentley mine, 48 km north-northwest of Leonora. The VMS deposit is estimated to contain a total indicated and inferred resource of 1.698 Mt at 1.9% Cu, 12% Zn, 0.8% Pb, 0.8 g/t Au, and 148 g/t Ag. The first ore is expected to be produced in late 2011 (Jabiru Metals Ltd, 2009, 2010).
- Silver Swan Group Ltd reported a maiden total measured, indicated, and inferred resource of 1.484 Mt at 1.02% Cu, 1.39% Zn, 0.24 g/t Au, and 3.51 g/t Ag for the VMS Quinns–Austin deposit, 60 km south-southwest of Meekatharra. Further significant intersections, such as 58 m at 2.0% Cu, 0.42 g/t Au, and 8.6 g/t Ag from 148 m, have been reported since the maiden resource announcement (Silver Swan Group Ltd, 2010a,b).
- Meridian Minerals Ltd has updated the total measured, indicated, and inferred resource of the Lennard Shelf project to 13.2 Mt at 6.3% Zn and 3.8% Pb. The deposits include Kapok, Cadjebut, Palijippa, Kultarta, Fossil Downs, and Napier Range. The viability of recommencing mining at Kapok is being examined (Meridian Minerals Ltd, 2010).
- Kagara Ltd completed a pre-feasibility study for its Admiral Bay project in the Canning Basin and has confirmed that it is a world-class project, with the potential to become one of the largest producers of lead and zinc in the world. The company is now planning a bankable feasibility study estimated to cost $184.5 million that will include sinking an exploration shaft to 1428 m to drill a 1.2 km section of the deposit to reserve status. The Admiral Bay deposit has an inferred resource of 72 Mt at 3.1% Zn, 2.9% Pb, and 18 g/t Ag (Kagara Ltd, 2008, 2010b).
- Ethan Minerals Ltd has estimated a total indicated and inferred resource of 394 419 t at 6.5% Pb for the Mary Springs deposit (50 km east of Kalbarri) in the Northampton Complex (Ethan Minerals Ltd, 2010).

Other highlights in the base metals exploration sector include:

- The first hole in the infill program at Mons Cupri pit intersected 53 m at 1.7% Cu and 23.2 g/t Ag from 40 m in hole MCR001, and the vertical diamond hole MCD001 intersected 39.4 m at 2.8% Cu and 1.61 g/t Au from 33 m, including an upper zone of 18 m at 5.0% Cu and 3.39 g/t Au. The mineralized

intersection confirms continuity of a high-grade copper–gold zone in the upper part of the Mons Cupri VMS system (Venturex Resources Ltd, 2010a,b).

- At Salt Creek VMS deposit, 17 km northwest of Whim Creek, high-grade lenses of massive sulfide were intersected, including 20 m at 16.8% Zn, 6.9% Pb, and 180 g/t Ag. In the eastern massive sulfide lens, diamond hole SCD005 intersected 3.45 m at 49.2% Zn, 7.1% Pb, 327 g/t Ag, and 4.1 g/t Au from 107.95 m and diamond hole SCD009 intersected 4.75 m at 47.8% Zn, 8.7% Pb, 294 g/t Ag, and 0.9 g/t Au from 72.4 m (Venturex Resources Ltd, 2010c,d).

- Ashburton Minerals Ltd reported encouraging wide copper intersections in a remote greenfields area at Pokali prospect of the Mount Webb project, in the Arunta Orogen. These include 246 m at 0.22% Cu from 4 m (including 12 m at 1.1% Cu from 168 m) and 299 m at 0.10% Cu from surface. The mineralization is thought to be of iron oxide–copper–gold (IOCG) type (Ashburton Minerals Ltd, 2010).

- Drilling by Redstone Resources Ltd at Tollu, in another remote greenfields area in the Musgrave Province, has returned impressive copper intersections. These include 17 m at 2.2% Cu from 145 m and 14 m at 3.5% Cu from 126 m. The mineralization is interpreted to be related to a large nickel–copper sulfide system (Redstone Resources Ltd, 2010a,b).

- Thundelarra Exploration Ltd reported impressive copper intersections at the Red Bore prospect, 2 km east of the DeGrussa deposit, in the Bryah Basin. These include 7 m at 7.25% Cu from 20 m. In addition, analysis of drill cuttings with a hand-held XRF analyser produced significant intercepts including 18 m at 8.37% Cu from 29 m. The VMS mineralization is associated with mafic volcaniclastic rocks of the Narracoota Formation (Thundelarra Exploration Ltd, 2010).

- Drilling by Anglo Australian Resources NL at the VMS Sandiego deposit of the Koongie Park project, 25 km southwest of Halls Creek, continued to produce spectacular copper–zinc–silver–gold intersections including 71 m at 5.04% Cu, 7.69% Zn, 68 g/t Ag, and 0.43 g/t Au and 56 m at 3.7% Cu, 9.26% Zn, 33 g/t Ag, and 0.49 g/t Au (Anglo Australian Resources NL, 2010b).

- RC drilling by Jindalee Resources Ltd at Bow River, 80 km south of Kununurra, yielded encouraging copper intersections including 2 m at 1.4% Cu from 108 m, 5 m at 1.3% Cu from 123 m, and 2 m at 1.9% Cu from 126 m (all in hole BRRC011), as well as 3.8% Cu from 81 m and 1 m at 1.2% Ni from 88 m in hole BRRC012 (Jindalee Resources Ltd, 2010).

- Rock-chip sampling at the Speewah project, about 85 km south-southwest of Wyndham, returned significant assays of copper, gold, silver, and lead. These include 16.5% Cu and 138 g/t Ag at the Eiffler prospect and 8.26% Cu, 4.28 g/t Au, 786 g/t Ag, and 1.25% Pb at the Grey's Vein prospect. The mineralization at Eiffler prospect is associated with malachite-rich, strongly sheared and altered wall rock quartz vein and that of Grey's Vein prospect is associated with quartz veins containing azurite, malachite, galena, and sphalerite (NiPlats Australia Ltd, 2010a).

Diamond

Diamond production (more correctly sales production rather than mine production) in Western Australia in 2009–10 increased to 16.3 Mct (million carats), which is a significant increase of 77% compared to the 2008–09 production (global financial crisis low) of 9.2 Mct. However, the large increase in weight of production only led to a smaller increase in value of diamond sales, which rose by only 16% to $304 million, as a result of only a slow recovery in unit prices. A considerable portion of these sales were from stock as mine production totalled only about 11.1 Mct, with mine production at both Argyle and Ellendale falling during 2009–10 (see below).

The diamond exploration expenditure for Western Australia in 2009–10 was not released by the Australian Bureau of Statistics (ABS), but is estimated by us at about $4 million. This represents a fall of about 20% ($1 million) from the estimated $5 million spent in 2008–09 (Fig. 9, in 2009–10 dollars). Diamond exploration expenditure is now less than 1% (Fig. 4) of the total Western Australian mineral exploration expenditure. This is the eighth year in a row that diamond expenditure in Western Australia has declined (now at its lowest level in 30 years), reflecting the general lack of exploration success and hence investor interest

Overview

and the now more-cautious spending behaviour of consumers, with the luxury markets hard hit by the global financial crisis.

Rio Tinto owns and operates the Argyle diamond mine in Western Australia. Mine production for 2009–10 decreased to 10.91 Mct from the 14.72 Mct produced in 2008–09. Production at Argyle during 2009–10 has been low due to the global financial crisis in 2009 that severely affected demand for rough diamonds — which is highly reliant on the US economy. This led Rio Tinto to slow down the transition to underground mining at Argyle and also to suspend the surface operations for 12 weeks. First production from the underground operation is now expected in 2012. However, Rio Tinto is of the view that the medium- to long-term fundamentals for the diamond industry are positive with an anticipated material supply shortfall that will drive future price growth (Rio Tinto Ltd, 2010b,c,d,e).

Gem Diamonds Ltd, a global diamond company, acquired the Australian-listed Kimberley Diamonds in December 2007. Kimberley owned the Ellendale mine, 135 km east-southeast of Derby. The mine production of diamond from Ellendale in 2009–10 decreased by 56% to 194 274 carats compared to the 2008–09 production of 442 651 carats. There was a significant reduction in the scale of operations due to the placing of the E4 operation on care and maintenance. In addition, the plant availability and rain hampered plant throughput from March to June 2010. In the latter part of 2009, Kimberley Diamonds formalized an existing supply arrangement with Laurelton Diamonds Inc. (the diamond sourcing and polishing subsidiary of Tiffany & Co.) for the supply and sale of its yellow diamond production from the Ellendale mine. Effective from December 2009, the agreement will run for the economic life of the Ellendale mine (Gem Diamonds Ltd, 2010a,b).

In September 2009, Blina Diamonds NL discontinued mining activities at Ellendale 9 until diamond prices improve (Blina Diamonds NL, 2009).

Heavy minerals (Ti–Zr and garnet)

The production of heavy mineral sands (garnet, ilmenite, rutile, leucoxene, and zircon) in Western Australia in 2009–10 decreased by 10% to 981 278 t, with the value decreasing by 23% to $342 million.

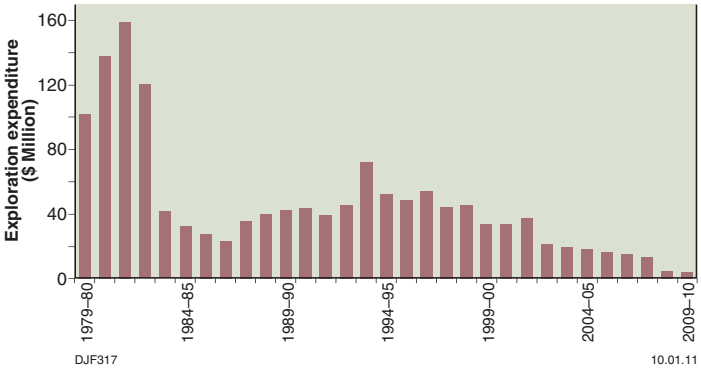


Figure 9. Western Australian diamond exploration expenditure (2009–10 dollars)

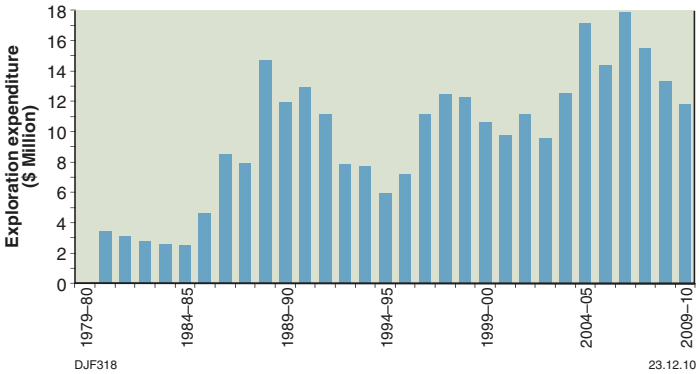


Figure 10. Western Australian heavy mineral sands (Ti–Zr) exploration expenditure (2009–10 dollars)

In 2009–10, exploration expenditure in Western Australia for heavy minerals decreased by 11% to $12 million (Fig. 10). With the switch in exploration focus to the eastern Eucla Basin and the Murray Basin in Australia's eastern states in the mid-1990s, Western Australia's share of Australian exploration expenditure for heavy minerals fell from nearly 69% of the total in the mid-1990s to only 29% in 2002–03. There was a noticeable recovery in Western Australia's share in 2008–09 to 42.5% with a marginal decrease in 2009–10 to 41.7%.

In early 2010, Iluka Resources Ltd, the market leader of the heavy mineral sands industry in Western Australia, confirmed its decision to shut its remaining Mid West mining operations in June 2010 and replace them with production from the Jacinth–Ambrosia mine in South Australia. The Narngulu mineral separation plant, near Geraldton in Western Australia, is being upgraded to enable it to receive and process heavy mineral concentrate (HMC) from South Australia. In the South West of Western Australia, Iluka's mining operations ceased at Waroona in late 2009 and the North Capel Separation Mill and Capel Dry Plant are now idle pending the commencement of mining at the

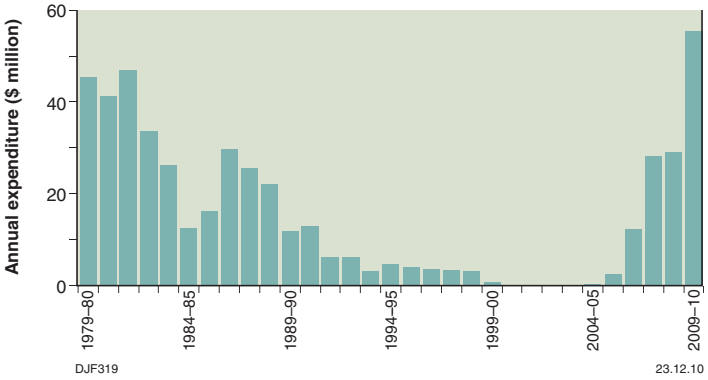


Figure 11. Uranium exploration expenditure in Western Australia since 1979–80 (2009–10 dollars)

Tutunup South project in 2010 (Iluka Resources Ltd, 2009, 2010a,b).

Other highlights in 2009–10 in the heavy minerals sector include:

- Image Resources NL has estimated an initial resource of 148 Mt at 1.5% heavy minerals (HM) (0.75% HM cut-off), containing 445 kt of zircon and 189 kt of rutile and leucoxene for the Cyclone Extended deposit of the Serpentine Lake project in the Eucla Basin. The Cyclone and Cyclone Extended deposits have low clay (slimes) contents making them amenable to low-cost conventional mineral sands mining techniques. Combined with the contiguous Cyclone deposit held by Diatreme Resources Ltd, Image estimated a global resource containing 2434 kt of zircon and 990 kt of rutile and leucoxene, with a 0.75% HM cutoff (Image Resources NL, 2010a).
- Diatreme Resources has signed a Memorandum of Understanding with BaoTi Group Ltd, based in Shaanxi Province, Central China, for potential development of the Cyclone deposit (Diatreme Resources Ltd, 2010).
- Image Resources is also actively exploring for HM in the North Perth Basin and currently has identified a total inferred resource of 6.4 Mt of HM. The company has also discovered a 16 km-long high-grade HM target zone at Gingin and aircore drilling within this zone has produced significant HM intersections (Image Resources NL, 2009, 2010b).
- Gunson Resources Ltd announced that several parties have expressed interest in a partnership for the Coburn zircon project, 230 km north of Geraldton. A definitive feasibility study on the project suggested positive economics and a potential mine life of more than 20 years (Gunson Resources Ltd, 2010a,b).

Uranium

The pro-uranium policy of the State Government continues to have a positive effect on the exploration expenditure for uranium in the State. Expenditure that had been negligible in the period from 2001 to 2006, increased by a further 91% to $55 million in 2009–10 and there have now been five years of successive increases in uranium exploration expenditure (Fig. 11). The expenditure now is at a level not experienced since at least 1979–80, that is, since the ABS started compiling commodity-specific exploration expenditure statistics.

Highlights in 2009–10 in the uranium sector include:

- BHP Billiton released a Public Environmental Scoping Document in early 2010 on the proposed Yeelirrie uranium mine and a pre-feasibility study is in progress. The scoping document outlined a planned mine life of 30+ years producing 3500 tpa of U_3O_8 concentrate. About 5 Mtpa of ore and waste would be mined by conventional openpit methods, and alkaline tank leaching was preferred over heap leach. Construction may commence in 2013, with construction and operational workforces of about 650 and 300 people, respectively. Vanadium may not be recovered. The work currently underway includes resource definition drilling, test work, process-plant concept design, environmental impact assessment, capital and operating costing, and economic evaluation. The indicated resource estimated for the deposit is old, dating back to at least 2001 when WMC Ltd owned the deposit, and is 35 Mt at 1.5 kg/t U_3O_8 for 52.5 kt of contained U_3O_8. However, BHP Billiton's proposed production is far in excess of the old resource estimate; a new resource estimate is imminent (WMC Ltd, 2002; BHP Billiton Ltd, 2010).
- A bankable feasibility study for Toro Energy Ltd's Lake Way project near Wiluna is underway and the company plans project commissioning and production of uranium by 2013. The project has estimated measured, indicated, and inferred resources totalling

Overview

20.21 Mt at 548 ppm U_3O_8 for 11.0 kt of contained U_3O_8 (Toro Energy Ltd, 2010a).

- Cameco Corporation plans to negotiate an agreement with the Martu people (the native land title holders for the Kintyre mine area) for the development of the Kintyre mine, 75 km south-southwest of Telfer. The company also plans to complete drilling and prepare a fresh resource estimate for the Kintyre deposit, conduct metallurgical testing to define the milling process, and begin a prefeasibility study. The historical indicated and inferred resource estimate (CRA brochure in 1990) totalled 23.3 Mt at 1.5 kg/t U_3O_8 for 35 kt of contained U_3O_8 (Cameco Corporation, 2010).
- A scoping study for the recovery of uranium from lignite- and sandstone-hosted material at the Mulga Rock deposits has yielded positive results. The test work demonstrated that reasonably high uranium extraction rates can be achieved using conventional commercially proven processing methods. The Mulga Rock deposits are estimated to contain 55.4 Mt at 0.49 kg/t U_3O_8 for 27.1 kt of contained U_3O_8 (Energy and Minerals Australia Ltd, 2010a,b).
- Mega Uranium Ltd released the Environmental Scoping Document for the Lake Maitland uranium project (95 km north-northeast of Leinster) for public review. The project has an anticipated mine life of 10 years, producing up to 1000 tpa of uranium peroxide concentrate. The deposit is estimated to contain a total indicated and inferred resource of 31.2 Mt at 0.37 kg/t U_3O_8 for 11.4 kt of contained U_3O_8 (Mega Uranium Ltd, 2009, 2010).
- Energia Minerals Ltd announced a maiden inferred resource estimate of 12.2 Mt at 280 ppm U_3O_8 for 3.4 kt (7.46 Mlb) of contained U_3O_8 for the Carley Bore deposit, within the Nyang uranium project, 174 km north of Gascoyne Junction. The mineralization is interpreted to be roll-front type associated with sandstone (Energia Minerals Ltd, 2010).

Highlights for greenfields exploration include:

- Scout drilling by Mindax Ltd along paleochannels on the Yilgarn Craton near Mukinbudin, 200 km northeast of Perth, has intersected economic grades of roll-front type uranium mineralization. The significant intercepts in the Jindarra area include 1 m at 1690 ppm U (equivalent to 0.20% U_3O_8) from 37 m in hole YAA0184 and 3 m at 1243 ppm U (equivalent to 0.15% U_3O_8) from 38 m in hole YAA0188. The Jindarra target area is approximately 2 km long and up to 300 m wide and contains consistent uranium mineralization in two horizons at 35 m and 60 m depths (Mindax Ltd, 2009, 2010).
- Toro Energy Ltd discovered uranium mineralization at the remote Theseus prospect of the Lake Mackay project in the Arunta Orogen. The drilling intersections include 6 m at 216 ppm U_3O_8 and 2 m at 646 ppm U_3O_8 (Toro Energy Ltd, 2010b).
- In the Tanami region (stretching 100 to 250 km southeast of Halls Creek) exploration is increasing at and near some old prospects known from the early 1970s. Prospects include Killi Killi, Gardiner Range, and Birrindudu. These occur at or near the unconformity between the basal Paleoproterozoic Granites–Tanami Complex and overlying flat-lying sandstones of the Mesoproterozoic Birrindudu Basin. Companies exploring these targets include Toro Energy in joint venture with Cameco Corporation, Orion Metals Ltd, Northern Uranium Ltd, Manhattan Corporation Ltd, and Quantum Resources Ltd.
- In the East Kimberley region:
  - U3O8 Ltd explored for uranium and rare earths at Mad Gap, about 70 km northwest of Halls Creek, where the basal Brown Sandstone unit of the O'Donnell Formation unconformably overlies older metamorphic rocks and the Whitewater Volcanics.
  - Kimberley Mining Pty Ltd and Pegasus Metals Ltd are exploring for uranium and gold–tin–tantalite–tungsten–molybdenum mineralization associated with skarn, pegmatite, and radioactive granite of the eastern zone of the Lamboo Complex, about 80 km southwest of Halls Creek.

Other commodities

Exploration expenditure for other mineral commodities in Western Australia in 2009–10 has decreased by 11% to $65 million. 'Other commodities' include all industrial minerals, alumina, construction materials, platinum group elements (PGE), molybdenum, tantalum, lithium, manganese, chromium, vanadium, rare earth elements (REE), and coal–lignite. Activities

during 2009–10 were mainly focused on rare earth elements, molybdenum, vanadium, manganese, tungsten, lithium, and coal.

Rare earth elements

In the REE sector, construction work on the concentration plant and tailings storage facility at the Mount Weld rare earth project, 18 km southeast of Laverton, recommenced in April 2010 and the first ore feed is expected in late 2010. Phase 1 of the project will produce approximately 11 000 tpa of rare earth oxide (REO), with plans to increase the capacity to approximately 22 000 tpa of REO by 2013. The Central Lanthanide Deposit sector of the Mount Weld project is estimated to contain a total measured, indicated, and inferred resource of 12.24 Mt at 9.7% REO for 1184 kt of REO (Lynas Corporation Ltd, 2010a,b).

Molybdenum

Moly Mines Ltd announced a US$700 million (A$780 million) debt and equity funding deal with Hanlong Mining Investment, a subsidiary of China-based Sinchuan Hanlong Group Co., for the Spinifex Ridge molybdenum–copper project, 50 km northeast of Marble Bar. Discussions are still continuing and there is a possibility that the project will start soon. The deposit is estimated to contain proven and probable reserves of 450.8 Mt at 0.05% Mo, 0.08% Cu, and 1.3 g/t Ag for contained metal values of 218 000 t of molybdenum, 368 000 t of copper, and 18.6 Moz of Ag (Moly Mines Ltd, 2009, 2010b).

Vanadium

In the vanadium sector, a number of companies' plans to develop projects were deeply affected by the global financial crisis in late 2008 and early 2009. The main highlight for the year was the ongoing successful exploration at Speewah in the Kimberley, with its huge increase in estimated resources. The Speewah mineralization is now Western Australia's largest vanadium resource, and within Australia it is second only to the Julia Creek vanadiferous oil shale in Queensland. The main activities in the vanadium sector were:

- NiPlats has estimated a measured, indicated, and inferred resource of 3.16 billion tonnes grading 0.3% V_2O_5, 2% Ti, and 14.8% Fe for its Speewah vanadium deposit, about 85 km south-southwest of Wyndham, confirming it as Australia's largest hard-rock vanadiferous titanomagnetite deposit. The company is carrying out metallurgical and feasibility studies for a potential openpit with downstream processing of the vanadium into vanadium pentoxide and ferrovanadium (NiPlats Australia Ltd, 2010b).
- In April 2010, Atlantic Ltd agreed to acquire the Windimurra vanadium project, 75 km east-southeast of Mount Magnet. Atlantic will procure a full funding package for completion and commissioning of the project and will raise up to $55.6 million. The Windimurra deposit is estimated to contain measured, indicated, and inferred resources totalling 177 Mt at 0.46% V_2O_5 (Windimurra Vanadium Ltd, 2009; Atlantic Ltd, 2010).
- In 2009, Reed Resources completed a definitive feasibility study aimed at establishing a vanadium mine at Barrambie, 65 km north of Sandstone. The company is continuing to investigate various project development alternatives and strategies. The deposit is estimated to contain indicated and inferred resources totalling 65.2 Mt at 0.82% V_2O_5. Based on the existing resources, the Barrambie vanadium processing plant and associated infrastructure will target a throughput of 3.2 Mtpa of vanadium-bearing magnetite at a grade of 0.82% V_2O_5 to produce 7700 tpa of ferrovanadium for a minimum period of 12 years (Reed Resources Ltd, 2009, 2010b).
- Investigations by Aurox Resources Ltd show that 7000 t of ferrovanadium could be produced annually from 1.75 Mtpa of titanomagnetite feed at the Balla Balla ferrovanadium project, 10 km northwest of Whim Creek. The ferrovanadium plant could also produce 1 Mtpa of iron concentrate as a byproduct with grades over 61% Fe, which would be suited for blending with the iron concentrate produced from the proposed Balla Balla 10 Mtpa iron concentrate operation. Aurox Resources has now merged with Atlas Iron (Aurox Resources Ltd, 2009b, 2010).

Manganese

Manganese production from Western Australia (i.e. mostly from Woodie Woodie) fell sharply during the global financial crisis, but bounced back during 2009–10, increasing by 66% in quantity to 693 392 t of manganese concentrate and by 55% in value to $350 million.

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In the manganese sector there have been numerous exploration activities in diverse geological terranes, such as the Archean Pilbara and Yilgarn Cratons, the Proterozoic Manganese Group, and a number of Proterozoic Basins such as Edmund, Earaheedy, Collier, and Bryah. The main developments in the manganese sector were:

- Consolidated Minerals Ltd, the owner of Western Australia's largest manganese mine, plans to spend $40 million on the Woodie Woodie project in the Pilbara Craton, 105 km west of Telfer, because of increasing demand and higher prices for manganese (Consolidated Minerals Ltd, 2010).

- Mesa Minerals Ltd has received positive feedback from Chinese customers on the trial shipments of 42 009 t of high-grade manganese ore despatched from the Ant Hill mine in the Pilbara Craton, 400 km south of Port Hedland. The ore apparently exhibited excellent handling characteristics and good smelting performance. Mesa Minerals is ready to re-open the mine once final approvals are granted and joint venture issues are resolved. The mine has a total indicated and inferred resource of 4.9 Mt at 20.3% Mn, 25.4% Fe, and 19.8% SiO_2 (Mesa Minerals Ltd, 2010a,b).

- Jupiter Mines Ltd reported encouraging manganese intersections up to 49.6% Mn from its drilling in the Oakover area of the Manganese Group, about 100 km east of Newman (Jupiter Mines Ltd, 2010).

- Also from the Oakover area, 95 km east of Newman, Brumby Resources Ltd reported significant intersections from a number of prospects. At Sixty Six prospect there were intersections up to 27.75% Mn and at JI prospect up to 20.8% Mn. The company also reported nodular manganese intersections within a buried paleochannel at Ethel Creek, 80 km east of Newman (Brumby Resources Ltd, 2010a,b).

- Drilling by Shaw River Resources Ltd at the Baramine project, 80 km northwest of Woodie Woodie, led to identification of more manganese mineralization in Areas 1, 3, 4, and 5. Intersections include 6 m at 14% Mn from 16 m in Area 1, 5 m at 18.2% Mn from 48 m in Area 3, 8 m at 13% Mn from 36 m in Area 4, and 11 m at 10.6% Mn from one metre in Area 5. Mineralization is similar to that at Woodie Woodie, where manganese is hosted in Archean Carawine Dolomite and the Pinjian Chert Breccia (Shaw River Resources Ltd, 2010a).

- At Wandanya, 40 km southwest of Woodie Woodie, rock chips assaying up to 65% Mn have been found in northeast-trending outcrops. The geological sequence present at Wandanya is also considered to be similar to that at Woodie Woodie, with the Pinjian Chert Breccia and Carawine Dolomite present (Shaw River Resources Ltd, 2010b,c).

- Shaw River Resources has confirmed the presence of extensive manganese-rich laterite at 701 Mile project, 80 km south of Newman. The laterite lies alongside outcropping manganese-rich shales, with samples assaying up to 48.6% Mn. The company proposes to outline shallow free-dig manganese gravel suitable for simple beneficiation (Shaw River Resources Ltd, 2010b,c).

- Aurora Minerals Ltd continued to get high-grade manganese from its Capricorn Southeast project in the Edmund Basin. Rock-chip samples collected from various prospects had assays up to 59.1% Mn. The mineralization is associated with paleochannels at the base of the laterite and is also hosted by the Proterozoic Ullawarra Formation (Aurora Minerals Ltd, 2009a,b).

- Zinc Co. Australia Ltd reported assays up to 47% Mn from rock-chip sampling at the Lockeridge manganese prospect, 125 km north-northeast of Wiluna, in the Earaheedy Basin. The mineralization is hosted by the Karri Kari Member, a shale unit stratigraphically overlying the Frere Formation, both part of the Paleoproterozoic Earaheedy Group (Zinc Co. Australia Ltd, 2010a,b).

- General Mining Corporation Ltd reported assays up to 48.4% Mn from rock-chip sampling near the Shoemaker project area, 105 km northeast of Wiluna, also in the Earaheedy Basin. The sampling was in the Proterozoic Frere Formation (General Mining Corporation Ltd, 2010).

- An airborne reconnaissance sampling program by Shaw River Resources over a large area, some 200 to 300 km southeast of Onslow, has identified manganese-bearing horizons within the Proterozoic Ullawarra Formation. A peak assay of 33.8% Mn was returned from manganiferous shales and siltstones, which were

traced for more than 33 km of strike length (Shaw River Resources Ltd, 2010b).

- Montezuma Mining Company Ltd has identified manganese mineralization in a number of prospects at the Butcherbird project in the Collier Basin, 120 km south of Newman. The company considers Bindi Bindi Hill prospect of this project to be a significant discovery with a potential target of 10 to 20 Mt at between 8 and 12% Mn, where manganese appears to occur as high-grade lump. At the Bilby Hill prospect, rock-chip sampling indicates a new target area with samples assaying up to 45% Mn. Manganese mineralization in these prospects is associated with supergene weathering processes (Montezuma Mining Company Ltd, 2010b).

- A preliminary reconnaissance drill program at Horseshoe in the Bryah Basin had an intersection of 15 m at 32.15% Mn including 7 m at 47% Mn. The drilling has demonstrated the continuity of high-grade manganese and iron outcropping over a 4-km strike, and limited drilling has intersected significant widths of high-grade manganese under cover (Montezuma Mining Company Ltd, 2010c).

- In the Earaheedy Basin, samples from two sites in the Stanley project (170 km east of Wiluna), returned assays ranging from 23% Mn to 48% Mn. The samples are approximately 20 km apart, and in both localities samples are approximately 500 m up-dip from historical drill sites, which had reported intersections up to 4% Mn at shallow depths from 10-m composite samples. Mineralization is in thick carbonate units stratigraphically above the iron formations that occur near the base of the Proterozoic Frere Formation (AusQuest Ltd, 2010).

- Assay results of drill samples from the Wolfe project, 50 km southeast of Halls Creek, had anomalous manganese concentrations in 12 holes, with a best result of 3 m at 18.3% Mn. Average manganese values for the remaining 11 holes varied between 1% and 4% Mn. Mineralization is at the lower contact of the Proterozoic Eliot Range Dolomite and the underlying Proterozoic Mount Kinahan Sandstone (AusQuest Ltd, 2010).

Tungsten

Western Australia does not currently have any operating tungsten mines, but Hazelwood Resources Ltd moved a step closer to mining when it completed a pre-feasibility for the Big Hill deposit, 45 km northeast of Nullagine, and started a definitive bankable feasibility study. The deposit has measured, indicated, and inferred resources totalling 47.43 Mt at 0.1% WO_3 for 4.8 million metric tonne units. Of this 25.21 Mt at 0.11% WO_3 (for 2.8 million metric tonne units) are proven and probable reserves, which could support a 12-year operation. The deposit is apparently suited to low-cost openpit mining and gravity separation to recover high-purity tungsten concentrate (Hazelwood Resources Ltd, 2010a,b).

At the O'Callaghans polymetallic skarn deposit, 10 km south-southeast of Telfer, Newcrest Mining Ltd announced a total indicated and inferred resource of 78 Mt at 0.33% WO_3, 0.29% Cu, 0.50% Zn, and 0.25% Pb for contained metal values of 260 kt of WO_3, 220 kt of Cu, 390 kt of Zn, and 190 kt of Pb (Newcrest Mining Ltd, 2010).

Lithium

Galaxy Resources Ltd has commenced extracting ore from the Dowling pit, part of the Mount Cattlin spodumene project at Ravensthorpe. The company signed off-take agreements with Mitsubishi Corporation and thirteen major Chinese lithium-cathode producers for its battery-grade lithium carbonate product. These agreements equate to 100% of Galaxy's planned lithium carbonate production of 17 000 tpa and also includes supply of battery-grade product commencing in 2011. The total measured, indicated, and inferred resource of the Mount Cattlin project is estimated at 15.9 Mt at 1.08% Li_2O and 161 ppm Ta_2O_5 (Galaxy Resources Ltd, 2010a,b,c).

Reed Resources, together with Mineral Resources Ltd, is carrying out a pre-feasibility study to produce battery-grade lithium carbonate from lithium concentrates to be produced at the Mount Marion lithium project, 40 km south of Kalgoorlie. The joint venture hopes to produce 200 000 tpa of approximately 6.5% Li_2O concentrate with first shipment in 2011. The deposit is estimated to contain a total measured, indicated, and inferred resource of 10.5 Mt at 1.4% Li_2O for 146 500 t of contained Li_2O (Reed Resources Ltd, 2010c,d).

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Coal

Major headlines were made when The Griffin Coal Mining Co. Pty Ltd (one of the two operators in the Collie Basin) and some of its related entities, ran into financial difficulties and were placed under External Administration in January 2010. Power supplies to the State's South West region were threatened, but mining at Collie continued.

Production of coal during 2009–10 was 6.7 Mt, which was lower than the 6.9 Mt produced during the previous year. All of this production was by Wesfarmers and Griffin Coal from Collie. About 90% of Collie coal is used as thermal coal, mostly in power stations, and the majority of the remainder is used metallurgically (i.e. as a reducing agent) by the mineral sands industry to transform ilmenite to synthetic rutile. In 2007, Griffin Coal commenced trial export shipments, and up to June 2010 a total of 38 shipments had been made to India and China through the port of Kwinana.

A pre-feasibility study by Rey Resources Ltd on the Duchess–Paradise project, 135 km southeast of Derby, concluded that an initial operation producing 2 Mtpa of saleable thermal coal is the best and most financially robust approach to commercially develop the project. The deposit is estimated to contain measured, indicated, and inferred resources totalling 511 Mt of thermal coal. The company has commenced a definitive feasibility study. The plans are for the coal to be transported by road to Derby port and then shipped to markets in China or India. During the year, an attempted takeover of Rey Resources by Gujerat NRE Coke Ltd (of India) failed (Rey Resources Ltd, 2010a,b).

Drilling activity

The sharp decline in drilling activity throughout Australia in 2008–09 showed signs of recovery in 2009–10. The details are as follows:

- Metres drilled during 2009–10 in Australia increased by 5% (by 411 million metres) to a total of 8298 million metres (Fig. 12).
- However, the estimated mineral exploration drilling in Western Australia has decreased during 2009–10 by 3% (195 million metres) to a total of 5901 million metres (based on Western Australia's proportion of total Australian exploration expenditure for each year as the ABS does not release WA-specific data).

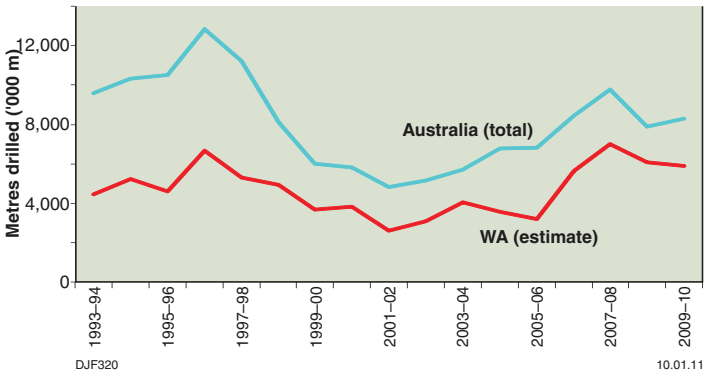


Figure 12. Mineral exploration drilling in Australia and Western Australia

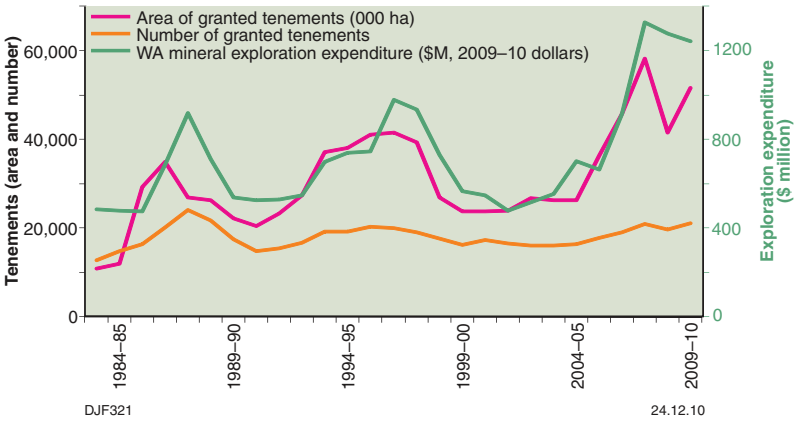
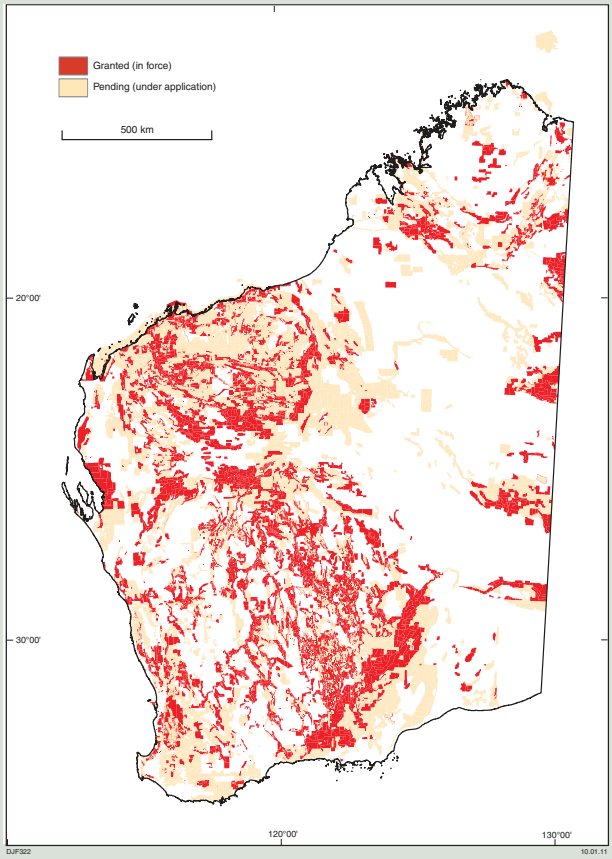


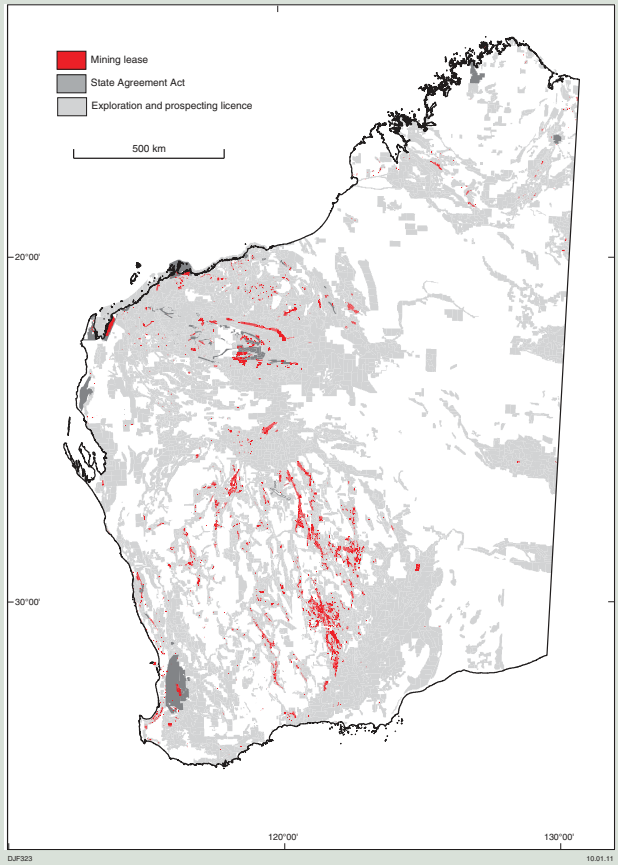
Figure 13. Trends in exploration expenditure and tenement activity (1904 and 1978 Mining Acts) since 1983–84 (source: Department of Mines and Petroleum)

- Mineral exploration drilling for new deposits in Australia increased by 12%, from 2710 million metres in 2008–09 to 3055 million metres in 2009–10.
- Mineral exploration drilling at existing deposits in Australia also marginally increased (2%), from 5167 million metres in 2008–09 to 5245 million metres in 2009–10.

Mining tenement activity

Tenement statistics demonstrate a recovery from the worst of last year's global financial crisis with a substantial increase in the number of granted Exploration Licences, area covered by granted Exploration Licences, and new (pending) applications for tenements. The number of granted Mining Leases increased only marginally. The details of these are:





- The increase in the number of granted tenements (in force) in Western Australia during 2009–10 was by 8% (1538) from a total of 19 594 in force at 30 June 2009 to 21 132 at 30 June 2010 (Fig. 13).
- The area, in million hectares, under granted tenure increased by 24% (10.2 Mha) from a total of 41.5 Mha at 30 June 2009 to 51.6 Mha at 30 June 2010 (Fig. 13).
- There was a significant increase in the number and the area of granted Exploration Licences — the number of granted ELs in force at 30 June 2010 increased by 29% (1183) and the area under tenure of granted ELs increased by 28% (9.7 Mha). The number and area held under all other tenement types over the year rose only marginally, by 2% and 6% respectively.
- Statistics for Mining Leases show a small increase in granted Mining Leases from 2008–09 to 2009–10, rising in number from 5525 to 5764 and in area under granted tenure from 2.03 Mha to 2.12 Mha.
- The number of applications received by the Department during the year for new tenements increased substantially (30%), from 3883 in 2008–09 to 5043 in 2009–10.

The distribution of tenements, both granted and under application at 30 June 2010, is shown in Figure 14. The distribution of Mining leases, Exploration and Prospecting licences (granted and under applications) and State Agreement Act areas is shown in Figure 15.

Figure 14. (above) Distribution of mining and exploration tenements, granted and pending, in Western Australia as at 30 June 2010

Figure 15. (left) Distribution of Mining leases, Exploration and prospecting licences (granted and pending) and State Agreement Act areas in Western Australia as at 30 June 2010

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History of 1:250 000 geological mapping of Western Australia

by Dennis Gee, John Blockley, and Peter Dunn (formerly GSWA)*

Preparing the way

The mission to complete the 1:250 000 geological mapping of Western Australia as part of a national program was a contest of will and endurance. As with any contest, one must specify the beginning, identify the finish line, approve of the participants, and agree the rules.

In 1911, well before the official starting gun, HWB Talbot began systematic mapping of the more remote regions of the State at a scale of 1 inch to 300 chains (Figs 2 and 3). Only geologists of a bygone era, and cricket-ground curators, will know that a chain is 22 yards, which is 792 inches. So Talbot's scale of 1:237 600 was close to destiny — an act of clairvoyance. One can presume he surveyed with compass, chain, and sextant. The Talbot team produced all or parts of 26 rectangles before he was unfortunately speared by Aboriginals, not fatally, but of sufficient seriousness for him to abandon the program.

Creation of the BMR

First impetus for systematic mapping came immediately after another significant skirmish — the creation of the Bureau of Mineral Resources (BMR) in 1946. Its mandate inter alia was to '*undertake in cooperation with State mining departments, geological surveys and other work associated with exploration*'. Major mapping campaigns, and indeed collaborative exploration with industry, began in the Canning and Carnarvon Basins in 1948. Such was the swiftness of this 'invasion', that Chief Government Geologist Matt Ellis sent a solitary graduate geologist to

Figure 1. Dennis Gee leading the Capricorn excursion (about 1978)

Figure 2. HWB Talbot in the field

* *Dennis Gee presented this paper as part of the Earth Science History session at the Australian Earth Sciences Convention 2010 in Canberra in July. The session provided an historical perspective of the first systematic geological-mapping program of the whole of Australia — a major scientific achievement. Dennis was appointed Supervising Geologist, Regional Mapping in 1972 and was Deputy Director, GSWA from 1984 to 1987. John Blockley was Supervising Geologist, Mineral Resources until his retirement in 1995. Peter Dunn was Assistant Director, Regional Geoscience Mapping Branch until he retired in 1995.*

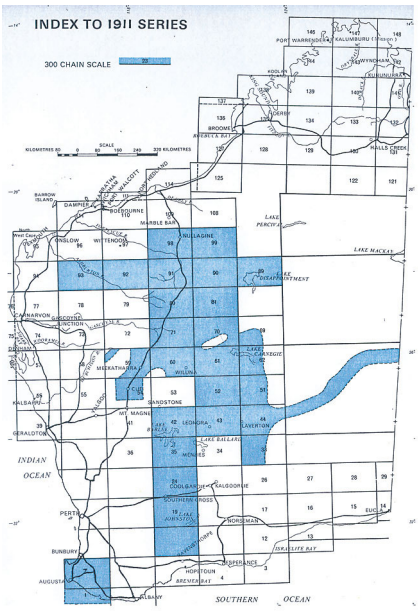

Figure 3. Index map of Talbot's map coverage at 1 inch to 300 chains

Exmouth to keep an eye on the BMR. Jack Sofoulis thereby became the first Geological Survey of Western Australia (GSWA) collaborator with BMR on a mapping program. No such embedded agents were provided for the BMR Canning Basin campaigns at this stage. Figure 4 shows Western Australia's geology before the onset of the series mapping.

State's rights

Over the ensuing decade, BMR published eight 1 inch to 4 mile sheets. Matt Ellis gave grudging acceptance to BMR mapping in the sedimentary basins, but mineral provinces were GSWA territory! Matt Ellis asserted that BMR knew nothing about minerals, and had no right to explore for minerals in a State jurisdiction that owned those minerals. BMR geologist Peter Dunn, after two field seasons mapping and exploring in the Northern Territory, was told by his then Chief Geologist Norm Fisher that his next year's assignment in 1956 would be mapping the Marble Bar and Nullagine sheets in Western Australia.

The response of Matt Ellis was swift. He despatched his geologists Jim Noldart and John Wyatt to Marble Bar and Nullagine, and Laurie de la Hunty to Balfour Downs, to instigate GSWA's own mapping campaigns. Thus began the first 1 inch to 4 mile regional mapping program by GSWA in its own right. The resulting 4-mile sheets were released in 1962 (Fig. 5a). At the same time, Jack Sofoulis was withdrawn from Exmouth and sent to Boorabbin to undertake the first 1:250 000 mapping by GSWA. Boorabbin was presumably chosen because of the great swathes of granite and sandplain which would expedite map production (Fig. 5b).

Joe Lord's influence

In 1961 incoming Director, Joe Lord, restructured GSWA into the Regional Mapping, Mineral Resources, Sedimentary, and Hydrology and Engineering Divisions, and a Common Services Division, which included services such as petrology, geophysics, paleontology, and technical information. He then deployed most geologists on regional mapping duties. Few were spared. This was the springboard for independent modern-era standard-series geological mapping in the Geological Survey. Excellent work was done in the Hamersleys, where geological teams coordinated by Bill MacLeod and guided by Alec Trendall

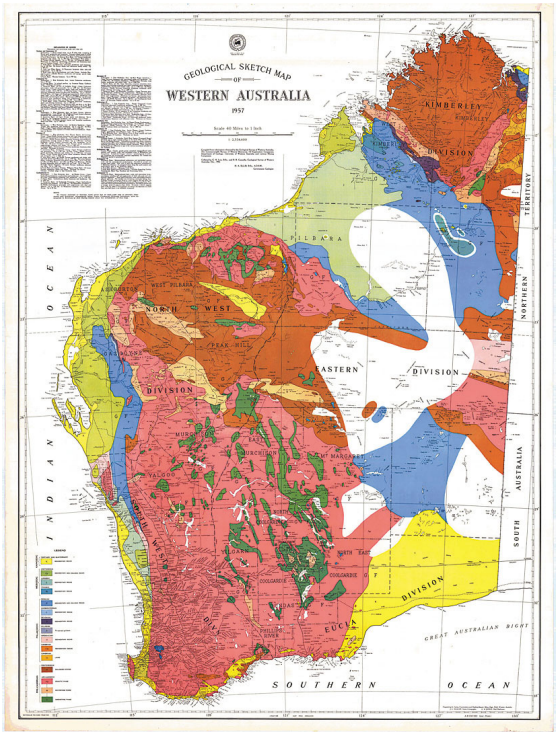

Figure 4. State geological map (1957) before the commencement of series mapping

Series mapping

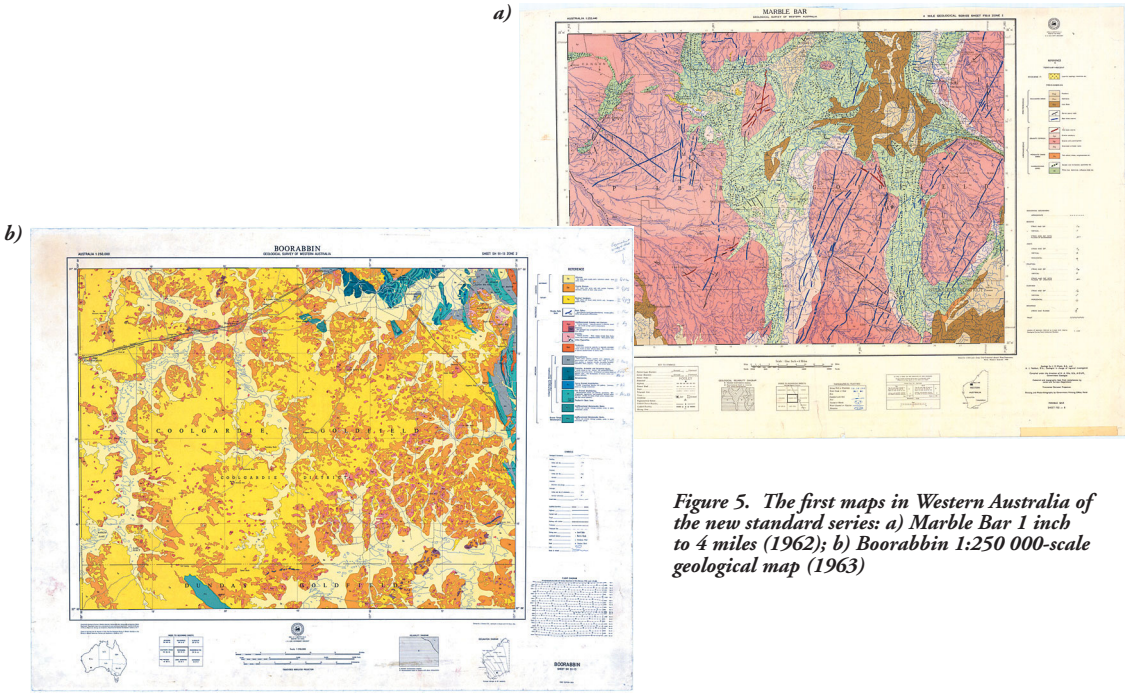

Figure 5. The first maps in Western Australia of the new standard series: a) Marble Bar 1 inch to 4 miles (1962); b) Boorabbin 1:250 000-scale geological map (1963)

and John Blockley, elucidated the stratigraphy of the now-famous banded iron-formations, and the controls on mineralization. Similarly Phil Playford laid the foundations for understanding the Canning Basin. In this melange of mappers, mineral resource geologists were scattered to mineral-poor provinces, hydrogeologists were systematically banished to the Kimberley where groundwater was not an issue, and regional mappers opened windows into mineral provinces. Multi-skilling was mandatory, and out of this mixture emerged two legendary mapping machines — Ian Williams and Arthur Hickman.

The mission to accelerate mapping required staff to be recruited. Funding for this was facilitated by the burgeoning mining and petroleum industries. The nickel boom caused severe staff losses, and several waves of recruitment were necessary, the majority coming from British institutions. Following the collapse of the nickel boom, momentum was regained, and with the appointment of a Regional Mapping Supervisor (RD Gee) dedicated to the mapping mission, GSWA finally established integrated multi-member parties, working concurrently on adjacent sheets, tackling individual tectonic units, with frequent field reviews by all involved geologists. Then ensued a decade of staff stability, high productivity, team enthusiasm, and map consistency.

Our modus operandi was two geologists per map sheet, each with a Land Rover and a field assistant, on weekly fly camps, and generally sharing an office caravan in a central field location. Long-range fuel tanks, spare leaf springs and stub axles were prescribed. It was a protracted battle to have refrigerators and auxiliary batteries installed into field vehicles. Initially, field stints were of six months duration. By the grace of Joe Lord, this was softened to either three lots of 8 weeks or two lots of 12 weeks — depending on location. This was tough on geologists, especially those with young families. As far as we know there was only one defalcation, and that person made a real meal of it by plagiarizing his companion's field notes to cover his absence.

GSWA was legendary for its field excursions, which were run after completion of map sheets. These were multi-vehicle escorted tours for industry geologists, and were very well patronized. Most memorable was the Edjudina excursion in 1971, which I attended as an industry geologist (Fig. 6). The official tally was 99 vehicles, but on one leg I counted 103 — every one of them Land Rovers. Then there was the remote Nabberu Basin excursion in 1977 when some 37 vehicles attended. All of them — except the GSWA vehicles — were Toyotas. Not only were there dramatic changes in field-support systems, but equally dramatic

Figure 6. Queue of Land Rovers at the start of the Edjudina sheet excursion in 1971

changes in geological understanding. Despite representations from field staff, Joe Lord hung onto the Land Rover well beyond its use-by date. Fortunately Joe attended the Nabberu excursion, and witnessed this seminal change. The final straw came when John Bunting had to drive 83 km in reverse out on the desolate Plumridge sheet. Finally Joe agreed to phase out Land Rovers — in favour of Nissans! That was the only instance when we were years behind our geological colleagues in industry.

Unravelling the architecture of the shield (now Yilgarn Craton) demonstrated that regional mapping was indeed worthy research. We brought in academics, generally with mutual benefits. But some academics derided our work as 'only reconnaissance'. They followed us around with their own studies, but with less memorable results.

One memorable output of this campaign was the production in 1979 of a State 1:2 500 000 geological map (Fig. 7). This map largely resolved the representational problems of legend structure and map-unit classifications in the Precambrian by integrating classical lithostratigraphy with radiometric dating into a chronostratigraphic framework. It also revealed major advances in the understanding of the State's geology since the 1:250 000 mapping program began in the mid-1950s, in particular within the Proterozoic in which the once ubiquitous Nullagine Series was shown to consist of at least half a dozen separate basins of widely disparate ages. It also solved the mystery of the enigmatic salt lakes of the State's interior, revealing them to be the remnants of ancient rivers flowing into long-departed seas. The map, published at about the time that Joe Lord retired, was a fitting tribute to his leadership over a period of some 20 years.

The productivity of the 1970s and early 1980s occurred at a time when BMR and its successor, The Australian Geological Survey Organisation (now Geoscience Australia), endured endless reviews, the core issue being its role in regional mapping. Specialists in basin analysis were engaged in the Officer Basin, but BMR participation was absent from Precambrian terrains except ironically for the Yilgarn Craton, where GSWA 'borrowed' some first-class veteran field mappers in 1979 to help complete the Lord's Mission. Joe Lord threatened not to retire till the mapping of the State was done. Although he was much loved by most of his staff, this was a real incentive to accelerate even more. By 1979, the State was 90% mapped at 1:250 000 scale. Fieldwork on the last square holes in the Yilgarn was complete, and Joe retired. But the finish gun could not be fired till 1986 when Kellerberrin and Corrigin Maps and Explanatory Notes were released under the authorship of Richard Chin.

Series mapping

The quarter-million mapping provided the essential framework for mineral exploration, which flourished through four decades. It made direct contributions to many discoveries. On reflection the quarter-million mapping standard was just right to build a regional framework. One cannot efficiently build up from 1:100 000 scale. Similarly one cannot effectively scale down from 1:1 000 000 to get the right picture. The Chief Government Geologists Conference of 1950 got it right.

Daring to mention individual geologists in this anthology runs the risk of being a little secular. But they are the folks, wittingly or otherwise, who mark the milestones of this historic program in Western Australia. There were, and indeed remain, many fine geologists that contributed magnificently, but their deeds would take much more than this chronicle. Last, but not least, we must pay tribute to the excellent cartographic, logistic, and clerical support staff, who shared the euphoria of this achievement.

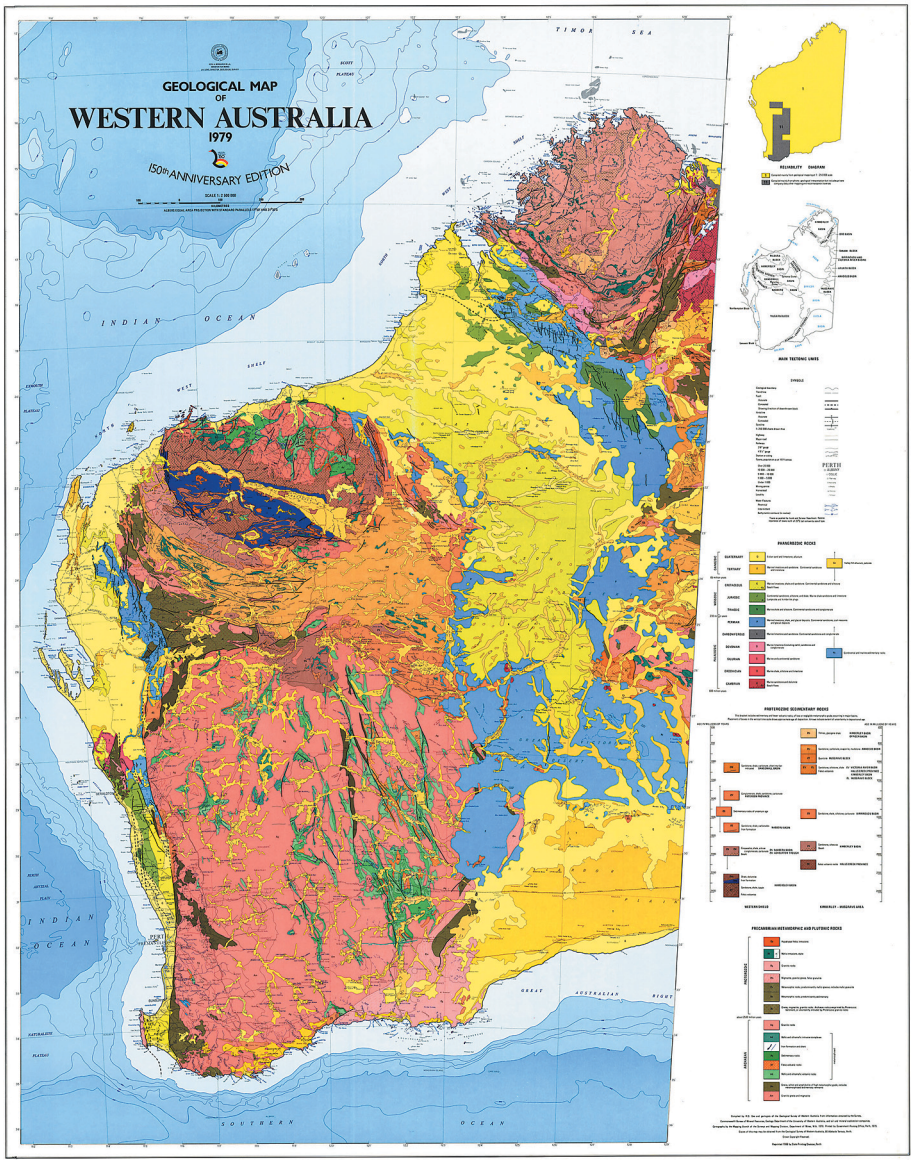

Figure 7. The new State geology map for the Sesquicentenary of Western Australia (1979)

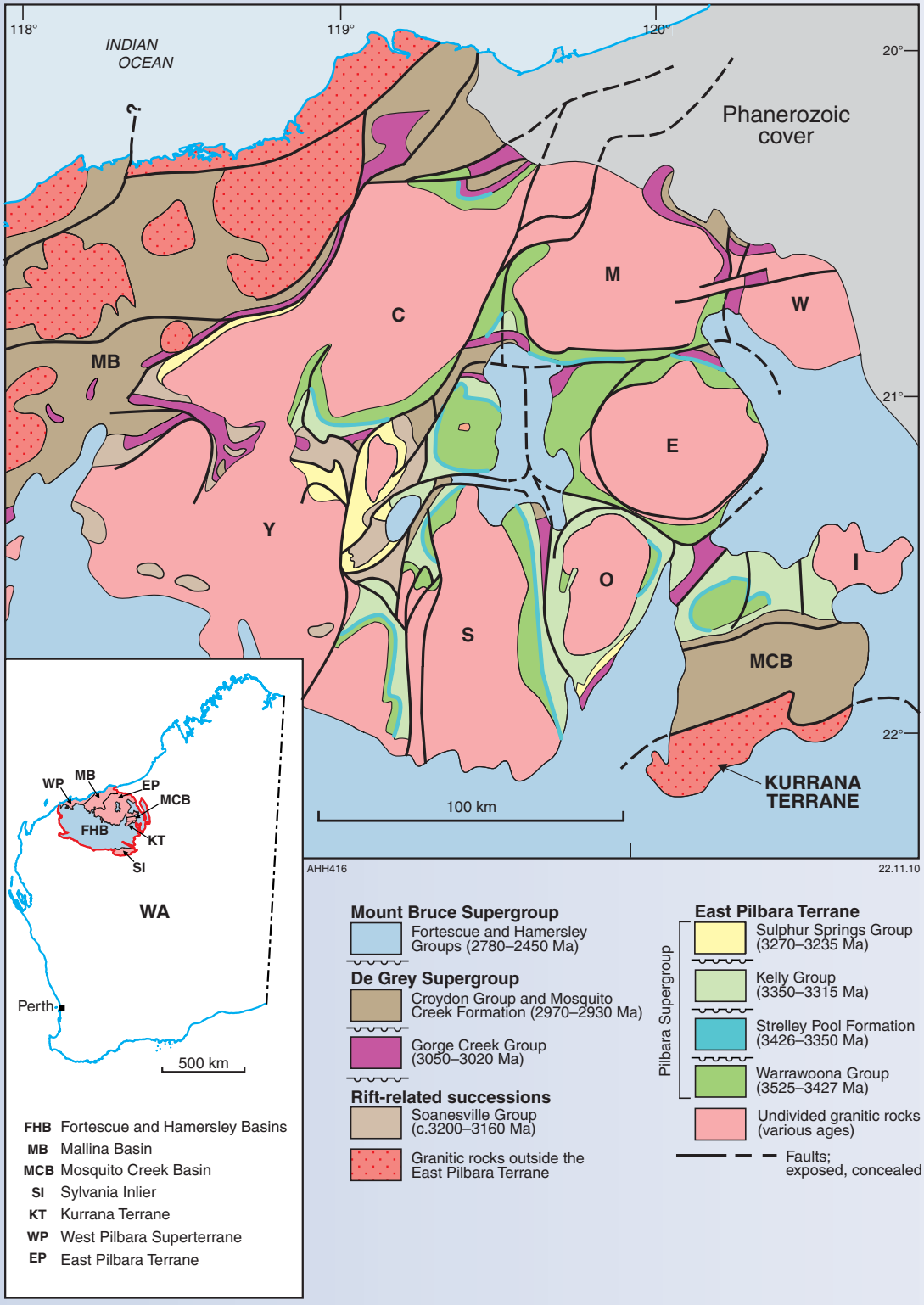

Figure 1. Simplified geological map of the East Pilbara Terrane showing eight granite–greenstone domes. Most of the domes are separated by Paleoarchean–Mesoarchean boundary faults within the greenstones. Dome names: C = Carlindi; M = Muccan; W = Warrawagine; Y = Yule; E = Mount Edgar; S = Shaw; O = Corunna Downs; I = Yilgalong. Modified from Van Kranendonk et al. (2006, fig. 1).

Pilbara Supergroup of the East Pilbara Terrane, Pilbara Craton: updated lithostratigraphy and comments on the influence of vertical tectonics

by AH Hickman

Abstract

Since the entire lithostratigraphy of the northern Pilbara Craton was formally revised in a Geological Survey of Western Australia Record in 2006, evidence from new mapping and geochronological data has led to various lithostratigraphic revisions, in particular for the 3.53–3.23 Ga Pilbara Supergroup. This paper provides a summary of the changes and briefly introduces the question of the relationship between the stratigraphy of the Pilbara Supergroup and its tectonic environment.

The lithostratigraphic changes made since the 2006 publication are:

i) the Soanesville Group has been removed from the Pilbara Supergroup because it marks the commencement of plate-tectonic processes
ii) the Budjan Creek Formation, previously assigned to the 3.27–3.23 Ga Sulphur Springs Group, is reassigned to the Soanesville Group based on its sedimentology and interpreted tectonic setting
iii) the Strelley Pool Formation has been removed from the Kelly Group
iv) the Dresser Formation has been correlated with the McPhee Formation, based on reinterpretation of its age from 3.52 Ga to 3.48 Ga
v) a basaltic succession underlying the Dresser Formation is correlated with the North Star Basalt instead of the Coonterunah Subgroup.

The stratigraphy of the Pilbara Supergroup must have been influenced by its depositional setting within an environment of vertical tectonics. This paper reports an example where the distribution of one formation — the Apex Basalt — provides some support for this concept, and examination of the variable distribution of several other formations, combined with thickness and facies data, is expected to provide additional evidence.

KEYWORDS: Pilbara Supergroup, lithostratigraphy, Soanesville Group, Budjan Creek Formation, Strelley Pool Formation, Dresser Formation, Apex Basalt, vertical tectonics, East Pilbara Terrane, Pilbara Craton, tectonic environment, plate tectonics, depositional setting, Sulphur Springs Group.

Introduction

In 2006, the lithostratigraphy of the northern Pilbara Craton was formally revised and redefined (Van Kranendonk et al., 2006, 2007a). New evidence from university researchers, additional geochronology, and ongoing evaluation of data from the Pilbara Craton mapping project, have resulted in further revisions for the Pilbara Supergroup, which comprises the greenstone succession of the Paleoarchean East Pilbara Terrane (Hickman, 2008, 2010; Hickman and Van Kranendonk, 2008; Hickman et al., 2010; Van Kranendonk et al., 2010). The accumulated changes to the lithostratigraphy of the Pilbara Supergroup are now causing a problem because the most comprehensive lithostratigraphic reference works (Van Kranendonk et al., 2006, 2007a) are now partly out-of-date. This paper summarizes and briefly explains the recent revisions, and presents them in the context of an updated interpretation of the evolution of the Pilbara Supergroup. The revised lithostratigraphy has been incorporated into Geological Survey of Western Australia's (GSWA's) Explanatory Notes database, and is being used in GSWA's GIS products.

Previous interpretation of the Pilbara Supergroup

The Paleoarchean East Pilbara Terrane of the Pilbara Craton (Fig. 1) is distinguished by its structural style, which has no close analogues in terranes formed by plate-tectonic processes. Numerous publications over the last 35 years have explained its characteristic 'dome-and-syncline' pattern, well displayed on geological maps and satellite imagery, as the product of vertical tectonic processes; earliest accounts were by Hickman (1975, 1981, 1984) and recent contributions have included those by Van Kranendonk et al. (2006, 2007a,b). GSWA geological mapping between 1995 and 2003 revealed that, rather than consisting of alternating domes and synclines, the regional outcrop pattern was produced by a cluster of adjoining granite–greenstone domes (Van Kranendonk et al., 2002). Boundary faults within the greenstones separate these domes (Fig. 1). In total, there are eight granite–greenstone domes, and there are 20 greenstone belts (Fig. 2).

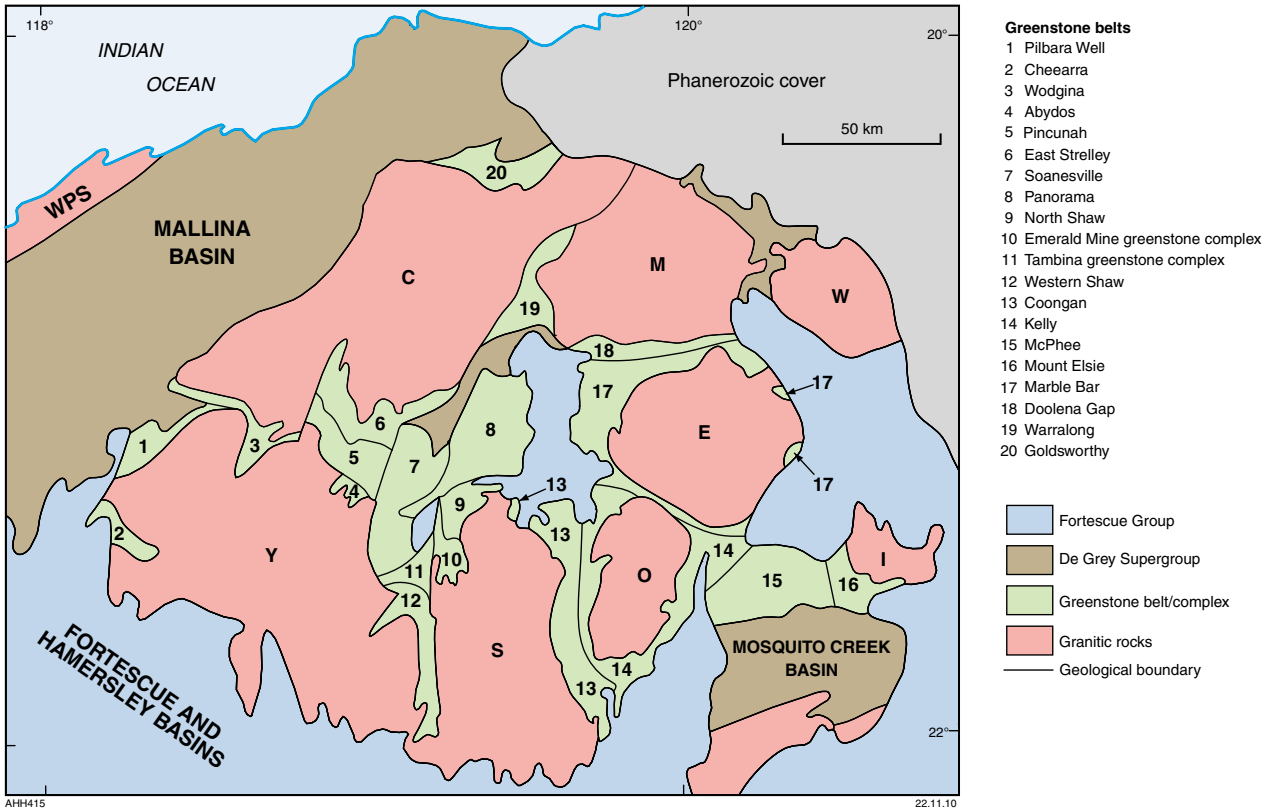

Figure 2. Greenstone belts and complexes of the East Pilbara Terrane. Dome names as in Figure 1. WPS = West Pilbara Superterrane. Modified from Van Kranendonk et al. (2006, fig. 4).

As defined by Van Kranendonk et al. (2006), the Pilbara Supergroup comprises the greenstone succession of the East Pilbara Terrane, and is divided into four groups, as shown in Figure 3:

- 3525–3427 Ma Warrawoona Group (predominantly volcanic);
- 3350–3315 Ma Kelly Group (volcanic formations above a thin basal sedimentary formation of the group, the Strelley Pool 'Chert');
- 3270–3230 Ma Sulphur Springs Group (volcanic formations overlying a basal sedimentary formation, the Leilira Formation);
- 3230–3165 Ma Soanesville Group (predominantly sedimentary).

Revisions to the Pilbara Supergroup

Figure 3 shows an older version of the lithostratigraphy (modified from Van Kranendonk et al., 2006) with five lithostratigraphic units discussed in this paper highlighted in red. Figure 4 presents the revised stratigraphic column for the Pilbara Supergroup. This lithostratigraphy is described as 'generalized' because the thicknesses and compositions of the formations vary between different greenstone belts. With the exception of the change to the Budjan Creek Formation (below) all of the individual changes summarized in this paper have already been published but with little or no explanation, except for the changes involving the Strelley Pool Formation (Hickman, 2008).

Soanesville Group

The Soanesville Group outcrops in the western part of the East Pilbara Terrane where it overlies the 3.27–3.23 Ga Sulphur Springs Group. The lower part of the Soanesville Group is composed of a >2500 m-thick succession of siliciclastic sedimentary rocks containing minor chert and BIF; in contrast, the upper part of the group is composed of volcanic rocks in the formally defined Honeyeater Basalt (references in Van Kranendonk et al., 2006), and may include unnamed volcanic formations in the Wodgina and Pilbara Well greenstone belts (Van Kranendonk

et al., 2010). Stratigraphic relations between the unnamed formations and the Soanesville Group will remain uncertain without further mapping and geochronology.

Van Kranendonk et al. (2006) removed the Soanesville Group from the Gorge Creek Group (Lipple, 1975; Van Kranendonk et al., 2004) because recent mapping had indicated an erosional unconformity between the two successions. Previously, the Gorge Creek Group had been included in the Pilbara Supergroup, and the revision by Van Kranendonk et al. (2006) retained the Sulphur Springs Group in this supergroup while moving the Gorge Creek Group into the De Grey Supergroup (Van Kranendonk et al., 2004). The contact between the Soanesville Group and the underlying Sulphur Springs Group was described as a disconformity by Van Kranendonk et al. (2006). Based on an interpretation that hydrothermal alteration at the top of the underlying Sulphur Springs Group extends into the lower part of the Soanesville Group, Van Kranendonk et al. (2006) inferred no significant age difference between the two groups. However, a transition between the Sulphur Springs Group and the Soanesville Group was questioned when Rasmussen et al. (2007) dated monazite within the Soanesville Group at c. 3.19 Ga, and interpreted this to be the approximate age of deposition. This result indicates that the Soanesville Group is 40 million years younger than the Sulphur Springs Group. Additional geochronology was subsequently reported by Van Kranendonk et al. (2010) to support the interpretation that the Soanesville Group was deposited after c. 3.20 Ga.

The contact between the 3.27–3.23 Ga Sulphur Springs Group and the <3.2 Ga Soanesville Group marks a major change in the crustal evolution of the Pilbara Craton. From 3.53 to 3.23 Ga the Pilbara crust was progressively thickened by a succession of plume-related magmatic events that involved ultramafic–mafic–felsic volcanic cycles, contemporaneous granitic intrusion, vertical deformation, and metamorphism (Van Kranendonk et al., 2002). The 3.53 to 3.23 Ga crust formed during these events is now preserved as the East Pilbara Terrane. Rifting of this terrane probably commenced towards the end of deposition of the Sulphur Springs Group (Hickman, 2004). Post-3.2 Ga deposition and tectonic activity was interpreted by Van Kranendonk et al. (2010) to indicate a Mesoarchean Wilson cycle that reached the stage of arc accretion at 3.07 Ga, followed by 3.07–2.90 Ga extension and accretion, with orogenic

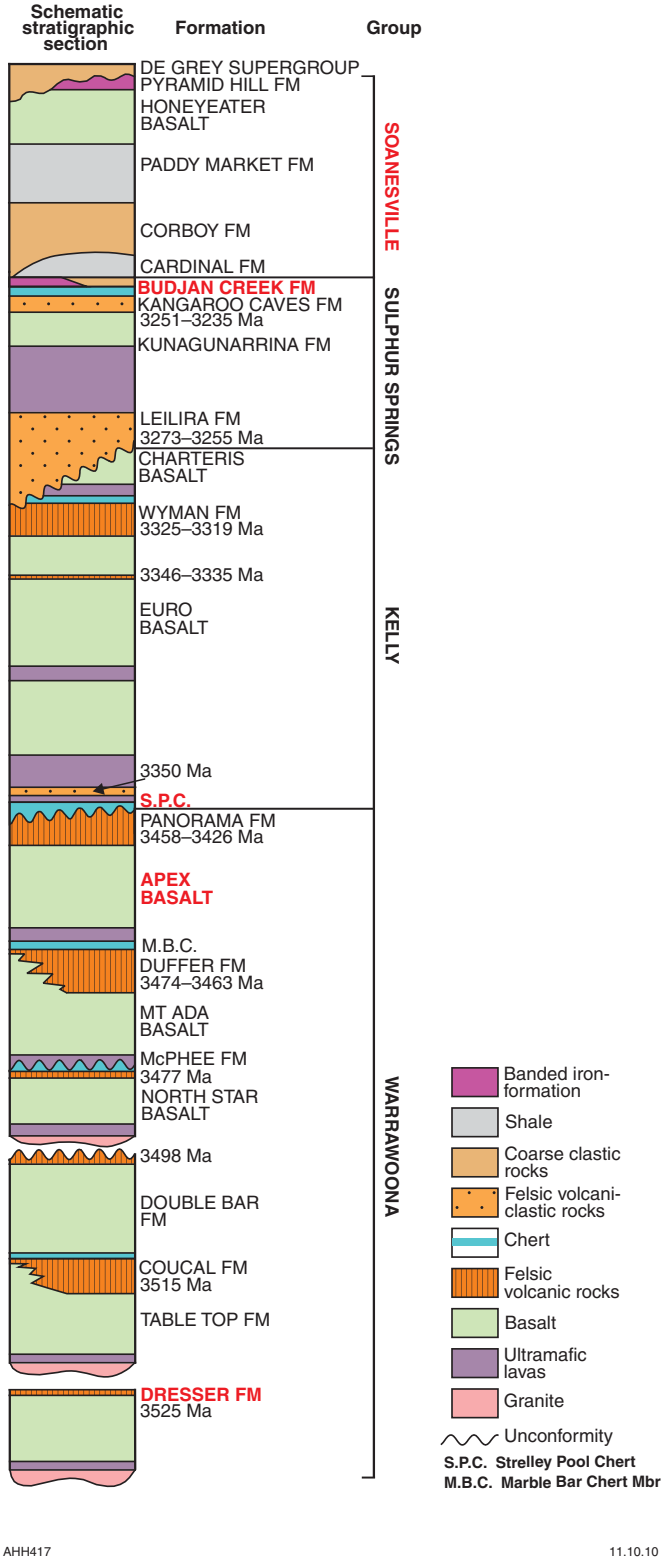

Figure 3. Summary of the lithostratigraphic column of the Pilbara Supergroup published in the last formal revision (Van Kranendonk et al., 2006, fig. 5). Stratigraphic names in red highlight units discussed in this paper.

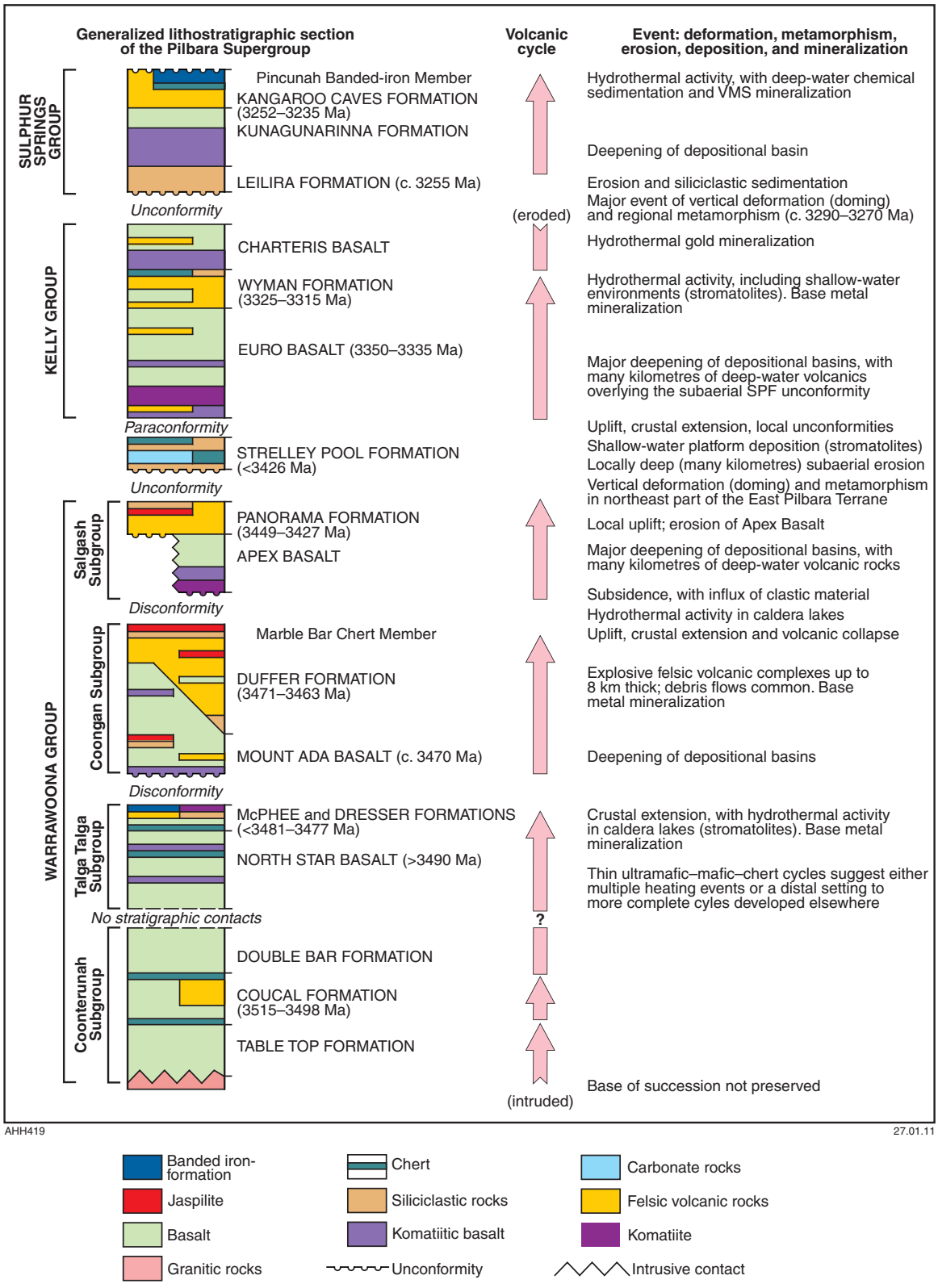

Figure 4. Revised generalized lithostratigraphy of the Pilbara Supergroup (this paper). The succession is interpreted in terms of eight successive volcanic cycles, most of which are separated by unconformities. Events of deformation, metamorphism, erosion, sedimentary deposition, and mineralization are briefly noted.

deformation. The earliest stage of this Wilson cycle is represented by thick clastic sedimentation in the lower part of the Soanesville Group.

Sedimentological observations made by Eriksson (1981) within the lower Soanesville Group of the Pincunah and Soanesville greenstone belts (Fig. 2) are still relevant today, although he mistakenly grouped this <3.2 Ga succession with c. 2.95–2.93 Ga formations of the De Grey Supergroup. Eriksson (1981) interpreted the lower Soanesville Group as a submarine mid-fan to outer fan succession deposited during intracratonic rifting.

Budjan Creek Formation

The Budjan Creek Formation (Fig. 3) is a succession of clastic sedimentary rocks that unconformably overlies the 3.35–3.31 Ga Kelly Group north and west from Nullagine. U–Pb zircon data indicate a maximum depositional age of c. 3.22 Ga (Van Kranendonk et al., 2006). Eriksson (1981) described the composition and sedimentary structures of the formation, and interpreted the depositional environment as one of intracratonic rifting progressing to deposition on a rifted continental margin. Numerous stacked progradational cycles were interpreted as evidence for sinking graben and deepening lakes. Van Kranendonk et al. (2006) used the maximum depositional age of 3.22 Ga to tentatively assign the Budjan Creek Formation to the top of the Sulphur Springs Group, but the sedimentology of the formation and its rift-related deposition now strongly support its inclusion in the Soanesville Group.

Strelley Pool Formation

The 3.43–3.35 Ga Strelley Pool Formation is a succession of clastic sedimentary rocks, carbonate rocks, and chert that separates the volcanic successions of the Warrawoona and Kelly Groups in eleven greenstone belts of the East Pilbara Terrane (Hickman, 2008). The formation was deposited in shallow-water shelf, stromatolite reef, estuarine, beach, sabkha, lacustrine, and fluviatile environments. Extensive silicification of primary carbonate and fine-grained clastic rocks has locally transformed much of the formation into secondary 'chert', explaining why it was initially named (Lowe, 1983), and for many years referred to, as the 'Strelley Pool Chert'. The Strelley Pool Formation is only 10 to 50 m thick in most areas, although in the Doolena Gap greenstone belt it is almost entirely composed of 1000 m of quartzite. The regional distribution of the Strelley Pool Formation across more than 30 000 km^2 of the East Pilbara Terrane (Hickman, 2008), together with sedimentological evidence, indicates that it was deposited across a regionally peneplained land surface.

As recorded by Hickman (2008), the formation is absent in some greenstone belts where the Euro Basalt of the Kelly Group directly overlies formations of the Warrawoona Group. This feature could be due to non-deposition of the Strelley Pool Formation across upland areas.

Van Kranendonk et al. (2002) interpreted the Strelley Pool Formation (then 'Strelley Pool Chert') to conformably overlie the Panorama Formation and to be genetically related to it. Later, Van Kranendonk et al. (2004, 2006) re-assigned the Strelley Pool Formation to the Kelly Group on the basis that it overlies a regional unconformity and represents the first stage of the mantle plume event that was responsible for the Kelly Group. Hickman (2008) reviewed more-recent evidence indicating that only the upper volcaniclastic part of the Strelley Pool Formation is genetically related to the Euro Basalt. In the East Strelley and Panorama greenstone belts (Fig. 2), detailed stratigraphic studies have found this upper part of the formation to consist of a boulder conglomerate containing lithified clasts derived from the underlying part of the Strelley Pool Formation (Allwood et al., 2007; Wacey et al., 2010). Above the conglomerate is a thin volcaniclastic unit that includes silicified volcanic ash. Lowe (1983) recorded ashfall tuff and volcaniclastic units at the top of the formation that he interpreted to represent distal volcanic deposits. Mantle plume events are commonly preceded by uplift and erosion, so the relatively thin topmost section of the Strelley Pool Formation, above the conglomerate, may be of similar age to the Euro Basalt. However, the main part of the Strelley Pool Formation contains no volcaniclastic material, and is composed of sedimentary facies indicating depositional environments unrelated to volcanism.

Other lines of evidence that argue against the main part of the formation being deposited as the first stage of the Kelly Group mantle plume event include:

- Previous plume events in the Warrawoona Group, as represented by five volcanic cycles (Fig. 4), involved volcanic eruption less than about 10 million years after deposition of the last volcanic unit of the preceding cycle. Unless

the Kelly Group plume event was very different from its predecessors, this suggests that it commenced no earlier than c. 3.36 Ga (Euro Basalt volcanism commenced at 3.35 Ga).

- Previous plume events in the Pilbara Supergroup did not produce volcanic cycles commencing with widespread deposition of conglomerate, sandstone, and carbonate rocks. It could be argued that the Sulphur Springs Group, which unconformably overlies the Kelly Group, does contain a basal clastic succession, the Leilira Formation. However, the Leilira Formation differs from the Strelley Pool Formation in that it (a) contains felsic volcanic and volcaniclastic components and wacke (Van Kranendonk, 2000); and (b) is of similar age to the overlying volcanic formations of the group (Buick et al., 2002).
- Geochronology on the clastic sedimentary rocks of the Strelley Pool Formation in four greenstone belts (reviewed by Hickman, 2008) reveals detrital zircon populations ranging from 3.51 to 3.43 Ga, ages consistent with detritus derived by erosion of the underlying Warrawoona Group. Of the 129 zircon grains analysed, 12 of the youngest had U–Pb model ages of between 3.43 and 3.40 Ga, and two zircons had ages close to 3.36 Ga. These data do not support deposition of the main part of the Strelley Pool Formation shortly before eruption of the volcanic rocks of the Kelly Group at 3.35 Ga.

Dresser Formation

Van Kranendonk et al. (2006) placed the Dresser Formation in the Coonterunah Subgroup of the Warrawoona Group based on a preliminary SHRIMP U–Pb zircon date of 3525 ± 2 Ma for a felsic volcaniclastic unit. However, the maximum age of deposition of this rock was later revised to 3481 ± 3.5 Ma (Van Kranendonk et al., 2008) when it was recognized that a younger concordant zircon population was also present. Hickman and Van Kranendonk (2008) therefore supported a correlation between the Dresser Formation and the 3.48 Ga McPhee Formation of the Talga Talga Subgroup (Van Kranendonk et al., 2007a,b). The Dresser and McPhee Formations are each composed of basalt, chert, carbonate rocks, and minor felsic volcaniclastic rocks, and both formations underlie the 3.47 Ga Mount Ada Basalt. The Dresser Formation also contains hydrothermal barite, evaporites, and stromatolites not present in the McPhee Formation. This is explained by the interpretation that the Dresser Formation was deposited in a caldera setting (Van Kranendonk et al., 2006).

Basalts underlying the Dresser Formation

Following revisions to the interpreted age and stratigraphic position of the Dresser Formation, the underlying basaltic succession in the Panorama greenstone belt has been correlated with the North Star Basalt of the Talga Talga Subgroup (Hickman, 2010).

Apex Basalt

Throughout the Marble Bar greenstone belt, the Apex Basalt is an approximately 3000 m-thick formation of komatiite, komatiitic basalt, tholeiitic basalt, and thin units of chert. The formation disconformably overlies the 3.47 Ga Duffer Formation and conformably underlies felsic volcanic rocks of the 3.45 to 3.43 Ga Panorama Formation. The Apex Basalt is 2500 m thick in the eastern part of the Warralong greenstone belt, but is absent in the western Warralong, Panorama, and Coongan greenstone belts where the Panorama Formation directly overlies the Duffer Formation. These stratigraphic differences can be explained by differential uplift of the granite–greenstone domes (Fig. 1) across the boundary faults prior to 3.45 Ga. If the boundary faults were active following 3.47 to 3.46 Ga deposition of the Duffer Formation they could have controlled the extent of the depositional basins of the Apex Basalt. Alternatively, if the boundary faults became active shortly after deposition of the Apex Basalt, this could have led to it being eroded across those domes that were uplifted. Hickman and Van Kranendonk (2004) interpreted the boundary faults as 3.30 to 2.95 Ga structures, and the present suggestion that pre-3.43 Ga Warrawoona Group stratigraphy was influenced by these boundaries is a new concept. Evidence that the Apex Basalt was eroded from the Coongan greenstone belt may lie in the existence of numerous dolerite dykes that intrude the 3.47 Ga Duffer Formation in this greenstone belt; a similar situation exists in the Marble Bar greenstone belt where dolerite dykes in the Duffer Formation were feeders to the overlying Apex Basalt (Hickman and Van Kranendonk, 2008). More-detailed mapping is required to establish if any of the dolerite dykes of the Coongan greenstone belt are truncated at the base of the Panorama Formation.

Discussion

Figure 4 presents a revised lithostratigraphic succession for the Pilbara Supergroup, and interprets the main events that were responsible for the deposition of the succession. A key feature of the Pilbara Supergroup is that it is composed of vertically repeated ultramafic–mafic–felsic volcanic cycles, each of which is attributed to plume-related partial melting of the upper mantle and lower crust (Van Kranendonk et al., 2002; Smithies et al., 2005). Another important feature is the presence of several unconformities in the succession (Fig. 4). Two major unconformities separate the three groups, and disconformities or paraconformities separate the volcanic cycles within the groups. Some of the disconformities are marked by laterally discontinuous clastic sedimentary lenses formed by erosion of small-scale surface structures at the tops of the cycles. These structures were most likely formed either by crustal extension (related to regional doming or local subvolcanic intrusion) or by volcanic collapse that produced calderas. Alternating stages of uplift and subsidence are evident from the repeated examples of subaerial erosion and/or shallow-water deposition followed by pillow basalt successions more than 3000 m thick (Mount Ada, Apex, Euro, and Charteris Basalts). Such rapid and major variations in basin depth are best explained by periods of domal uplift and basin subsidence. Structural evidence (Hickman, 1984; Collins, 1989; Van Kranendonk et al., 2002, 2006, 2007a,b; Hickman and Van Kranendonk, 2004) demonstrates that the domes were formed by vertical uplift. Geochemical evidence (Smithies et al., 2005, 2007; Van Kranendonk et al., 2007a,b) supports a relationship to mantle plumes. Stratigraphic evidence, such as that discussed here for the Apex Basalt, could be investigated to provide more information on differences in the timing and amounts of uplift and subsidence in the eight granite–greenstone domes.

Conclusions

Further work since a formal lithostratigraphic definition of the Pilbara Supergroup (Van Kranendonk et al., 2006) necessitates revision of its composition and succession. The Soanesville Group is now formally excluded from the Pilbara Supergroup because its deposition marked a major change in tectonic processes operating in the Pilbara Craton (Van Kranendonk et al., 2010). The age, sedimentology, and interpreted tectonic setting of the Budjan Creek Formation support assignment to the Soanesville Group instead of the Sulphur Springs Group. The Strelley Pool Formation is no longer assigned to the Kelly Group for reasons previously published (Hickman, 2008), and is interpreted to be a sedimentary formation that separates the Warrawoona Group from the Kelly Group. The 3.48 Ga Dresser Formation has been moved from the Coonterunah Subgroup to the Talga Talga Subgroup following revised geochronology and a new correlation with the McPhee Formation; accordingly, basalts underlying the Dresser Formation in the Panorama greenstone belt (Fig. 2) have been assigned to the North Star Basalt (Hickman, 2010). All these revisions are shown on Figure 4.

The restriction of the Apex Basalt to particular greenstone belts is now thought to be the result of differential vertical movement (several kilometres) of the east Pilbara domes between 3.46 and 3.45 Ga. The domes differ not only in size but also in variable amounts of uplift. This raises the possibility that regional thickness variations in other formations are also at least partly due to variations in the amplitude and timing of domal uplift, and to varying subsidence in the different greenstone basins. Differences in uplift may be explained by varying extents of intrusion by the four granitic supersuites of the East Pilbara Terrane. These supersuites were largely responsible for inflation of the domes between 3.49 and 3.23 Ga (Hickman and Van Kranendonk, 2004; Van Kranendonk et al., 2006). Available geochronology indicates that the volumes of individual supersuites vary considerably between the domes, and some domes lack any intrusions of some supersuites (Van Kranendonk et al., 2006, Figs 10–13).

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A geological framework for coastal planning

by Bob Gozzard

Abstract

Marine and coastal planning and management need a sound scientific basis. An important component of this involves the mapping of coastal landforms leading to the identification of coastal compartments and sediment cells along the coast of Western Australia. The approach is similar to that used for land systems and river catchments and involves the identification of a hierarchy of units based on natural coastal systems. This hierarchy provides a physical framework for a variety of applications. These include planning and management of natural resources within the nearshore marine and coastal environment, assessment of vulnerability to coastal hazards, climate change, and rise in sea level.

KEYWORDS: coastal features, littoral zone, geomorphology, coastal management, climate change, sea-level rise.

Introduction

The Intergovernmental Panel on Climate Change has released a number of reports detailing the extent of predicted sea-level rise throughout the 21st century (Pachauri and Reisinger, 2007). These and other scientific and research reports predict that southwest Western Australia is particularly at risk to the impacts of sea-level rise through climate change, principally because of the area's low tidal range and generally low, sandy coastline. Future coastal erosion potentially threatens coastal assets such as roads, urban, commercial and industrial development, as well as tourism and recreation.

Two projects being undertaken by State Government agencies are contributing to the identification and use of natural coastal units in a variety of marine and coastal planning and management applications. The agencies involved in these projects are the Geological Survey of Western Australia (GSWA), Department of Planning, Department of Transport, and Department of Environment and Conservation, who have identified marine and coastal planning units consistent with the hierarchy of scales currently used in land use planning. At each scale, the units are based on geological and geomorphological boundaries, and each unit includes a suite of landforms consistent with the landform classes represented in the State Coastal Planning Policy SPP 2.6 (Western Australian Planning Commission, 2003).

In a separate but related coastal mapping project, GSWA has gathered information supporting and extending the potential applications of the marine and coastal planning units (Gozzard, 2009). This project provides more-detailed descriptions of the landform attributes required for coastal hazard and risk assessment at specific sites and at broader scales.

Planning units

In the past coastal planning and management in Western Australia has been based mainly on Local Government boundaries and other cadastral information, but as the pace of development increases, as projects get bigger, and as the threat to coastal infrastructure becomes more important

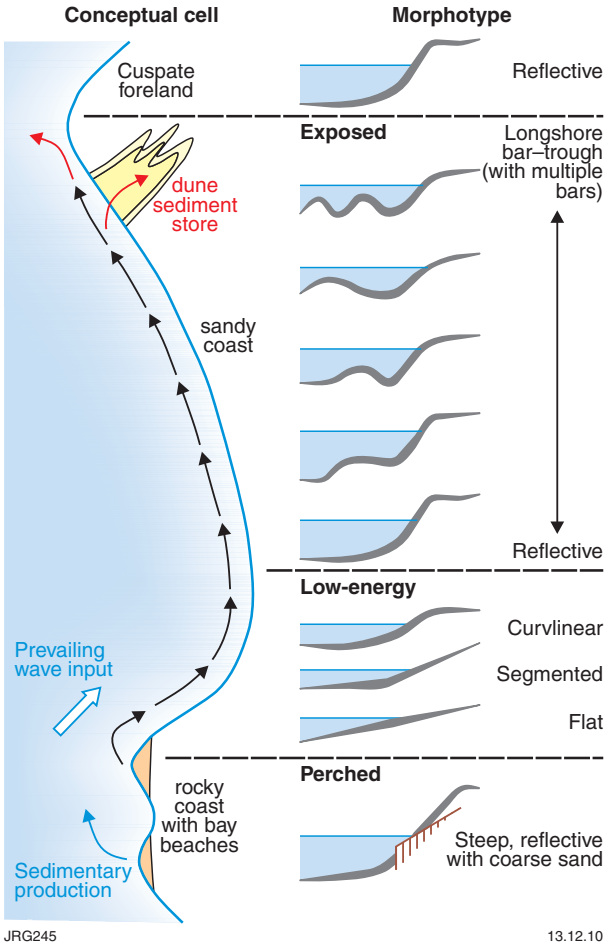

Figure 1. Conceptual model of a sediment cell (from Stul et al., 2007)

Figure 2. Main coastal morphologies along the southwest coast of Western Australia:
a) rocky coast in gneiss at Cape Naturaliste; b) rocky coast in calcarenite at Cape Peron; c) mixed sand and rock coast at Green Head; d) perched beaches at Trigg; e) barrier system along the Yalgorup coast; f) tombolos at Albany

to the State's continued development, it is more appropriate to identify natural risks and use these to define a hierarchy of natural coastal units at scales that closely match planning scales currently adopted by the Western Australian Planning Commission. At the same time there is the need also to recognize adverse threats to various parts of the coastal system by inappropriate development. Each level in the hierarchy should be linked to and limited by the type of information and detail required for the type of planning to be undertaken. Higher levels in the hierarchy can be used to determine broader, more general policy settings, whereas the lower levels are more suitable for the preparation of detailed management plans for specific sites. At each level in the hierarchy the scale of key landforms is matched with meteorological and oceanographic processes at related scales and linked to the major environmental risks for the appropriate coastal unit.

The concept of coastal compartments and littoral sediment cells and subcells has been adopted world-wide as the basis for coastal management and planning, especially in North America and Europe (Hansom et al, 2004; May and Hansom, 2003). In Western Australia, Sanderson and Eliot (1999), Searle and Semeniuk (1985) and Stul et al. (2007) employed a similar approach between Busselton and Geraldton and identified several primary sediment cells and numerous nested secondary cells. However, the sediment-cell concept has yet to be consistently incorporated into coastal management and planning in Western Australia.

Segmentation of the coast

Coastal compartments are large, regional-scale (i.e. tens to hundreds of kilometres), structural features primarily related to the regional geology — which exerts structural control on the shape of the coastline. The direction the coast faces (coastal aspect) and large coastal landforms such as deltas and cuspate forelands visible at a scale of 1:250 000 are secondary factors in determining the boundaries of coastal compartments. Each compartment encompasses the terrestrial coastal zone and the intertidal zone as well as the waters of the inshore and inner continental shelf.

In contrast, sediment cells are three-dimensional units that incorporate both nearshore terrestrial and marine environments and are usually smaller than coastal compartments. They are defined by the movement of unconsolidated sediments between source areas and deposition sites within geological and geomorphological boundaries identifiable at scales of 1:50 000 or larger (Fig. 1). A sediment cell can be relatively self-contained with regard to the movement of sediment, acting as a closed system with little exchange of sediment between adjacent cells (Komar, 1996). However, not all cells are discrete segments of the coast, and in Western Australia open-cell circulation involving sediment exchange between adjacent cells is not uncommon. Rocky headlands or man-made structures usually represent fixed-cell boundaries, whereas sandy promontories that move with changing wave conditions form migratory boundaries to sediment cells.

The classical approach to the identification of sediment cells (Gelfenbaum and Kaminsky, 2010; Hansom et al., 2004) is based on the principle of a complete sedimentation cycle in which sand is brought to the coast by rivers and streams, carried along the coast by longshore currents, and lost to sediment sinks such as submarine basins. In Western Australia generally, and southwestern Western Australia in particular, this classical approach requires modification, principally because of a lack of major rivers contributing sediment to the offshore (Fig. 2). On the west coast, the main sediment sources are the extensive sand flats, seagrass meadows, and offshore calcarenite reefs, and the major sediment sinks are the extensive dune barriers found along the whole coastline. The inherited geological framework, as, for example, where barrier systems are perched on older lithified sediments, is also more influential in the identification of sediment cells along the west coast than it is in classical models.

Eliot et al. (2010) identified a hierarchy of compartments for the whole of the Western Australian coast at three levels — primary, secondary, and tertiary (Fig. 3). There are thirty-six primary compartments, which have been grouped into 13 coastal regions, and there are 114 secondary compartments, and 242 tertiary compartments.

Tertiary compartments have been further subdivided into a hierarchy of sediment cells. The subdivision of tertiary coastal compartments into sediment cells is determined by the presence of geological controls, such as headlands, a change in beachface and nearshore sediment characteristics, a change in wave climate, and the presence of man-made structures such as groynes, breakwaters, and marinas (Fig. 4). The use of high-resolution LiDAR (Light Detection And Ranging) data and detailed nautical charts is particularly useful in

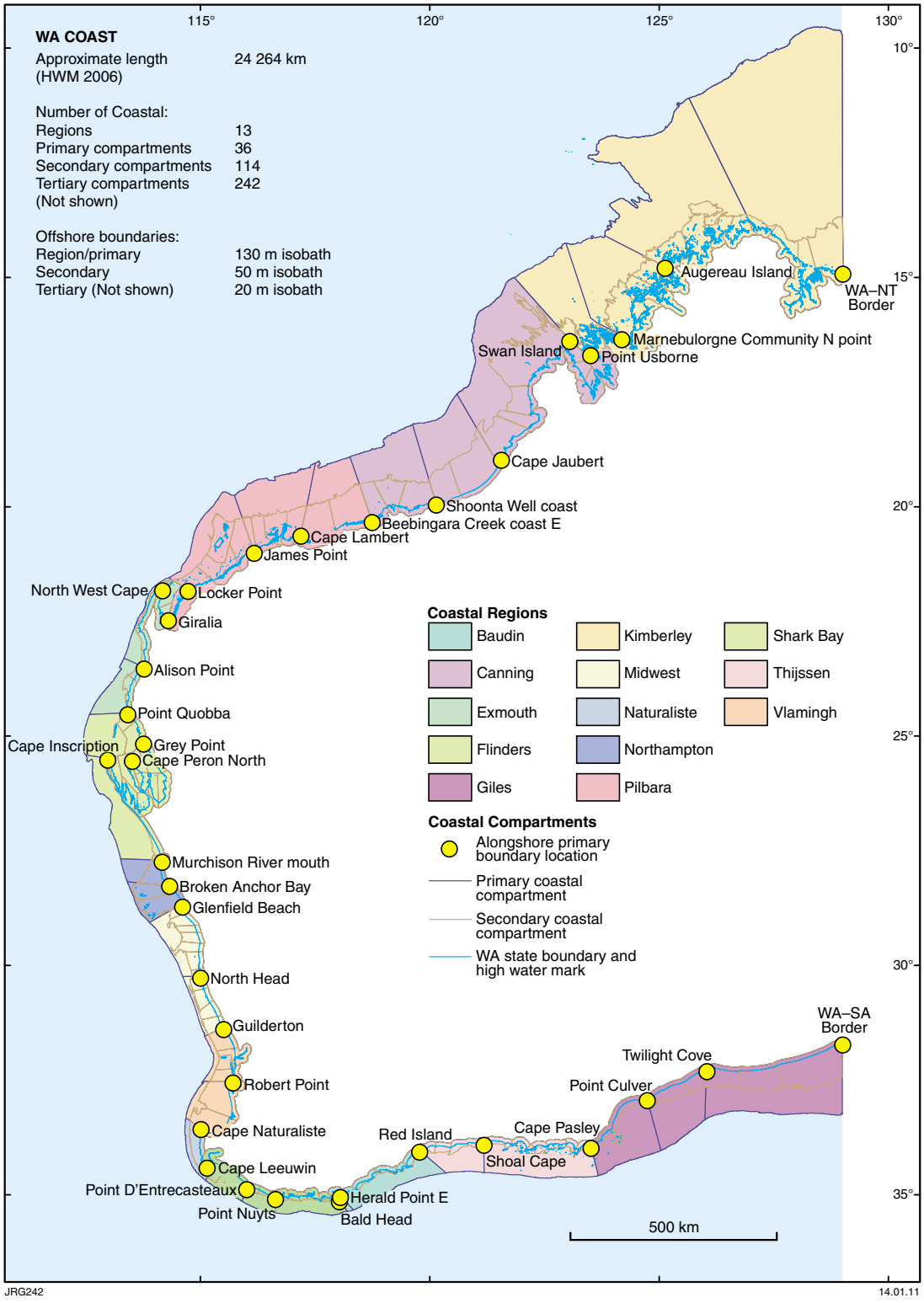

Figure 3. Coastal compartments recognized along the Western Australian coast. Data sources are GSWA, Department of Conservation, Damara Pty Ltd

discriminating sediment cell boundaries. Stul et al. (2007) suggested that the exchange of sediment between sediment cells is likely to be greater than that between compartments because compartment boundaries tend to be rocky headlands or man-made structures whereas sediment-cell boundaries are more susceptible to wave conditions.

All levels in the compartment and sediment-cell hierarchy use a standardized nomenclature for coastal landforms that can be used for a variety of shoreline types. The classification is simple and yet comprehensive enough to encompass landforms that are found at a range of scales in the landscape as well as those landforms that are more scale-specific. For each of the primary, secondary and tertiary compartments the geology and dominant landforms have been identified at a level appropriate to the compartment scale. For example, the Swan primary compartment (Vlamingh Region, Fig. 4), which is bounded by Guilderton in the north and Robert Point, Mandurah in the south, is wholly contained within the Phanerozoic Perth Basin and contains offshore limestone reefs, tombolos, beaches, and dunes. It has been subdivided into three secondary compartments. The coastal landforms associated with primary, secondary, and tertiary sediment cells have been identified as part of the WACoast project (Gozzard, 2009).

WACoast — coastal geology and landforms

There have been many studies undertaken along the coast of Western Australia for the purpose of identifying and mapping the geomorphological components of the coast in detail and assessing the response of the coast to potential future sea-level rises (Green, 2008; Travers, 2007). However, it can be difficult to compare the results from different studies, even when two areas are apparently very similar. For example, the results from one section of rocky calcarenite coastline cannot always be

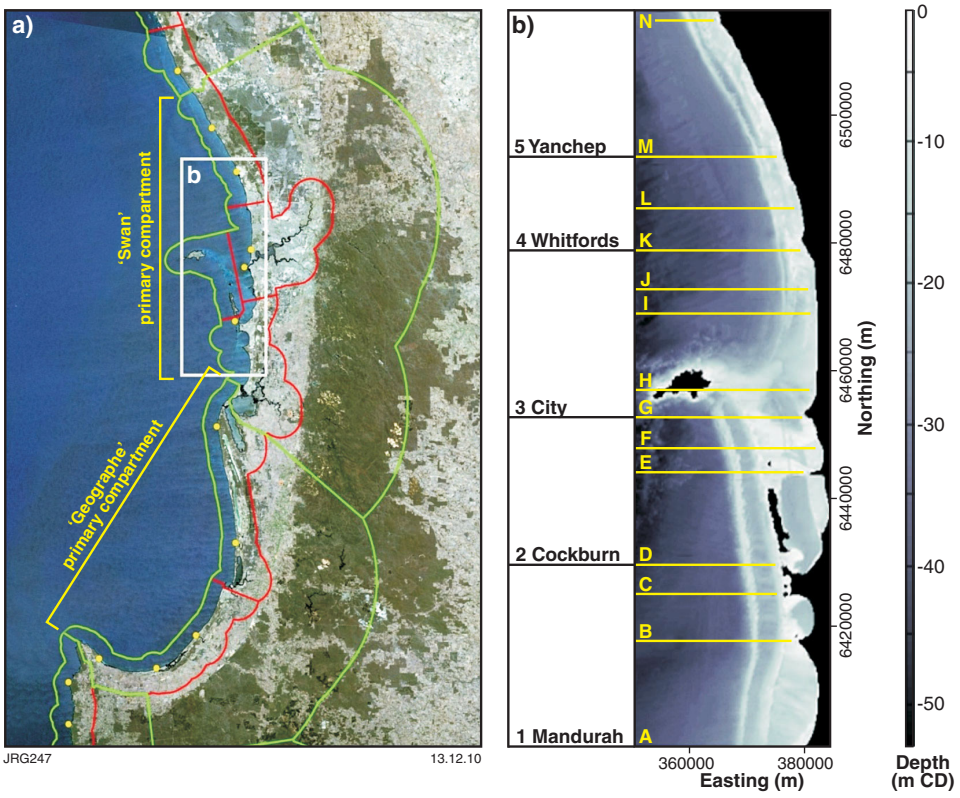

Figure 4. Subdivision of compartments into sediment cells (cells from Stul et al., 2007). mCD = metres Chart Datum

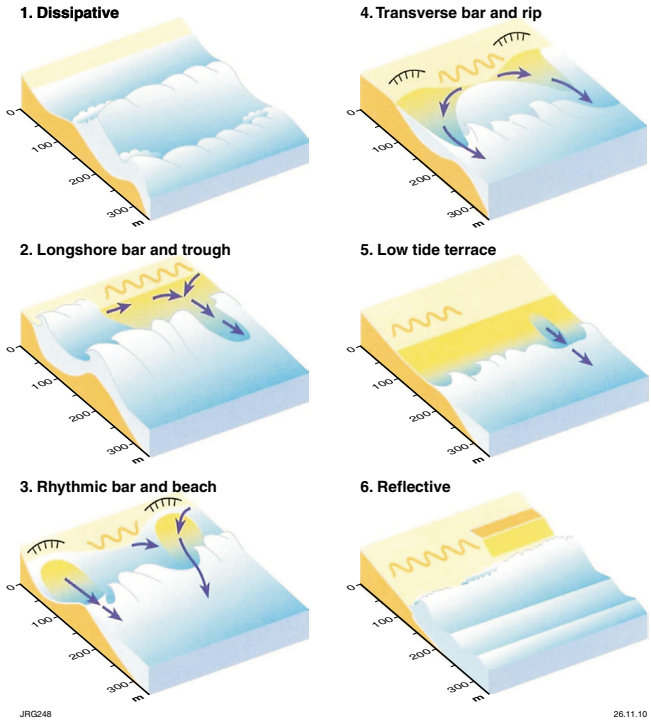

Figure 5. Classification of nearshore and foreshore morphologies (from Short and Woodroofe, 2009)

compared in a meaningful way with those from another similar section of rocky calcarenite coastline because both the classification of landform types and the modelling approach used were often too different.

The WACoast project, which covers Rottnest Island and the 1010 km of open coastline between Cape Naturaliste and Kalbarri, was completed in 2010 (Gozzard, in press a,b,c). The aim of the project was to collect fundamental, baseline geological and geomorphological data for the entire open coastline and create a highly detailed coastal geomorphological dataset using consistent landform classifications. The method adopted followed the 'Smartline' mapping concept of Sharples et al. (2009). Using this approach the coastline can be divided into a number of tidally defined zones — nearshore, foreshore, and backshore. The **nearshore** is permanently inundated by the sea and, for the purposes of the project, was defined as being immediately seawards of the foreshore zone, but may extend to an arbitrary distance of approximately 500 m offshore. The **foreshore** is the intertidal zone, including beaches. The **backshore** can be further divided into proximal and distal zones: the proximal backshore is immediately landward of the foreshore, and the distal backshore is the hinterland landward of the proximal backshore and for the purposes of the project was considered to extend an arbitrary distance of approximately 500 m inland.

Each of the four tidally defined zones was mapped using established published classifications. For example, for sandy shorelines the classification of Short (1999) was used to describe nearshore and foreshore (beach) morphologies (Fig. 5), that of Hesp (1999) to describe proximal backshore landforms (Table 1), and that of Chapman et al. (1982) to describe distal backshore barrier systems (Fig. 6). In addition, coastal exposure and the geological substrate of the coastline were also classified. From these six data layers the whole coastline can be represented in a single GIS polyline layer with multiple attributes attached to each segment.

All 468 beaches and intervening sections of rocky coastline in the study area were identified, mapped, and attributed using data collated from Short (2006). Each beach was characterized at one or more locations in the field. As well as data describing each tidally defined zone, coastal exposure, and geological substrate, four context photographs were taken at each location, two at the backshore looking left and right along the beach, and two at the proximal foreshore looking left and right along the beach.

There is also a map of the geomorphology of the coastline, which shows landforms within three kilometres inland of the coast. This map is based on field data, high-resolution orthophotographs, a high-resolution digital elevation model, and Landsat TM multispectral data.

Oblique aerial photographs of the whole coastline were taken from a fixed-wing light aeroplane. To view these photographs, an interactive map-based viewing system is being developed by GSWA that allows users to access the photographs by either overview or in detail, to zoom in and out of each photograph, and to activate an animated sequence of photographs.

Conceptual mapping of the coast

The work carried out so far on coastal compartments and sedimentary cells and WACoast provides detailed data and information on the cross-shore and alongshore structure of the coast at regional to local, site-specific scales. However, planners and managers also need a clear understanding of the processes that might present a threat to existing or future infrastructure, fisheries,

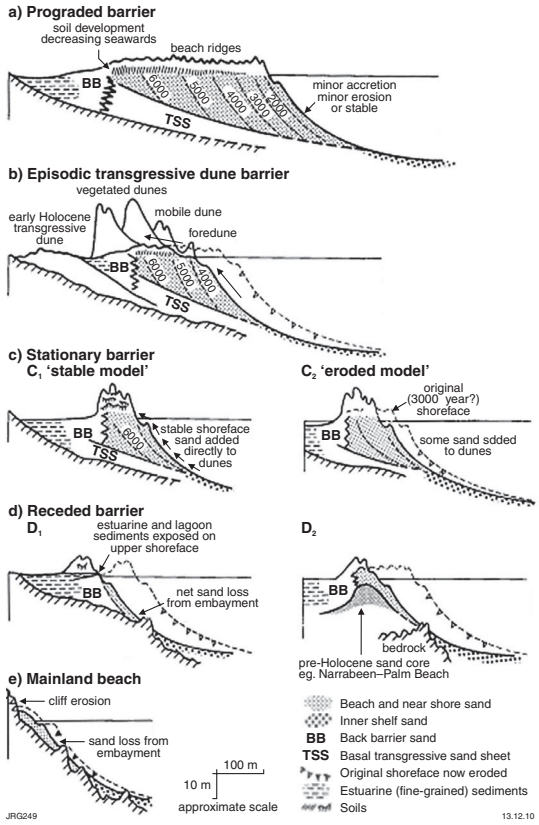

Figure 6. Conceptual models of various barrier types (from Chapman et al., 1982)

conservation areas, or marine habitats, and this can be provided in conceptual models of coastal behaviour. Concept mapping was chosen as the most effective method of modelling the collected information.

Concept maps are graphical tools for organizing and representing knowledge (Cañas et al., 2004). They use boxes or circles to represent concepts which, in the current context, are geological or geomorphological components of the coast. Connecting lines link concepts to indicate the relationships between them.

Conceptualizing coastal systems is a two-stage process. The first stage identifies the individual components (concepts) of the study area and the interactions between these components. Figure 7 is a concept map of Geraldton using data collected during the WACoast project and using CMapTools software (available from <*http://cmap.ihmc.us*>). Large-scale features, in this case two bays, a tombolo, a headland, and a river, are shown as white rectangles. The natural elements comprising each feature are shown as white ovals, and man-made features such as groynes and port facilities are shown as black rectangles. Solid lines represent sediment transport pathways and are helpful in understanding the sediment budget system. Dashed lines represent an influence link that does not involve sediment transfer.

The second stage of the process is the detailed analysis of the links between coastal components to provide a quantitative measure of the sediment budget in a particular geomorphological setting. Curtin University and the Department of Transport are jointly undertaking detailed offshore mapping to determine sediment budgets and, when available, these data will be incorporated into the concept mapping.

Potential applications

GSWA's geological and geomorphological mapping of the coastline has been done in consultation with the Department of Planning, Department of Transport, and Department of Environment and Conservation with the aim of providing consistent information readily usable by those responsible for coastal planning, risk assessment, and management. Local Government agencies have also been included in the process.

The hierarchical approach to characterizing the coast in terms of functional compartments and sediment cells has significant benefits for a wide range of applications, including risk management. Two factors are involved in assessing coastal risk: instability, or the changes taking place under existing conditions; and susceptibility, or the potential for change under different sea-level and climatic conditions. Risk can be assessed at any level in the hierarchy by combining instability and susceptibility in a matrix based on landforms.

Table 1. Terminology of backshore landforms (from Hesp, 1999)

Term	*Mode of formation*
Berm	Swash-deposited terrace, sand and/or gravel or shingle ridge
Beach ridge	Swash- and storm-wave deposit or ridge, sand and/or gravel or shingle
Storm ridge	Storm or high-energy wave-built ridge
Shingle ridge	Shingle or cobble or gravel (wave-built) ridge
Chenier	Storm wave-built ridge (sand, shell), often formed in mud-dominated environments
Beach-foredune ridge	Swash-deposited terrace or ridge with eolian capping
Foredune	Eolian sand deposited in vegetation at rear of backshore

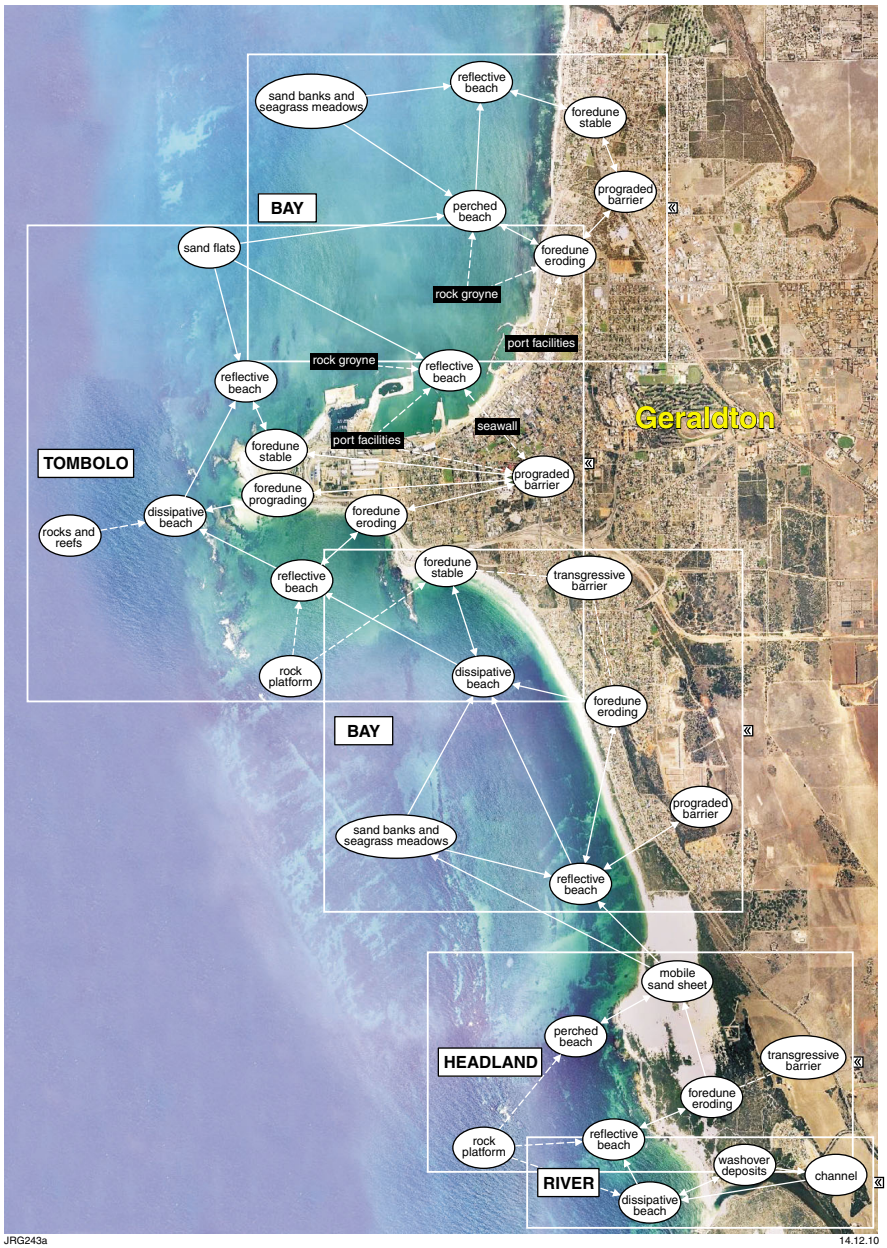

Figure 7. Concept map of the Geraldton coast. The individual components (concepts) of the coast and their interactions are shown. Natural elements are shown as white ovals and constructed features as black rectangles. Solid lines represent sediment transport pathways. Dashed lines represent influence links. The concepts occur in five natural groups represented by white rectangles.

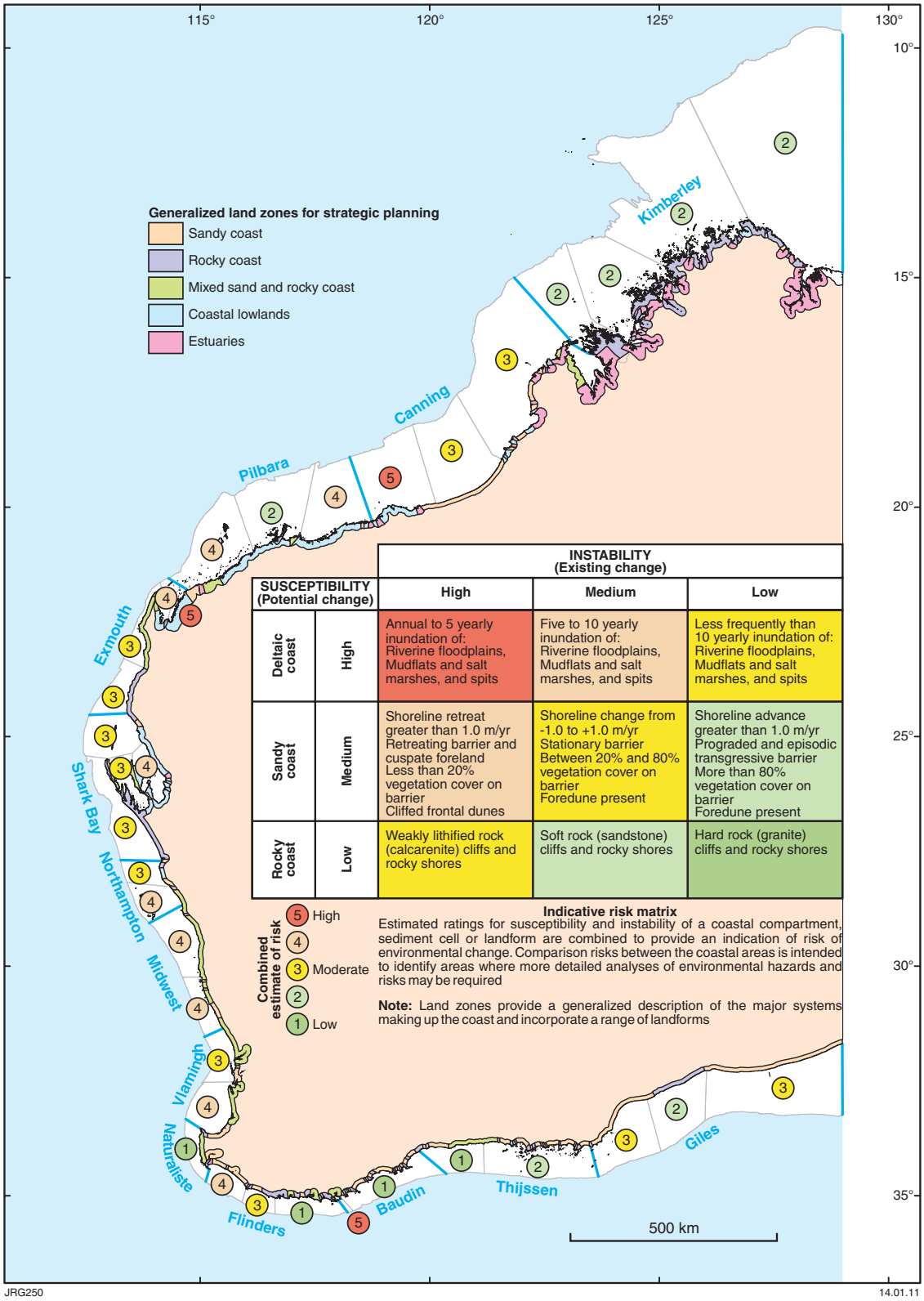

Figure 8. Coastal land zones and indicative risk for the Western Australian coastline. Data sources are GSWA, Department of Conservation, Damara Pty Ltd

At the primary compartment scale susceptibility to change is the primary factor; it relates to the structure of rocky coasts and the morphology of landforms. Instability describes the current state of the land surface and is secondary to susceptibility. Considered together, susceptibility and instability provide a broad indication of the level of potential risk (Fig. 8). A higher number represents a higher potential risk. At the most detailed levels in the sediment-cell hierarchy WACoast data can be used to develop indicative risk matrices for specific landform patterns such as, for example, episodic transgressive dune barriers and perched beaches on intertidal rock surfaces.

Other applications for the data include coastal planning for infrastructure and urban development, and natural resource management for determining marine conservation areas, sanctuary zones, and ecologically based fisheries management.

Conclusions

Coastal processes are not controlled by man-made administrative boundaries but by geology, geomorphology, meteorological, and oceanographic processes. The sediment-cell concept has become an essential part of proactive coastal management in Europe and North America, and its acceptance in Western Australia will represent a significant advance over existing approaches.

Breaking the coast up into compartments and cells based on geology, geomorphology, and marine processes provides a framework of coastal and nearshore management units that will enable managers and planners to understand coastal problems and potential solutions in terms of natural features and processes, which will allow them to anticipate the consequences of changes in coastal behaviour, whether man-made or natural, so that they will be better able to make informed strategic decisions in a wider context than has previously been the case.

Acknowledgements

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Program review

MINERALS AND PETROLEUM RESOURCES STUDIES

Petroleum systems studies

Highlights and activities 2009–10

The Canning and Amadeus Basins were the focus of activities during 2009–10 with other basins under a watching brief. Detailed studies of the Canning Basin continued and highlights included:

- Completed studies in the Canning Basin showing it is 'cooler' than first evaluated. Commenced basin studies determining the geothermal potential of the Carnarvon Basin, incorporating legacy data to do temperature at basement, depth to basement, and thermal conductivity analyses. The report has been released.
- Work on the western Amadeus Basin has already provided major improvements in the knowledge of the stratigraphy, demonstrated the use of stromatolite biostratigraphy for intra- and inter-basin correlations, and increased the likelihood that Neoproterozoic petroleum systems that have been demonstrated in the Northern Territory are present in Western Australia.
- Quality control of navigation for seismic surveys in the south west and south east Canning Basin has shown anomalies in the navigation data and some post-stack data missing which is now being corrected to provide interpreters good-quality data.
- The quality of some post-stack data is poor and efforts are needed to look at new reprocessing techniques to improve the data.

Objective: To develop consistent, basin-wide stratigraphic, structural and petroleum systems frameworks to encourage increased onshore petroleum exploration by establishing regional context and thus help secure the State's energy future.

Products 2009–10

- Prospectivity of State acreage release areas L09–3 and L09–4, September 2009 (Record)
- Geothermal Acreage Release, September 2009 (digital product)
- State Acreage Release, September 2009 (digital product)
- The Amadeus Basin in Western Australia: a forgotten corner of the Centralian Superbasin (Annual Review 2008–09 technical paper)
- Reassessment of the geology and exploration potential of the Western Australian Amadeus Basin (Record)
- Prospectivity of State acreage release area T10–1, Perth Basin (Record)
- Prospectivity of State acreage release area L10–1, Lennard Shelf, Canning Basin (Record)
- Prospectivity of State acreage release areas L10–2 and L10–3, Bangemall Supergroup (Record)
- Prospectivity of State acreage release areas L10–4 and L10–5, Blake Sub-basin, Officer Basin (Record)

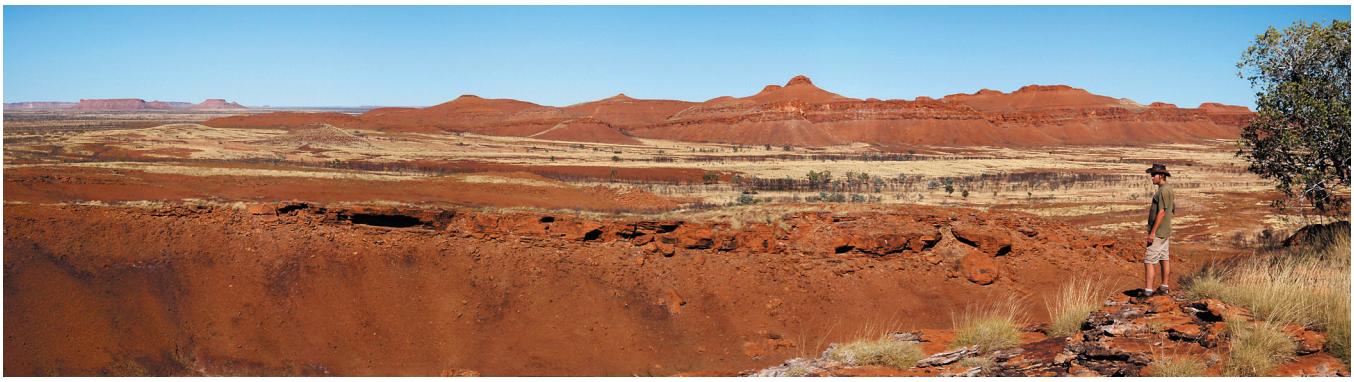

Figure 1. A view of Middle Permian siliclastic strata, Lightjack Formation in Shore Range, Fitzroy Trough, Canning Basin

Figure 2. Permian diamictite and contorted facies, Grant Group at 347 m in Newcrest HAC9201, Anketell Shelf, southern Canning Basin

- Geothermal Energy Potential in Selected Areas of Western Australia (Carnarvon Basin) (Record)
- Geothermal Acreage Release, March 2010 (digital product)
- State Acreage Release, May 2010 (digital product)
- Pre-interpretive package, SW Canning Basin seismic (digital product)
- New heat flow data aids exploration in the Canning Basin, Western Australia (APPEA Journal 2010, external paper)
- Did the Delamerian Orogeny start in the Neoproterozoic? (The Journal of Geology, external paper)
- Submarine origin for the Neoproterozoic Wonoka Canyons, South Australia (Sedimentary Geology, external paper)
- The Carribuddy Group and Worral Formation, Canning Basin, Western Australia: reassessment of stratigraphy and petroleum potential (APPEA Journal 2010, external paper)

Future work

Future work will focus on the Canning and Amadeus Basins, unconventional gas and geothermal energy. Products will consist of pre-interpretive and interpretive data packages, reports, presentations and papers including:

- Commence a stratigraphic study of the Devonian – Carboniferous Fairfield Group
- Continue a study of the Devonian carbonates in the central Canning Basin and Devonian clastics within the Fitzroy Trough (delayed due to maternity leave of geologist conducting this work)
- Detailed seismic interpretation of the Crossland Platform and Barbwire Terrace to deal with correlation issues and help prioritise the location of a stratigraphic hole to be drilled under EIS
- A regional seismic interpretation of the basin to refine basin subdivisions in the Canning Basin and enable stratigraphic correlations across the basin
- Continue the western Amadeus Basin project
- Build an inventory of potential shale gas formations of Western Australia, starting in the Perth and Canning Basins.

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Figure 3. A view of Middle Permian siliciclastic strata, Lightjack Formation in Shore Range, Fitzroy Trough, Canning Basin

Commodity and industry analysis

The Commodity and Industry Analysis group provides statistics and expert analysis on mineral exploration activity, mineral resources and reserves, and mining, for all commodities. Users of the group's outputs include other divisions of the Department of Mines and Petroleum, government agencies, industry, and the community at large. The group responds to about 400 enquiries annually.

A key component of this service is the maintenance and enhancement of Western Australia's mines and mineral deposits information database (MINEDEX), which can be accessed via the Department's website (<http://www.dmp.wa.gov.au/minedex>). MINEDEX data, and products derived from it, are highly valued — the database is regarded as the point of truth for information on mines and deposits, their location, compilation of mineral resource estimates, and historical production data. The database is also used to efficiently produce annual or biannual updates of a series of GSWA maps and publications, as well as a range of promotional posters and commodity information sheets. MINEDEX data are displayed in the Tengraph and GeoVIEW.WA systems, and on most maps produced by GSWA.

Highlights and activities 2009–10

The main achievement during 2009–10 was completion of compilation and editing of the draft GSWA Bulletin on 'Dimension stone in Western Australia, Volume 2 — dimension stones of the southern, central and northern regions' by Mike Fetherston, with publication in late 2010.

In conjunction with the Gemmological Association of Australia, a major review of gems and semiprecious stones in Western Australia has commenced.

MINEDEX was further enhanced throughout the year, but with deployment of the new features scheduled for 2010–11.

Products 2009–10

- Maintenance of the mines and mineral deposits database, MINEDEX (live via the Web)
- Miscellaneous articles on dimension stone in Western Australia (external publications)

Objective: To provide statistics, expert analysis, and authoritative opinion on all commodities in the context of mineral exploration activity, mineral resources and reserves, and mining to a range of customers including: other divisions of the Department of Mines and Petroleum (DMP), 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).

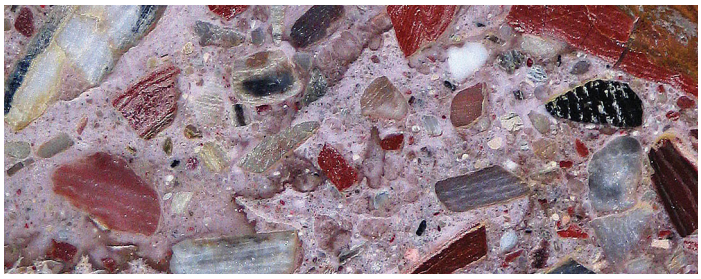

Figure 4. Asteroid Breccia from the Fields Find area. The stone comprises subrounded to angular pebbles, mainly chert and banded jasper.

- Major resource projects, Western Australia, 2010 (map)
- Iron ore deposits of the Yilgarn Craton, 2010 (map)
- Western Australian mines — operating and under development, January 2010 (map)
- A suite of commodity information sheets
- Annual overview on mineral exploration and development in Western Australia

Future work

- Annual updates of some of the standard products will be prepared
- Preparation of additional commodity fact sheets, together with updates of existing fact sheets
- Additional functionality of the MINEDEX system will be deployed
- A major review of gems and semiprecious stones in Western Australia will continue
- Compilation of a new Bulletin on the heavy mineral sand (Ti–Zr) deposits of Western Australia, which is an update of GSWA Mineral Resources Bulletin 10 (Baxter, 1977).

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Land use geoscience

Highlights and activities 2009–10

It is important to provide good geological advice to the community and government on the significance of the resource sector to the sustainable well-being of the Western Australian community and to ensure that government planning decisions do not impede resource access. The land use group provides resource assessments and thereby ensures that geological information is used in the decision-making processes of Government.

Objective: To maintain access for exploration and development of minerals, petroleum, and building materials on all lands in the State through provision of information and advice to government authorities, the resources sector, and the community. Assessments of the economic geology of areas proposed for land title and land use changes are carried out, and thereby provide advice on the impact on future exploration and resource development.

Referrals from other government departments

The group provides geological advice and comments to the Department of Regional Development and Lands regarding the potential impact that proposed land title and land use changes, including infrastructure development, could have on future access to mineral resources. This involves resource assessments, and facilitating discussions with companies and other government agencies. In addition, comments are provided to the Western Australian Planning Commission (WAPC) regarding the resource implications of land subdivision proposals.

Information on geology and mineral resources has been provided to local government and the WAPC on a range of planning schemes and policies related to Town Planning Schemes, Local Planning Strategies and the Metropolitan Region Scheme.

During 2009–10 advice was given on 1159 requests for subdivision proposals, land title or land use changes. This number is higher than for the previous year, reflecting increased economic activity across the State.

Conservation issues

- The group continued to be involved in policy development aimed at developing a balance between economic resource developments and managing the conservation values of resource-rich areas of Western Australia. This is particularly important with respect to the 57 pastoral leases, purchased by the Department of Environment and Conservation (DEC), whole or in part, throughout Western Australia for conversion to conservation reserves. Resource assessments of these proposed conservation reserves are continually being updated with the results of company exploration programs.
- Discussions with DEC are well advanced towards finding a balanced approach to conservation and mining activities on several DEC-purchased pastoral leases in the Mt Manning region where there are substantial exploration and mining interests, particularly for iron ore.

Planning and geological initiatives

- With the assistance of both explorers and miners, the titanium–zircon mineralization mapping project in the northern part of the Swan Coastal Plain was completed and published. As for the similar mapping south of Perth, these maps will be useful to planners and land owners as well as the mining industry by providing a compilation of known titanium–zircon deposits.

- Recent geological mapping, data compilation, digital data processing and new interpretations resulted in a digital dataset of significant basic raw material areas for the Metropolitan, Peel and Greater Bunbury Region Scheme areas and for the remainder of the Swan Coastal Plain extending from Lancelin to Yallingup. This work was done for discussion purposes in close collaboration with the Department of Planning to inform government strategies and policy on basic raw materials. The intention is to assist in protecting significant basic raw material resources from being developed for incompatible land uses, thus ensuring the long-term availability of these resources at a reasonable cost.
- Additional mapping and policy development work involving Donnybrook Sandstone was carried out for the Shire of Donnybrook–Balingup. This will be incorporated into the Shire's draft Local Rural Strategy to manage land development that may affect future extraction of this valuable and unique dimension stone resource.
- This group has been assisting other government agencies with coastal vulnerability studies. This work will further our understanding of the impact of climate change on urban and other proposed developments along the Western Australian coastline.
- Development of a management policy for the Western Australian Register of Geoheritage Sites is continuing.
- Members of the group represent the Department on a number of intergovernmental committees dealing with basic raw materials, planning strategies and State mineral strategies.

Figure 5. Geologist examining a mobile limesand dune south of Port Denison.

Future work

Work on the above projects will continue as required, particularly the provision of geological information and advice, and input to regional plans, and urban, rural, and community developments. Further drilling will be carried out in collaboration with LandCorp in Kalgoorlie to follow up some anomalous results in the planned industrial site. Mapping and other data obtained from the geological mapping and data compilation on the Swan Coastal Plain and WA coastline studies will be published.

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Geoscientific advice relating to exploration

Highlights and activities 2009–10

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

Exploration performance on 2360 mineral tenements (Table 1) was reviewed during 2009–10 as part of the assessment of applications for:

- exemption from expenditure conditions
- extension of term of Exploration Licences
- exemption from drop-off provisions for exploration licencesretention status
- Retention Licences
- Special Prospecting Licences
- iron ore authorization under Section 111
- Ministerial consent to dealings in Exploration Licences during their first year of tenure.

Since the amendments to the Mining Act were introduced in February 2006, mining lease applications received after that date can only be granted if either a mining proposal has been lodged or the presence of significant mineralization has been demonstrated within the area. In the latter case, a mineralization report must be submitted which is then assessed by the Director of GSWA. Since the amendment, 150 mineralization reports have been assessed (61 during 2009–10). Mineralization reports that have been accepted are available for viewing on the Department website.

Changes to the *Mining Act 2006* also introduced the concept of retention status for exploration and prospecting licences. Retention status can be granted for the part of a licence which contains a JORC-compliant mineral deposit (the remainder of the licence must be surrendered). Licences with retention status do not carry an expenditure commitment. The first four applications for retention status were received during the period.

The regulations dealing with exemptions from drop-off requirements for exploration licences (Regulation 22A) were amended in March 2010 to include an additional reason for exemption i.e. that work carried out justifies further exploration. The applicant has to show that any area reduction would unduly impact their exploration program. Twenty applications were received during the period.

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.

About three years ago, the Department started to follow up breaches of Section 115A of the Act (requirement to lodge a mineral exploration report). Compliance (in respect of lodgement of reports on time) stands at about 60%. Overdue notices were issued for about 6000 tenements. For 319 tenements, these letters were followed up with 'Intention to forfeit' notices. During the period, fines for late lodgement of reports were imposed in respect to 209 tenements. Three tenements were forfeited during the year for failure to lodge a mineral exploration report.

Due to the strength of the world iron ore market, the number of applications under Section 111 of the Act to authorize the holder to explore for iron ore had increased substantially in recent years. This year, applications have remained steady at 322. There are currently 1985 tenements (up from 1635 last year) authorized to explore for, or mine, iron ore. Exploration expenditure for iron (from ABS figures) was close to $500 million.

There has been an ongoing interest in exploring for uranium. There are 48 active exploration projects (combined reporting groups) in the State, a decrease from 67 projects at the same time last year. However, expenditure on uranium exploration (from ABS figures) in 2009–10 increased to $55 million, up from $30 million last year. This is due to higher expenditure on some of the advanced projects, whereas there has been a reduction in the number of greenfields exploration projects.

The number of applications for exemption from expenditure conditions received by the Department during 2009–10 increased to 4709 (from 3914 in the previous year). About 16% of exemption applications were refused, a small decrease from last year (17% refused). About 77% of applications were granted (an increase from 70% last year). The difference was made up by lapsed applications (tenements were surrendered before the applications could be determined).

Most referrals of applications for expenditure exemptions that come to GSWA are those under Section 102(2)(e) and (f) — that the tenement contains a mineral deposit that is currently subeconomic 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 are reviewed to substantiate such claims.

Before an exemption application is finally recommended for refusal, a Departmental committee (Exemption Committee) reviews the recommendation. GSWA is represented on this committee to ensure that geoscientific issues are considered in any decision. The committee also considers whether a fine should be recommended in lieu of forfeiture where an expenditure exemption has been refused. The decision lies with the Minister and he imposed fines on 368 tenements in lieu of forfeiture during the 2009–10 period (336 in 2008–09). A number of tenements (26) were forfeited.

The number of granted exemptions seems high but most are for partial amounts. Also, the majority of exemptions are still being sought on a project basis under Section 102(2)(h). This reflects the fact that about 70% of tenements requiring reporting under Section 115A of the Act are part of projects (1140 Combined Reporting Groups in total).

Overall total expenditure on exploration and mining by industry as claimed on Form 5 Operations Reports is currently about 23 times the minimum expenditure commitment under the Act; a decrease of about $780 million from 2008–09 to about $10.2 billion in 2009–10. Expenditure on mineral exploration activities (as a subset of total expenditure) remained static for the period at $1.6 billion.

It should be noted that due to the mode of reporting (Form 5s are generally submitted after the end of the reporting period), the expenditure figures may be up to a year behind the date expenditure was incurred. The expenditure figures for the 2009–10 period would still be influenced by the Global Financial Crisis.

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Table 1. Tenement reviews

Geological advice provided	**Number of tenement actions**					
	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10
Expenditure exemption	2 146	1543	1310	920	1185	1554
Extension of term (Exploration Licences)	286	237	105	346	229	309
Dealings in first-year Exploration Licences	67	80	10	54	43	18
Iron ore authorization	195	333	654	332	331	322
Iron ore drop offs (Exploration Licences)	15	20	36	53	66	59
Drop offs (Exploration Licences)	-	-	-	-	-	20
Retention Licence applications/renewals	2	1	7	7	10	14
Retention Status	-	-	-	-	-	4
Special Prospecting Licence applications	2	1	3	10	3	23
Mineralization reports assessed	-	-	7	40	42	61
Total	**2 713**	**2215**	**2229**	**1762**	**1909**	**2360**

Mineral systems studies

This group was known as 'Mineralization and Exploration Assessment' until the end of 2009–10. At the beginning of 2010–11 it was re-formed and refocused and will now carry out comprehensive studies of mineral systems in Western Australia with a view to building genetic models that can provide insights into the geodynamic environment of ore formation and allow a degree of predictability that can assist exploration targeting within greenfield areas. This is to be achieved mainly through field, geochronological, isotopic and petrological work, integrated with existing geophysical and geochemical data.

Objective: To carry out comprehensive studies of mineral systems in Western Australia with a view to building genetic models that can provide insights into the geodynamic environment of ore formation and allow a degree of predictability that can assist in exploration targeting for greenfield areas. This is to be achieved mainly through field, geochronological, isotopic and petrological work, integrated with existing databases. The information will be disseminated by means of GIS packages, internal and external publications, for the benefit of government agencies, tertiary institutions, resource companies, and the community.

Highlights and activities 2009–10

The main achievement during 2009–10 was completion and release of the 'Mineral Occurrences and Exploration Activities of the Peak Hill Region' (DVD product). Activities also included assessment of Mineralization Reports submitted for Mining Lease applications under Section 74 of the Mining Act. Ongoing work during 2009–10 included an audit of all mines, deposits and prospects shown on 1:100 000-scale geological maps published by GSWA. Such audit work (to remove duplicate sites and revise the coordinates of selected sites) was done on about twelve 1:100 000 map sheets.

Fieldwork and laboratory studies continued on the polymetallic Abra deposit (Jillawarra Sub-basin, Edmund Basin), Magellan lead deposit (Yerrida Basin), Minnie Springs Mo occurrence (Gascoyne Province), and the Gifford Creek Carbonatite Complex (Gascoyne Province).

Products 2009–10

- Mineral Occurrences and Exploration Activities of the Peak Hill Region (DVD product)
- A review of the geology and geodynamic evolution of the Palaeoproterozoic Earaheedy Basin, Western Australia. Earth-Science Reviews (external paper)
- Magellan non-sulfide lead deposit (GSWA Record 2009/4) and Ore Geology Reviews (external paper)
- Chemical fingerprinting of multiple large-scale magmatic events in the Mesoproterozoic Bangemall Supergroup, Western Australia. Journal of Australian Earth Sciences (external paper)
- Contributions to the Explanatory Notes of the Gascoyne and Musgrave mapping projects
- A comprehensive study of large igneous provinces and associated mineral systems in Western Australia was compiled and is under review
- Mineral occurrences were audited for twelve 1:100 000 geological map sheets produced by GSWA.

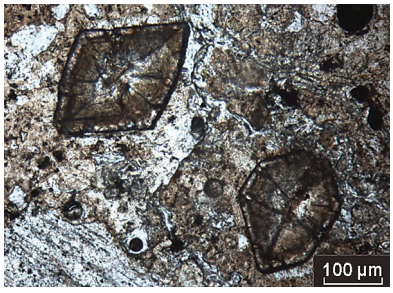

Figure 6. Photomicrograph of pyrochlore crystals in fenitized rocks of the Gifford Creek carbonatite complex

Future work

Studies are likely to focus on:

- The Abra breccia pipe polymetallic deposit and surrounding areas, with a view to understanding this complex mineral system and providing vectors for mineral exploration in similar settings.
- A study of the Doolgunna VMS mineralization is being undertaken with a view to assessing the potential for this deposit style elsewhere in the Capricorn Orogen.
- The Minnie Creek batholith, which contains molybdenum and tungsten mineralization.
- Study of REE mineral systems in Western Australia, leading to conceptual models of ore genesis and predictive targeting.
- Compiling an Explorer's Guide for Gold in the Yilgarn Craton (Yilgarn Gold Exploration Targeting Atlas) that addresses exploration techniques and targeting criteria aimed at the discovery of gold mineralization under cover. This is a two-year joint collaborative research project with The University of Western Australia.
- Archean VMS systems in the Yilgarn Craton.
- Significant mineralization revealed by co-funded drilling of the Exploration Incentive Scheme.

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REGIONAL GEOSCIENCE MAPPING

Pilbara Craton project

Highlights and activities 2009–10

- The Marble Bar 1:250 000 Geological Series map (third edition) was released. This map was compiled very differently from all previous 1:250 000 geological maps from the Pilbara. The new 1:250 000 geology was derived by a two-stage process involving GIS simplification (rolling-up) of the recently released 1:100 000-scale Geological Information Series geology followed by recompilation to further simplify areas still too complex for 1:250 000-scale publication. This process achieved a much improved consistency between the geology of this 1:250 000 map sheet and the 1:100 000 GIS database.
- Ongoing processing and interpretation of mapping data from the project, combined with new geological evidence from external researchers, revealed a need for further revisions to the lithostratigraphy of the Pilbara Craton. The most important change involved revising the lithostratigraphy of the 3525–3230 Ma Pilbara Supergroup; this has now been formally revised (see technical paper). The Pilbara Supergroup is now divided into three volcanic groups and one separate sedimentary formation. The oldest groups (Warrawoona and Kelly) are each more than 10 km thick and represent remnants of the world's oldest known large igneous provinces (LIPs).
- Field and office work was undertaken in preparation for a six-day field excursion to accompany the Fifth International Archean Symposium, Perth, in September 2010. Compilation of a field guide included updated reviews of the geology of the West Pilbara Superterrane, the De Grey Supergroup, and the Fortescue and Hamersley Basins.

Products 2009–10

- Marble Bar 1: 250 000 Geological Series map (third edition)
- Coongan 1: 100 000 Explanatory Notes
- Evidence for Mesoarchean (~3.2 Ga) rifting of the Pilbara Craton: The missing link in an early Precambrian Wilson cycle: Precambrian Research (external paper)

Objective: To increase geoscientific knowledge of the Pilbara Craton by the collection, synthesis, and dissemination of geological information. This is done 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.

Figure 7. Pillow structures in the Bradley Basalt, Whundo Group, 20 km south of Roebourne. The geochemistry of this group provides strong evidence for Mesoarchean plate tectonic processes, and this outcrop was one of many selected for the 5IAS field excursion to the west Pilbara.

Future work

Work during 2010–11 will include:

- Addition of eight 1:100 000 Geological Series map sheets to the Pilbara GIS database, requiring local reinterpretation of previously published geology in line with current lithostratigraphy
- Release of several Records on collaborative projects (external authors)
- Release of a Record (5IAS excursion field guide) on the West Pilbara Superterrane, the De Grey Supergroup, and the Fortescue and Hamersley Basins
- Release of a Record on the Trendall State Geoheritage Reserve
- Work towards compilation of Report 92 on the bedrock geology of the northwestern Pilbara Craton
- Geoscientific papers in external books and journals.

Beyond mid-2011, work will continue towards completion of the Pilbara GIS database, including production of interpreted bedrock geology maps at 1:250 000 scale for the East Pilbara Terrane. Reports on the Marble Bar and Kelly greenstone belts will be compiled, in addition to a Record on the geology and mineralization of the East Pilbara Terrane. Geoscientific papers will continue to be published in external journals.

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Geochemistry and regolith

Highlights and activities 2009–10

- Expansion of the WACHEM database to 28 367 analyses (a 4% increase from 2008–09), along with 1080 analyses of geochemical reference materials and 536 duplicate analyses. The relatively small number of reference material and duplicate analyses reflects the capture of legacy data, much of which does not have a high-quality control component. The available neodymium isotope data increased by 15% from 349 to 401 from 2008–09 to 2009–10
- GSWA's acquisition of a field-portable x-ray fluorescence (XRF) analyzer in 2008 has shown the value of making available real-time analytical data in the field. With advances in both hardware and software, GSWA investigated the acquisition of a second field-portable analyzer capable of analyzing light elements (e.g. Si, Mg, Al, P) in addition to lithophile and transition elements. Expansion to include light elements means acquisition of an almost complete major element composition, as well as usage to independently verify mineral identification data from GSWA's HyLogger™ drillcore spectral analyser
- Generation of regolith-landform coverage (as a complement to bedrock mapping) for the Pink Hills (2248), Lockier (2048) and Daurie Creek (2047) 1:100 000 Geological Series maps as a contribution to the Gascoyne mapping initiative. Targeted field work, sample collection, and geochemical analysis have been used to develop landscape evolution models for part of the Gascoyne region
- Presentation of a regolith workshop to GSWA staff, summarizing three-dimensional aspects of regolith and the selection and use of remotely sensed data for the generation of interpretive regolith maps
- Co-supervision of graduate student involved in extraction of open-file company data for drilling in the East Wongatha area to indicate the thickness and distribution of transported cover. These data have potential to be incorporated in an expanded style of regolith map as well as an aid in understanding regolith geochemical data
- Collaboration with Geoscience Australia in the identification and mapping of paleovalley deposits, in particular in relation to water resources

Objectives:

- To generate and collate geochemical and related data for regolith and bedrock throughout the State, and disseminate these data from a central repository in order to enhance prospectivity.
- To generate regolith-landform map coverage as a complement to bedrock mapping, and investigate the three-dimensional evolution of the regolith throughout time.

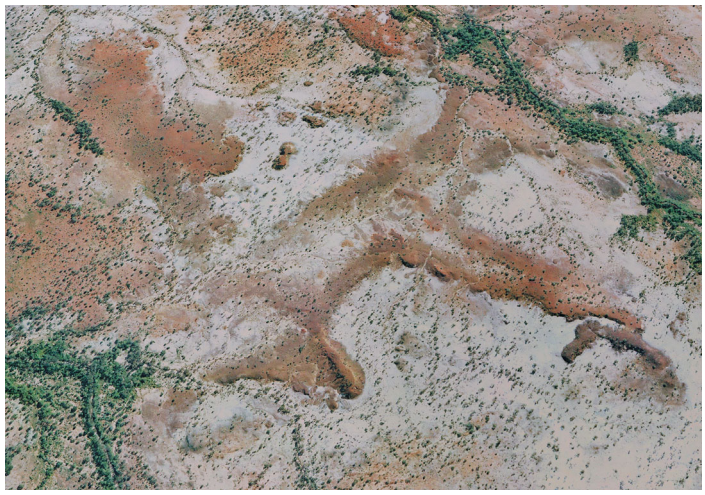

Figure 8. Orthophoto showing outline of paleochannel on Lockier sheet. Length of paleochannel ca. 2 km

Figure 9. Outcrop expression of paleochannel shown in image above

Figure 10. Large concentric weathering features in ferruginous duricrust representing paleo-ant nests on Pink Hills sheet

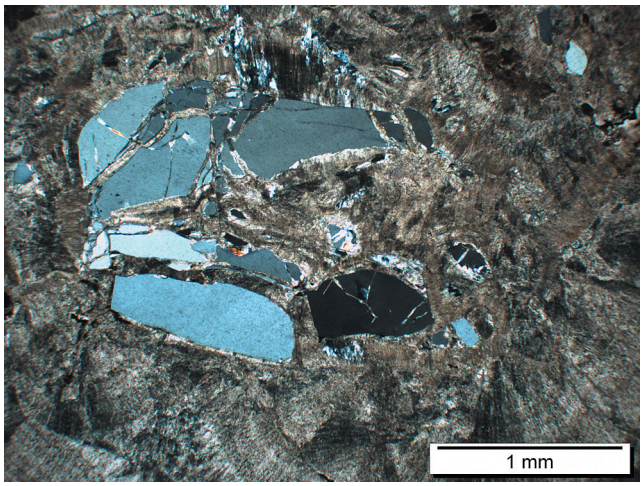

Figure 11. Brecciation of quartz grain due to calcrete development in paleovalley channel sands on Yinnetharra sheet

- Collaboration with staff from the South Australian Geological Survey in interpreting the recent geological history of the Eucla Basin margin with an emphasis on heavy mineral sand deposition
- Ongoing advice to team members of the Murchison, eastern Yilgarn, and west Musgrave team on the interpretation and mapping of regolith
- Collaboration and part sponsorship through MERIWA of biogeochemistry sampling program in the northern Yilgarn Craton.

Products 2009–10

Regolith coverage for Pink Hills 1:100 000 map sheet

Future work

- Commissioning second field-portable XRF analyser
- GSWA Record detailing the revision to GSWA's regolith classification scheme and approach to regolith mapping
- GSWA Record discussing regolith geology of part of the Gascoyne region
- Regolith coverage for the Mount Sandiman, Lyndon and Towera 1:100 000 map sheets
- Interpreted regolith coverage and bedrock geology for the Slaty Creek, Balwina, Watts, Kearney, and `Lewis 1:100 000 map sheets
- Continuing negotiation with Indigenous groups to secure access for completion of sampling for the National Geochemical Survey of Australia
- GSWA Record on biogeochemistry of the northern Yilgarn Craton.

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Gascoyne Province project

Highlights and activities 2009–10

During 2009–10, a collaborative Geoscience Australia, AuScope and GSWA deep crustal seismic reflection survey and gravity survey were completed. Fieldwork on the Gascoyne Province rocks was conducted on Lockier, Mount Sandiman and Lyons River. Mapping highlights included:

- Extensive SHRIMP U–Pb phosphate and zircon dating, combined with mapping, has confirmed the regional extent and significance of the 1280–1250 Ma Mutherbukin Tectonic Event. Deformation is bounded by the Ti Tree shear zone to the north where the metamorphic grade is low (low greenschist facies) but increases to the mid-amphibolite facies towards the south where regional-scale transtensional S–L fabrics dominate granitic rocks of the mid-crust.

Products 2009–10

- Release of hardcopy map for Candolle (version 2)
- Release of Explanatory Notes covering all lithostratigraphic units and tectonic events in the Gascoyne Province
- Publication of a GSWA record on the significance of the 2005–1950 Ma Glenburgh Orogeny and a GSWA report on the re-interpretation of the 1820–1770 Ma Capricorn Orogeny

Objective: To understand better the geological and metallogenic evolution of the Gascoyne Province by employing systematic regional mapping and associated geochemical, geochronological, geophysical, and petrological studies.

Future work

Work during 2010–11 will include:

- Mapping of Lyndon
- Update of the Western Capricorn Orogen Geological Information Series to include digital data from Pink Hills, Daurie Creek, Glenburgh, Landor, Lockier, eudamullah, edmund and maroonah
- Hardcopy maps for Pink Hills, Daurie Creek, Lockier, Glenburgh (version 2) and Landor (version 2)
- Explanatory notes updated for Mount Sandiman
- Interpretation, synthesis and publication of results from recent deep crustal seismic and gravity surveys
- Manuscripts for three GSWA Records will be published: 1) The nature and significance of the 1280–1250 Ma Mutherbukin Tectonic Event, 2) The geochronological and isotopic evolution of the Halfway Gneiss and 3) Geochemical and isotopic evolution of the 1820–1775 Ma Moorarie Supersuite
- Follow-up studies on (1) the age and petrogenesis of leucocratic granites in the Thirty Three Supersuite, and (2) the age of alkaline magmatism and hydrothermal activity in the Gifford Creek Carbonatite Complex are planned, in collaboration with Prof. B Rasmussen, and Dr CJ Gregory at Curtin University.

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Figure 12. Garnet–staurolite–andalusite schist of the Leake Spring Metamorphics on Mount Sandiman. The amphibolite facies metamorphic assemblage developed during the 1280–1250 Ma Mutherbukin Tectonic Event.

Edmund and Collier Basins

Highlights and activities 2009–10

During 2009–10 fieldwork focused on mapping and compilation of Bangemall Supergroup rocks on Mount Egerton and Mulgul 1:100 000 Geological Series maps. A collaborative Geoscience Australia, AuScope and GSWA deep crustal seismic survey was also completed with the aim of understanding the structure of the Edmund and Collier Basins and the nature of major growth faults. Highlights of mapping included:

- Padbury Group rocks on Mount Egerton 1:100 000 map sheet comprise low-grade pelitic and psammitic schist with lesser amounts of mafic schist and metadolostone. These unconformably underlie the basal Edmund Group and host gold mineralization at Hibernian and Gaffney Find workings of the Egerton Mining Centre
- The Edmund and Collier Groups have been extensively deformed with regional scale folds and faulting during the Edmundian Orogeny (1030–955 Ma). Younger strike-slip faults may be part of the Mulka Tectonic Event (570 Ma)
- U–Pb monazite and xenotime geochronology of the Abra polymetallic deposit demonstrate a hydrothermal mineralization event at c. 1380 Ma, and Re-Os geochronology of pyrite from the lode indicates an event at c. 1260 Ma.

Products 2009–10

- Hardcopy maps for Calyie, Tangadee, and Milgun (2nd edition) 1:100 000 map sheets
- U–Pb monazite and xenotime geochronology of the Abra polymetallic deposit and associated sedimentary and volcanic rocks (Record)

Objective: To increase the knowledge of the Edmund and Collier Basins (Bangemall Supergroup) 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.

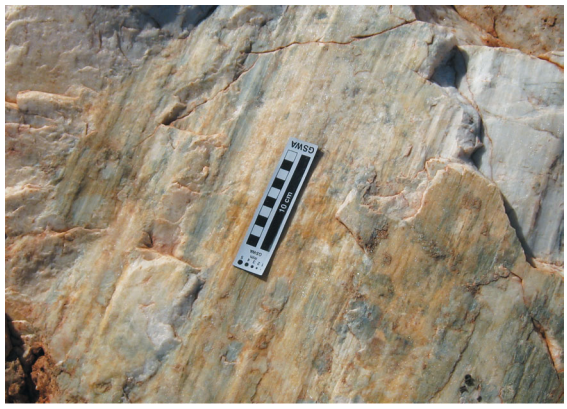

Figure 13. Slickensides in quartz veining associated with Edmundian Orogeny faulting, Mount Egerton 1:100 000 map sheet

Future work

Work during 2010–11 will include:

- Mapping of Mount Vernon, Lofty Range and Teano 1:100 000 map sheets
- Hardcopy maps for Mulgul, Mount Egerton and Teano 1:100 000 map sheets
- Update of the Western Capricorn Orogen Geological Information Series to include digital data from Calyie, Tangadee, Milgun, Mount Egerton, Mulgul, Teano, Elliott Creek, Capricorn, Ullawarra, Mangaroon, Maroonah and Edmund 1:100 000 map sheets
- Manuscripts for two GSWA reports will be published; one on the Lu–Hf isotopic composition of detrital zircons in the Edmund and Collier Groups, and the second on the Neoproterozoic structural evolution of the Edmund and Collier Basins
- Continued collaboration with Geoscience Australia on the interpretation of the Capricorn deep crustal seismic line
- Continuation of collaborative studies with Drs B Rasmussen and IR Fletcher at Curtin University, in order to provide age controls for selected sedimentary units in the Capricorn Orogen using U–Pb xenotime geochronology
- Continuation of a study of the geochemistry and geochronology of dolerite sills and dykes, including ring dykes, located mainly on the Edmund 1:250 000 Geological Series map.

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Chief Geoscientist and Terrane Custodianships

Highlights and activities 2009–10

- Ongoing work is related to quality control, geological consistency, database development and content validation, and capture of legacy data in current and future mapping areas. A significant portion of workflow is devoted to review and approval of manuscripts, maps, and digital products.
- Development of the Data Entry Application for the Explanatory Notes component of the Virtual Geology system commenced, and the application is presently under testing. Population and validation of the prototype version of the Explanatory Notes database continued in parallel, to ensure the currency of all lithostratigraphic units, tectonic units, and events referred to in all Geological Exploration Packages, Geological Information Series packages, manuscripts and printed or plotted map products released in 2009–10. Because of the cessation of traditional Explanatory Notes releases, an edited (with respect to layout) extract from the database covering the Gascoyne Province was compiled and released. A similar product is in process for the Musgrave Province. Assistance to Geoscience Australia on stratigraphic issues pertaining to Western Australia units continued.
- Planning and design work for the redevelopment of the WAROX field geology database commenced, with the aims of managing more diverse geological data and more effectively maintaining data integrity. This database holds GSWA field observations, and is the source of field observation data on GSWA maps and Geological Information Series releases. A test version of the database was established to allow for the development of a new front-end with improved editing, searching and downloading capabilities. WAROX continues to grow in size, with more than 60 000 legacy sites and associated field notes, lithology and sample data in the database. The redevelopment of the database will be important for meeting the future need to manage very large and diverse digital datasets. A key feature of the WAROX redevelopment has been the tight integration with the Virtual Geology system to ensure that data and reference tables from both sources are consistent.
- Field and office studies are continuing along the boundary zone between the eastern Yilgarn Craton and Albany–Fraser Orogen, and have highlighted the similarities with the Musgrave Province, and potential controls on mineralization and mineral systems. Owing to the emerging commonality in the geology of the Albany–Fraser and Musgrave Provinces, formal management of the Albany–Fraser work is moving to the Musgrave Province project in 2010–11.
- Collaborations with external organizations continued on the ARC Linkage projects on the Chronostratigraphy of Devonian Reef Complexes of the northern Canning Basin, focused on describing and sampling slope and

Objectives:

- To maintain an up-to-date and coherent geological framework for Western Australia
- To ensure that GSWA databases are consistent and integrated, and are capable of providing a seamless coverage of the State at a uniform standard, unconstrained by predefined geological or geographical boundaries, so that multi-themed geoscience information products can be generated from the data stored in GSWA databases
- To lead the development of standards for geoscience information collection and presentation within GSWA
- To provide scientific leadership within GSWA, and promote new developments in Western Australia to local, national, and international explorers and researchers.

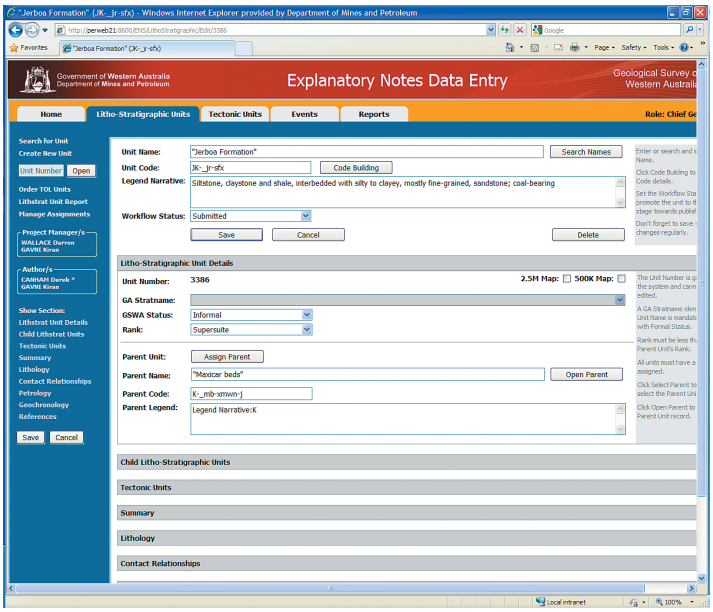

Figure 14. Explanatory notes database entry

basin facies, and the investigation of structural architecture of the Late Basins of the Archean Eastern Goldfields Superterrane. For the latter, outcomes were compiled in reports, delivered to grant members and interested parties every six months, and to the ARC yearly. For the former, laboratory work continues, and interim presentations have been made at several conferences worldwide by project workers. Planning meetings, discussions and presentations were also undertaken with project collaborators at Chevron San Ramon and California Institute of Technology, in conjunction with attendance and presentation at AAPG Annual Convention and Exhibition, in April 2010.

- Work on the compilation of the Geology and Resources of WA technical summary continued. The GSWA approach to geotourism products was the topic of a presentation at the 2nd Global geotourism Conference in Borneo, with subsequent requests for delivery of the same talk at various technical meetings in Perth.

Products 2009–10

- West Arunta Geological Exploration Package, 2009 update
- Geoscientific papers in external journals and public presentations.

Future work

- Work for 2010–11 will focus on generating updated 1:500 000 and 1:2 500 000 geological data layers, in both digital and hardcopy formats, to be derived from an updated (following recent 1:100 000 mapping) State 1:500 000 interpreted bedrock geology and regolith digital map layers. A spatially integrated linear geology (primarily dykes) layer, which has been lacking to date, is planned as part of the process at 1:500 000 and 1:2 500 000. A revised 1:2 500 000 tectonic units layer will follow on from the 1:2 500 000 geoscience layers.
- Database planning and supervision for Warox and Explanatory Notes development will continue, to ensure release of a populated, public version of the Virtual Geology system. Interim Explanatory Notes drawn from the trial database will continue to be released, along with Records providing geological overviews and progress reports.
- Other work for the year includes completion of initial Geology for Regions products, finalization of a collaborative project with PIRSA on mineral resource potential of the Eucla Basin and its hinterland, regular updating of 1:500 000 datasets, and ongoing appraisal and approval of GSWA products.
- Work related to quality control, uniformity of approach and data coverage, and state-wide issues will continue for the foreseeable future. Incremental updates of the 1:500 000 interpreted bedrock geology layer will continue as new mapping is completed in project areas. Review of GSWA manuscripts and graphic products will continue as usual, to maintain the quality and consistency of GSWA products. Advice will be provided to GA and other state geological surveys, and to academic researchers, for a coordinated approach to national geoscience initiatives, and for geological terranes that extend across state borders.

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East Yilgarn mapping

Highlights and activities 2009–10

- Publication of the last 1:100 000 map sheets required to complete coverage of the Eastern Goldfields Superterrane at 1:100 000 scale
- Release of an updated edition of the East Yilgarn GIS incorporating the newly published northeast Yilgarn mapping, and detailed mapping of metamorphic conditions generated through the pmd*CRC in cooperation with Geoscience Australia
- Field mapping and interpretation in the far eastern Yilgarn Craton (MINIGWAL and CUNDEELEE 1:250 000 Geological Series maps) for inclusion in the Albany–Fraser Orogen mapping product
- New field mapping in the southern part of the Youanmi Terrane is well advanced in the Southern Cross and Lake Johnston greenstone belts

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

This program focuses on the Eastern Goldfields Superterrane and the southern part of the Southern Cross Domain of the Youanmi Terrane in the Yilgarn Craton.

- Commencement of new ARC linkage project, in cooperation with the Centre for Exploration Targeting, to investigate the relationship between tectonic evolution and lode-gold mineralization in the Southern Cross district

- Commencement of project to implement stratigraphic subdivisions in the East Yilgarn GIS, incorporating findings from recent pmd*CRC and AMIRA projects, and results of current ARC Linkage project with Monash University and Gold Fields Ltd
- ARC Linkage project with Monash University and Gold Fields Ltd to study of the architecture of several late basins in the Eastern Goldfields, and its significance for gold mineralization
- The GSWA office in Kalgoorlie continues to provide advice and information to the general public, mining companies, and others about the geology of the Eastern Goldfields and adjacent areas.

Products 2009–10

- Strawbridge, Mulgabiddy Creek, Dorothy Hills, Toppin, Jutson, Yamarna, and Lightfoot 1:100 000 map sheets
- East Yilgarn 1:100 000 GIS digital package, 2010 update
- Application of SWIR spectroscopy in very low-grade metamorphic environments: a comparison with XRD methods (Record)

Future work

- Publication of the first-edition 1:100 000-scale mapping in the Southern Cross and Lake Johnston greenstone belts, and associated GIS layers and explanatory notes
- Ongoing development of the stratigraphy-based interpretation of the geology of the Eastern Goldfields Superterrane, and publication of tranches of the new interpretation, along with associated explanatory notes, as they are developed.

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Biostratigraphy and paleontological services

Highlights and activities 2009–10

- Continued digital capture of miscellaneous macrofossil and stromatolite data
- Continued work on the microbialite handbook
- Continued studies of stromatolites from the Amadeus Basin
- Continued studies of Cryogenian palynology from the Officer and Amadeus Basins

Figure 15. Holotype of** Horodyskia williamsii**, a new species name after the late Ian Williams

Figure 16. Lake Thetis microbialites before installation of a new boardwalk. Lake Thetis, now part of Nambung National Park, is the subject of a field guide and a useful model for Precambrian petroleum formation.

Objective: To provide biostratigraphic, paleoenvironmental, paleobiological and paleontological information that allows precise interpretation of correlations, age, environment, and processes in the evaluation of the State's hydrocarbon and mineral potential.

- Released a management plan for several newly created State Geoheritage Reserves
- Handled numerous requests for information from academics and industry.

Products 2009–10

- Published three papers on Archean microfossils (>3.0 Ga) from the Mount Grant area
- Published two papers, prepared a poster and gave several talks on the reassessment of the geology, exploration potential, and biostratigraphy of the Western Australian Amadeus Basin
- Published a paper on the molecular signature of the Neoproterozoic Acraman impact event
- Published a field guide to the microbialites of Lake Thetis at Cervantes
- Published two papers on *Horodyskia williamsii*, the string of beads fossil, and its discovery in Tasmania
- Published a management plan for State Geoheritage Reserves.

Future work

Paleontological collection and database work will continue. Current projects will be finalized in preparation for the retirement of the Chief Paleontologist.

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Geochronology

Highlights and activities 2009–10

- About 100 rock samples were processed for geochronology by GSWA's laboratory, and about 75 samples were dated using the Sensitive High-Resolution Ion Microprobes (SHRIMPs) in the John de Laeter Centre of Mass Spectrometry at Curtin University. These samples were dated in support of GSWA geoscience programs in the west Musgrave and Gascoyne Provinces, the Murchison, Eastern Goldfields, and Burtville regions of the Yilgarn Craton, the Albany–Fraser and Capricorn Orogens, and the Kimberley and Edmund Basins.
- Dating of pre- and post-tectonic leucosomes in migmatitic granites of the eastern Albany–Fraser Orogen has revealed an episode of deformation at c. 1680 Ma (now named the Zanthus Event). These results are important in understanding the tectonic setting of gold mineralization on the Yilgarn Craton margin and assessing the potential for mineralization elsewhere along the craton edge.
- Recent zircon analyses have revealed previously unsuspected c. 1400 Ma basement rocks in the west Musgrave Province. Several gneissic units are dominated by c. 1400 Ma protolith components, and zircons within a foliated monzogranite suggest that the rock crystallized at 1402 ± 4 Ma. The granite foliation is cut by a granite dyke intruded at 1318 ± 9 Ma, constraining the age of deformation between c. 1400 and 1320 Ma.
- New and previous geochronological data, together with petrography, geochemistry, and geological mapping, are helping to refine the ages of layered mafic–ultramafic intrusive suites in the northern Murchison Domain, some of which contain vanadium and Ni–Cu–PGE mineralization. Recent results for baddeleyite and zircon for the Narndee Igneous Complex indicate a crystallization age of 2799 ± 7 Ma, and zircon from an anorthosite of the Windimurra Igneous Complex indicates a crystallization age of 2802 ± 19 Ma. A dolerite of the Youanmi Igneous Complex yielded c. 2825 Ma xenocrystic zircons, which provide an older limit for emplacement of those mafic rocks.
- To help understand the petrogenesis of c. 1.8 Ga Moorarie Supersuite granites in the Gascoyne Province, a pilot project to measure oxygen isotopes in dated zircons was undertaken using the new IMS1280 ion microprobe at The University of Western Australia. The results indicate limited crustal contamination and a mantle component to some Moorarie magmas, which is consistent with an intracratonic rather than subduction setting during the Capricorn Orogeny.

Objective: As an integral part of GSWA's mapping programs and mineralization studies, the geochronology program acquires precise and accurate ages of rocks and geological events to better understand the geological history of Western Australia and contribute directly to enhancing the prospectivity of the State.

- GSWA continues to make improvements to web-based delivery of geochronology information. When accessed through the redesigned geochronology webpage, the interactive online mapping system, GeoVIEW.WA, opens with a geochronology theme pre-loaded. Spatially referenced GSWA (and Geoscience Australia) geochronology data can also be downloaded from the Data and Software Centre as an ESRI Shape file, a MapInfo TAB file, or as a KML file for use in Google Earth. Geochronology Records can also be accessed through the new Geochronology Cabinet within GSWA Publications' online catalogue. This allows users to search by author, year released, sample number, rock type, map name, tectonic unit, and interpretation (geological event dated) for the numerous rock ages (currently about 1000) across Western Australia that have been acquired since 1995.

Products 2009–10

- Compilation of Geochronology Information 2010 update (on DVD) — includes 97 new Geochronology Records

Contributions to:

- Explanatory Notes for the Gascoyne Province
- The Paleoproterozoic Capricorn Orogeny: intracontinental reworking not continent–continent collision (Report)
- Geochemistry, geochronology, and petrogenesis of Mesoproterozoic felsic rocks in the west Musgrave Province (Report)
- The Glenburgh Orogeny as a record of Paleoproterozoic continent–continent collision (Record)
- Age and geochemistry of the Alcurra suite in the west Musgrave Province (Record).

Future work

- Acquisition of geochronology in the Yilgarn Craton (Murchison and Southern Cross Domains), Gascoyne and west Musgrave Provinces, Albany–Fraser and Capricorn Orogens, and the Edmund and Canning Basins
- Expansion of GSWA's range of geochronological and isotopic techniques
- Continued improvements to web-based delivery of geochronological and isotopic data using GeoVIEW.WA, online catalogue, and Google Earth
- Compilation of Geochronology Information 2011 update (on DVD)
- Contributions to numerous GSWA publications.

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Geophysics and remote sensing

Highlights and activities 2009–10

- In this first year of the Exploration Incentive Scheme (EIS), nine separate surveys in the Eucla and Canning Basins were completed with the acquisition and release of a total of approximately 908 000 km of data.
- Three regional gravity surveys were carried out (South Yilgarn Margin — 6125 stations; Southern Cross — 6354 stations; North Gascoyne — 7292 stations) and the data from these released.
- Contracts were let for ten new airborne surveys to complete the coverage of the Eucla, Officer and Canning Basins, and for three regional gravity surveys in the southern Gascoyne, the Sandstone area, and in the northern Albany–Fraser region.
- An airborne gravity and gravity gradiometry test range was established at Kauring near York in collaboration with Rio Tinto Exploration and Geoscience Australia <www.ga.gov.au/minerals/kauring>.
- During the year, 180 new airborne survey datasets, containing approximately 690 000 line-km of data, were received for inclusion in the MAGIX data repository. At the end of the year, about 6.8 million line-km of private data from 1496 surveys were held in the repository.

Objective: To provide geophysical and remote sensing data, maps and interpretation products to support GSWA programs of regional and detailed geological mapping and analysis.

Products 2009–10

See Figure 17 for survey areas in which data were acquired and released.

Future work

- In 2010–11, the ten airborne surveys contracted in the Eucla, Officer and Canning Basins will be completed with the acquisition and release of an estimated 1.1 million line-km of data.
- Completion of the new gravity surveys contracted in the areas in the Gascoyne (9700 stations), Sandstone (6300 stations) and Albany–Fraser (9200 stations) will add a further 25 200 new gravity stations to the National Database.

See Figure 18 for programmed survey areas in 2010–11.

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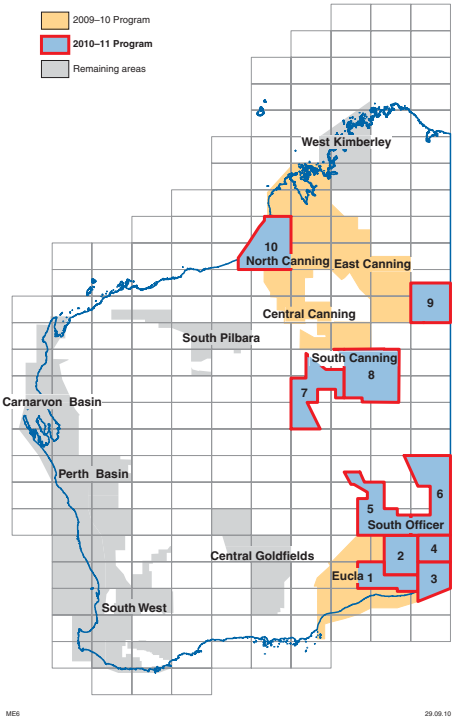

Figure 17. Aeromagnetic and radiometric survey areas 2009–10

Figure 18. Programmed gravity survey areas 2010–11

Program review

North Australian Craton project

Highlights and activities 2009–10

During 2009–10, work on the North Australian Craton mainly concentrated on the Kimberley region. Much of the work consists of capturing analogue data from first and second edition mapping (e.g. field sites, notes, photographs, structures, samples, and petrography) into GSWA's databases so these data can be used in a GIS environment. Highlights include:

- Capture of more than 8700 field site locations from the east Kimberley into GSWA's WAROX database. Capture of field sites from GSWA's and GA's second edition mapping is now complete.
- Entry of field notes and associated lithologies and structures for about 4500 sites on the Lissadell, Dixon Range, Gordon Downs, Mount Ramsay and Lansdowne 1:250 000 sheet areas in the east Kimberley.
- Compilation of solid geology layers for the Mount Remarkable, McIntosh and Dixon 1:100 000 sheet areas.

Products 2009–10

- Nil

Figure 19. Granite of the Bow River batholith near Bow River Homestead, east Kimberley

Objective: To understand better the geological and metallogenic evolution of the North Australian Craton by synthesizing existing regional mapping data with new targeted geochemical, geochronological, geophysical, and petrological studies.

Figure 20. Fold closure associated with backthrusting during the Yampi Orogeny in King Leopold Sandstone southwest of Dugong Bay, west Kimberley

Future work

Work during 2010–11 will include:

- Compilation of solid geology layers for the Turkey Creek, Bow and Tunganary 1:100 000 sheets for incorporation into an east Kimberley GIS data package.
- Capture of field sites from first edition mapping across the Kimberley region.
- Entry of remaining field notes and supporting data from the east Kimberley, and entry of field notes from the west Kimberley.
- Entering petrographic descriptions and photographs for all specimens sampled for geochronology and whole-rock geochemistry in the east Kimberley.
- Rationalizing the stratigraphy in the Kimberley region, and recoding rock units for GSWA's WA Geology Online database.
- Completion of a manuscript for a GSWA Record on the age of the Hart Dolerite large igneous province.

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West Musgrave Province project

Highlights and activities 2009–10

- Mapping of the Mount Eveline 1:100 000 Geological Series map was completed and mapping of the Bentley 1:100 000 map sheet commenced.
- Compilation of the Cooper 1:100 000 map sheet was completed.
- U–Pb SHRIMP dating of zircon showed that the felsic volcanic rocks in the Palgrave region of the Mount Eveline 1:100 000 map sheet spanned a depositional age of c. 1077 Ma to c. 1057 Ma, supporting previous suggestions that the Giles Event was complex and long-lived. Our work in this region has found no basis to suggest the Palgrave region reflects an ancient caldera structure.
- The Center for Exploration Targeting (CET) was contracted to conduct two magnetotelluric traverses to image deep crustal structures across and within the Musgrave Province.
- Monash University placed a PhD student, under co-supervision by GSWA staff, to investigate the physical volcanology of the Bentley Supergroup within the Palgrave region of the Mount Eveline and Bentley 1:100 000 map sheets.
- The University of Adelaide, GSWA and Curtin University were awarded an ARC Linkage Grant to investigate the conditions and timing of orogeny and reworking in the west Musgrave Province.

Products 2009–10

- Finlayson 1: 100 000 Geological Series map sheet
- West Musgrave Geological Information Series, 2010 update
- A kinematic, metamorphic, geochemical and geochronological framework for intracratonic reworking in the western Musgrave Block (Record)
- Age constraints and deformation history of the Shag Hill mylonites, western Musgraves (Record)
- Complex strain in mylonites from the western Musgraves, north of the Mann Fault, Western Australia (Record)
- Using calculated pseudosections in the system NCKFMASHTO and SHRIMP II U–Pb zircon dating to constrain the metamorphic evolution of paragneisses in the Latitude Hills, West Musgrave Province, Western Australia (Record)
- Age and geochemistry of the Alcurra Suite in the west Musgrave Province and implications for orthomagmatic Ni–Cu–PGE mineralization during the Giles Event (Record)
- Intracontinental orogenesis in the heart of Australia: structure, provenance and tectonic significance of the Bentley Supergroup, western Musgrave Block, Western Australia (Record)
- Age constraints and structure of the Cohn Hill shear zone, western Musgrave Block, Western Australia (Record)
- Geochemistry, geochronology and petrogenesis of Mesoproterozoic felsic rocks in the western Musgrave Province of central Australia, and implications for the Mesoproterozoic tectonic evolution of the region (Report).

Objective: To increase geological knowledge of the western part of the Musgrave Province by the collection, synthesis, and dissemination of geological information. This is done 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.

Figure 21. Crystal-rich volcaniclastic debris-flow deposit in the Bentley Supergroup, near Mt Elsie, west Musgrave Province

Future work

The following work is planned for 2010–11.

- Release of the Cooper 1: 100 000 map sheet and a further release of the West Musgrave 1:100 000 Geological Information package
- Completion of the compilation of the Mount Eveline 1:100 000 map sheet
- Mapping of the Bentley 1:100 000 map sheet will continue
- Redefining the Giles Event within the setting of the 1120 – 1020 Ma Ngaanyatjarra Rift, west Musgrave Province, central Australia will be released
- Provenance of the 1340–1270 Ma Ramarama Basin in the west Musgrave Province, central Australia will be released
- Geological evolution of the west Musgrave Province, central Australia — a field guide will be released.

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Youanmi Terrane project

This program focuses on the Murchison Domain and northern part of the Southern Cross Domain of the Youanmi Terrane in the Yilgarn Craton.

Objective: To increase geoscientific knowledge of the western part of the Yilgarn Craton by the collection, synthesis, and dissemination of geological information. This is done 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 2009–10

- Acquisition of almost 700 km of deep-crustal seismic and magnetotelluric data across the Narryer Terrane and the northern part of the Youanmi Terrane, Yilgarn Craton.
- Compilation of the Austin, Cue, and Reedy 1:100 000 Geological Series map sheets.
- Completion of field mapping on the Austin and Wynyangoo 1:100 000 map sheets; and over the area covered by the Narndee and Windimurra Igneous Complexes.
- The new stratigraphic interpretation of the north Murchison Domain was presented at the Australian Earth Sciences Convention in Camberra.
- Field mapping and studies undertaken as part of an ARC Linkage project with the Australian National University and Maximus Resources Ltd on the large layered mafic–ultramafic intrusions in the eastern part of the Murchison Domain have shown that Narndee Igneous Complex represents a different magma source from the igneous complexes of the Meeline Suite (e.g. Windimurra, Youanmi, Barrambie).
- Collection of data was completed for the Murchison Domain, and the Narryer and South West Terranes, for the collaborative West Yilgarn Metamorphic Project with Dr Ben Goscombe of Adelaide University. Analyses of samples collected from the Southern Cross Domain in 2008–09 were also completed.

Products 2009–10

- Murchison 1:100 000 GIS, 2009 update

Future work

- Interpretation of the newly acquired deep-crusal seismic and magnetotelluric data from the Narryer and north Youanmi Terranes
- Continuation of field mapping in the Meekatharra–Wydgee greenstone belt to complete mapping on the Meekatharra, Gabanintha, and Nowthanna 1:100 000 map sheets
- Compilation of mapping in the Meekatharra–Wydgee greenstone belt on the Wynyangoo and Mount Magnet 1:100 000 map sheets
- Publication of mapping over the Windimurra, Narndee, and Youanmi Igneous Complexes. These intrusions are spread across the Wynyangoo, Woodley, Challa, Windimurra, Coolamaninu, Youanmi, Bungar, and Malgar 1:100 000 map sheets, all of which will be published as first-edition maps
- Continuation of ARC Linkage project
- Continuation of the collaborative project with Dr Ben Goscombe of Adelaide University to generate a detailed metamorphic map and GIS layer, along with associated analytical data, over the whole of the Yilgarn Craton.

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Albany–Fraser Orogen project

Objective: To understand better the geological and metallogenic evolution of the poorly exposed Albany–Fraser Orogen through interpretive bedrock mapping utilising both government and company geophysical data, and combining this with field studies, whole-rock geochemistry, and a range of isotopic petrogenetic and geochronological studies.

Highlights and activities 2009–10

- Fieldwork focused on geochemical sampling of the 1700–1650 Ma Biranup Zone in areas north and south of the Trans Railway, and the c. 1300 Ma Fraser Zone to examine relationships between the two zones. The Fraser Zone is best interpreted as a lower crustal region of high to ultrahigh temperature metamorphism, extensively intruded by sheets of gabbro that melted the felsic country rock and produced granitic and hybrid magmas.
- SHRIMP dating of zircons in para- and orthogneisses has helped establish a temporal framework for the 1700–1650 Ma Biranup Zone, and identify a previously unknown tectonothermal event, the Zanthus Event, at c. 1680 Ma.
- Results of Lu–Hf analysis of dated zircons have shown a direct connection of the oldest Biranup Zone granites with the Yilgarn Craton, and that Biranup Zone granites become progressively more juvenile with time — this is potentially significant in terms of gold sources and mineralization events and shows that the Biranup Zone is not exotic to the West Australian Craton.
- Discovery of an Archean c. 2680 Ma fragment of metasyenogranitic rocks in the vicinity of Mt Andrew, surrounded by Biranup Zone migmatised orthogneisses — this supports the results of the Lu–Hf analysis that the Biranup Zone contains reworked Archean crust.
- Gravity and aeromagnetic data analysis combined with fieldwork has allowed interpretation of the geometry and kinematics of many of the major faults in the orogen, such as the Fraser Fault Zone and Newman Shear Zone, and to map out fold sequences and relationships with shear zones. The intent is to build a structural model of the orogen.
- Construction of a regional interpreted bedrock geology map based on all of the above — this provides geological and spatial context for sampling, and forms the basis for interpretations of tectonic events.

Products 2009–10

- Annual Review 2008–09 — New geochronology from the Albany–Fraser Orogen: implications for Mesoproterozoic magmatism and reworking
- External paper submitted to Precambrian Research — Paleoproterozoic tectonomagmatism and Mesoproterozoic reworking of the Albany–Fraser Orogen: U–Pb and Lu–Hf evidence for modification of the Yilgarn Craton margin
- Building the Proterozoic Albany–Fraser Orogen on the Yilgarn Craton margin: setting the scene for Tropicana (Extended abstracts)
- Geological Society of Australia Abstracts (SGTSG conference) — Building a proterozoic orogen on an Archean craton margin: the Albany–Fraser Orogen, Western Australia
- Regional gravity data (2.5 km^2 grid) of the southeastern Yilgarn Craton margin and Albany–Fraser Orogen (about nineteen 1:100 000 map sheets)

Future work

The Albany–Fraser Orogen project has now combined forces with the West Musgrave Province project, as it has been recognized that there is a strong temporal link of tectonothermal events from c. 1350 to c. 1120 Ma. It is likely that the Albany–Fraser Orogen might hold some keys to a better understanding of the geological evolution of the West Musgrave Province, and vice versa. Fieldwork and sampling has been undertaken to examine the relationships of the c. 1300 Ma Recherche Supersuite to the Fraser Zone.

- Geological Exploration Package — includes a new interpreted bedrock geology map covering over ten 1:250 000 map sheets
- Kinematics of bidirectional extension and coeval NW-directed contraction in orthogneisses of the Biranup Complex, Albany–Fraser Orogen, Southwestern Australia — PhD thesis as part of collaborative work with the University of Texas at Austin, USA (Report)
- Geophysical and structural interpretation of the central and eastern Albany–Fraser Orogen (Record)
- Inferences on crust-mantle interaction from Lu–Hf isotopes; a case study from the Albany–Fraser Orogen (Record)
- Whole-rock geochemical data analysis (Biranup and Fraser Zones) (Record)
- BSc. Honours theses, as part of a collaborative program between GSWA and Curtin University to undertake detailed studies of metamorphism and monazite dating
- Embedded researcher program with CSIRO and various exploration companies to look at relationships between regolith and basement
- ARC Linkage Grant administered through The University of Western Australia looking at numerical models of deep crustal fluid flow.

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LOGISTICS AND FIELD SUPPORT

Logistics support and core library services

Perth and Kalgoorlie core libraries

- The Perth Core Library has been at near full capacity for most of the year. Due to the ongoing high work load extra agency staff have been employed.
- Offshore petroleum exploration clients continue to set a high demand for viewing and/or sampling of core and cuttings in the Perth facility.
- A steady number of industry clients and research groups are also using the Kalgoorlie Core Library facilities.
- Increasing numbers of companies and Institutions are using the Perth Core Library for workshops and joint venture viewing with numerous international visitors attending these events.
- Both core libraries are also being used to show geologists and students the importance of drill core.
- There was a sharp increase of core added to the libraries due to the success of the co-funded drilling program.
- During the year, a total of 1772 clients viewed and/or sampled core or cuttings at the Perth and Kalgoorlie facilities. Clients spent a total of 7872 hours viewing core and cuttings, and took 2554 samples.
- Over 68 km of core and 947 ditch cutting boxes were accessed by these visitors.
- A total of 17 021 metres of core, 2068 boxes of cuttings and 318 sidewall cores were accessioned into the collection.

The Perth Core Library is investigating the need to increase its inside viewing area.

Field logistics

- The specialized 4WD fleet continues to satisfy all divisional field transport requirements. Air transport between Perth and regional centres for breaks during the field season ensures efficient use of the fleet.
- Additional field assistants required for field mapping programs continue to be sourced from an employment agency, allowing flexibility in meeting short-term needs for field staff. One permanent field staff resigned and the position was advertised.
- This year's field season started quite early and will be very busy.

Objectives:

- To manage core library facilities in Perth and Kalgoorlie to service the needs of industry, researchers and GSWA
- To manage field support services, including the provision of transport and other equipment, field assistants and communication links for all GSWA field parties
- To manage inventory services for all GSWA publications.

- Continuous improvement of work practices and training remain a priority for field safety. High Frequency radios installed in all field vehicles and at the Carlisle base station use leading-edge HF technology including Automatic Link Establishment.
- GPS antennas are now also fitted to the HF radios so we can check the vehicles location via HF radio. All field staff are also issued with a satellite telephone and personal EPIRBs.
- Vehicle tracking units using satellite technology have also increased the safety of field staff.
- GSWA's publication store at Carlisle maintained the issue of Reports, Bulletins and maps to the point of sale at the Information Centre in Mineral House.

A total of 20 547 publication items were dispatched from Carlisle to the sales counter on the first floor of Mineral House.

Figure 22. Field logistics depot, Carlisle

Figure 23. JH (Joe) Lord Core Library, Kalgoorlie foyer

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GEOSCIENCE EDITING AND PUBLISHING

Geoscience information

Objectives:

- Provide a quality and timely editing and publishing service for geoscientific manuscripts, maps, and digital data products produced by GSWA geologists and geoscientists
- Provide information and advice for the general public on all aspects of Western Australian geology
- Provide the infrastructure for the management of geoscientific data
- Develop and coordinate geoscientific database policies and standards
- Promote GSWA 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.

Products 2009–10

The Geoscience Information Group continued the delivery of high-quality publications, including maps, manuscripts, digital data packages and promotional activities, and information services through geoscientific advice and promotional activities (see Appendix Products and services 2009–10 for details of products).

The production of 13 series maps this year, combined with the 14 from last year, suggests that GSWA continued its efficiencies adopting new map compilation technologies, and standardizing map unit codes across the State.

Geological maps

24 maps at various scales were published including:

- 13 1:100 000 and 1:250 000 geological maps
- 11 project maps at various scales

Geoscience publications

36 manuscripts were published including:

- 3 reports
- 19 records
- 2 explanatory notes
- 12 non-series books

Digital data packages

- 22 geoscientific digital data packages were released including 1:100 000 geological information series, non-series digital products, 1:100 000 geological exploration package, GIS data layers

Airborne geophysics

- 19 973 gravity stations
- 907 783 line-km airborne geophysics were flown
- 60 024 metres of drilling

Figure 24. Collection of products

Program review

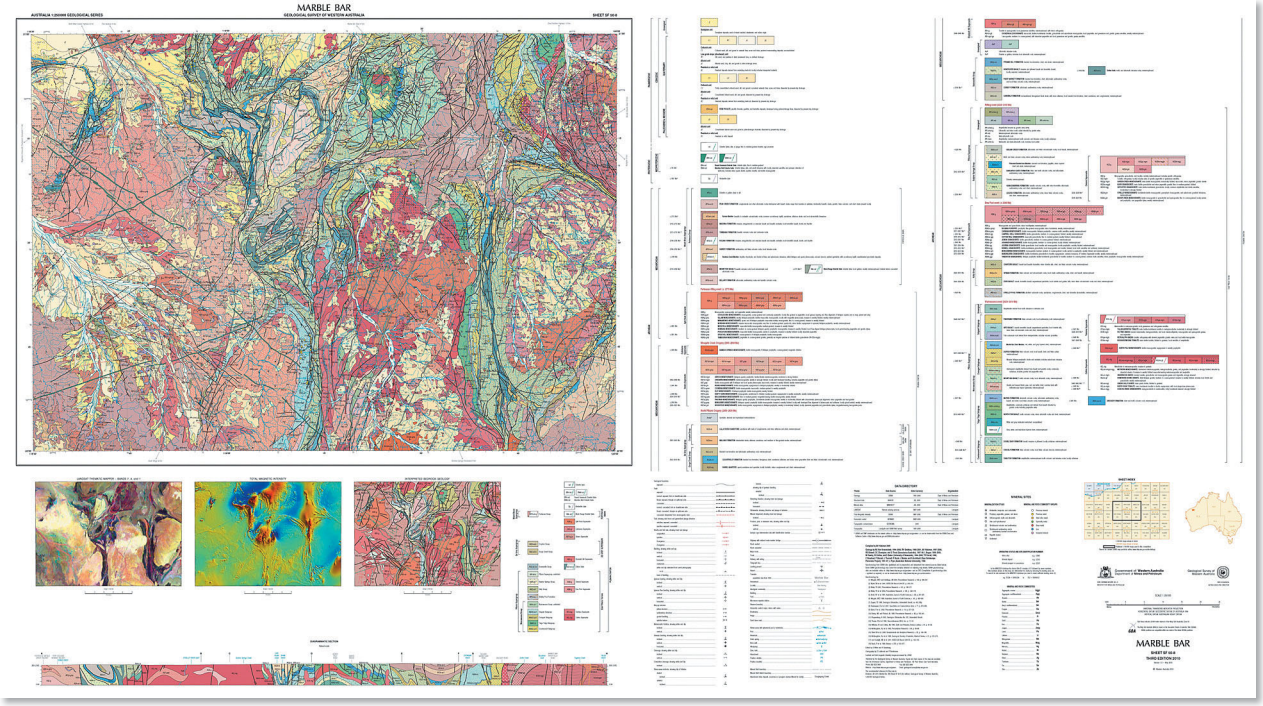

Figure 25. Image of Marble Bar 1:250 000 Geological Series map sheet

Other activities

There was continued focus on providing better access to and management of geoscience data through:

- the commencement of the migration of geoscience databases from Oracle to SQLServer
- addition of a number of image datasets to GeoVIEW.WA
- improvement of web-based access to geochronology data
- development of GeoMapWA, a free application distributed on DVD and USB drives to visualize and analyse GSWA geoscience information.

In collaboration with CSIRO, through the AuScope project, implementation of the Virtual Core Library and Earth Resources data models and web-based delivery systems began.

The promotion of Western Australia's prospectivity continued at industry events both in Australia and overseas (see Appendix Maps, books and datasets released in 2009–10 for details of products).

The Branch continued the successful technology training sessions in Perth and Kalgoorlie. The Petroleum and GSWA Open Days were held to promote better communication with our customers.

Future work

The Group will continue to provide geoscientific maps, manuscripts, digital datasets and promotional materials including:

- 13 Geological Series map sheets
- 12 map sheets at other scales
- 37 manuscripts
- 12 digital products
- Completion of the development of GeoMap.WA
- Completion of the migration of the geoscience data repository to SQLServer
- Commencement of the development of a web-based map viewer to replace GeoVIEW.WA
- Redevelopment of MAGIX application to manage the geophysical data repository and the submission, archive, and release of airborne survey datasets from the exploration industry.

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GEOSCIENTIFIC AND EXPLORATION INFORMATION

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.

Highlights and activities 2009–10

- The WAMEX database for managing mineral exploration reports and associated data was improved. Focus in the last year has been on the better data management of individual components including:
    - drilling data
    - surface geochemistry
    - geophysics
    - spectral data
    - GIS datasets.

  It has also included reorganization of the legacy WAMEX data for the website and updating of the bibliographic details of individual reports.
- During the year, 3376 digital mineral exploration reports were received. The total number of reports now held in the WAMEX database stands at approximately 77 000.
- There were 21 120 visits to the WAMEX online webpage, 86% from outside the Department. An additional 7686 reports were released to open file, making the total number of reports available 55 500, and of these reports 99.9% are available digitally to view or download.
- The second annual Sunset Clause reports (received in 2004) were released on the website in May 2009. A total of 758 reports were released. Over 20 000 reports have now been released to open file since the inception of the Sunset Clause.
- There were 4336 open-file reports scanned to PDF files (previously only available on microfiche) for release via the website.
- All digital open-file reports are now available on hard drives in the Kalgoorlie and Perth libraries for downloading of large numbers of reports. These are updated monthly.

Reporting standards

The compliance with the standards of reporting as specified in the 'Guidelines for Mineral Exploration Reports on Mining Tenements' is closely monitored and there is still room for improvement, particularly in the submission of geochemistry and drilling data. To ensure improved compliance, there is now a process in place whereby failure to respond to letters for missing data could lead to a notice of intention to forfeit the tenement.

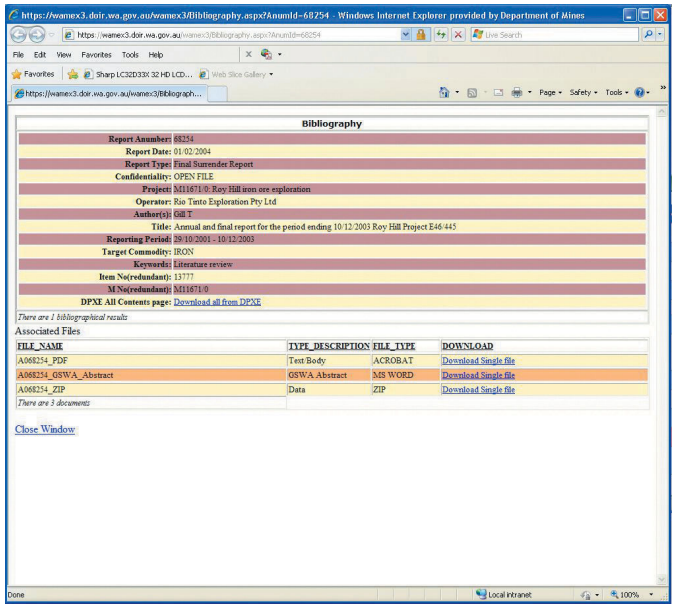

Figure 26. A WAMEX entry

Future work

- Update of the 'Guidelines for Mineral Exploration Reports on Mining Tenements'
- Update Mineral Exploration Reporting Templates to include QA/QC analyses
- The next release of reports under the Sunset Clause will be advertised in February 2011 for reports submitted in 2005
- Continue the development of the WAMEX database
- Continue to improve the searching capabilities of WAMEX Online, particularly the spatial front end.

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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 Australia Petroleum Information System).

Highlights and activities 2009–10

The program of scanning general well reports, title reports and seismic reports from hard copy to PDF and TIFF formats continued with a total of 1502 reports being scanned and loaded onto the WAPIMS system for online web viewing. The scanning program includes also the scanning of hard copy seismic sections to PDF and segy (where no digital post-stack data are available).

Transcription of seismic field and processed data from the Canning and Perth basins from nine-track reels to 3590/3592 cartridges (3058 tapes) continued to reduce the number of 'old' tapes in the archive (from 80 000 to 5000) and move this valuable data to new and more reliable data.

WAPIMS database

The WAPIMS technical upgrade project commenced and will be finished in 2010–11.

The project's objective is to upgrade DMP's WAPIMS database to provide a more streamlined data submission and release system for the petroleum industry.

Some of the benefits expected at the completion of the project include:

- Improved integration between core WAPIMS applications
- Eliminated reliance on Paradox Forms
- Ability to easily extend the underlying data model (Seabed)
- Consolidated all data into a single entitled data repository

Currently WAPIMS has 6456 external registered users, a total of 20 000 files (segy, logs, reports, and core images) and more than 750 GB of data available to the public.

WAPIMS data packages

- Comprehensive Data Package; the open file petroleum data from WAPIMS database is available on external hard drive, sorted by activity (seismic, wells) and basins for an easy access on request from the petroleum industry
- Geothermal Data Package
  - Petroleum Acreage Release Data Package
  - Navigation Data Package (onshore and offshore)
  - Barrow Island data package (reports and well logs)

2009–10 data release

During 2009–10, 266 requests were attended to, including general and data package requests for well and seismic data, with a total of more than 10 TB of petroleum data. In addition, 192 requests for sampling or borrowing slides were processed.

Around 30 000 backlog thin sections have been accessioned and been made available to the public in order to assist in the sampling approval process.

Future work

Future work will continue to focus on the uploading of data into online systems, digital data remastering, processing data requests, and approvals for core sampling and loaning of thin sections, specifically:

- completing the WAPIMS technical upgrade
- capturing well data from WCRs and Studies for 'Schedule of Wells' (using automatic data capture methods and spreadsheet loaders from the new ProSource facilities to increase accuracy and productivity)
- capturing general reports — paleontology, analyses
- continuation of the transcription program
- continuing to generate Public Reports (WAPIMS), addressing the most common requests from the industry.

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National Virtual Core Library (HyLogger)

As part of an Australia-wide initiative, the AuScope National Virtual Core Library (NVCL) aims to generate and make available via the Internet imagery and mineral spectral data for drillcore using HyLogger technology. HyLogger machines have been deployed to each State and the Northern Territory geological surveys; GSWA's HyLogger was delivered to the Perth Core Library in July 2009. Here, it is housed in a custom-built container, ensuring a dust-free and temperature-controlled workspace to provide optimum operational conditions.

Since its installation and commissioning, a variety of drillcore (both mineral and petroleum) has been scanned. The choice of core is made according to GSWA's work program, the geological significance of drillcore, core availability, and location of drilling within the Australian Geotransect zone. More recently, drillcore generated as part of the Western Australian Government Co-funded Exploration Incentive Scheme (EIS) Drilling Program has been routinely scanned with the HyLogger.

For the 12-month period from the installation of the GSWA HyLogger in June 2009 (i.e. the 2009–10 financial year), more than 19 200 metres of mineral and petroleum core from 65 holes and wells have been scanned, and the data successfully processed. This comprises 7603 metres of mineral core from 37 holes, 3480 metres of EIS core from 14 holes, and 8148 metres of petroleum core from 14 wells.

Objective: To provide high-resolution mineral spectral data and imagery for drillcore throughout Western Australia using HyLogger technology.

Highlights and activities 2009–10

- GSWA Annual Lectures presentation
- GSWA Open Day 2009 presentation and Poster
- Oral presentation and workshop at the AIG seminar 'Rapid Geochemistry and Mineralogy'
- Curtin University Applied Geology seminar presentation
- Poster at Petroleum Open Day 2009
- Induction sessions for GSWA staff
- Use of HyLogger data in 3D reconstruction of Minnie Springs (Gascoyne Province) molybdenum mineralization

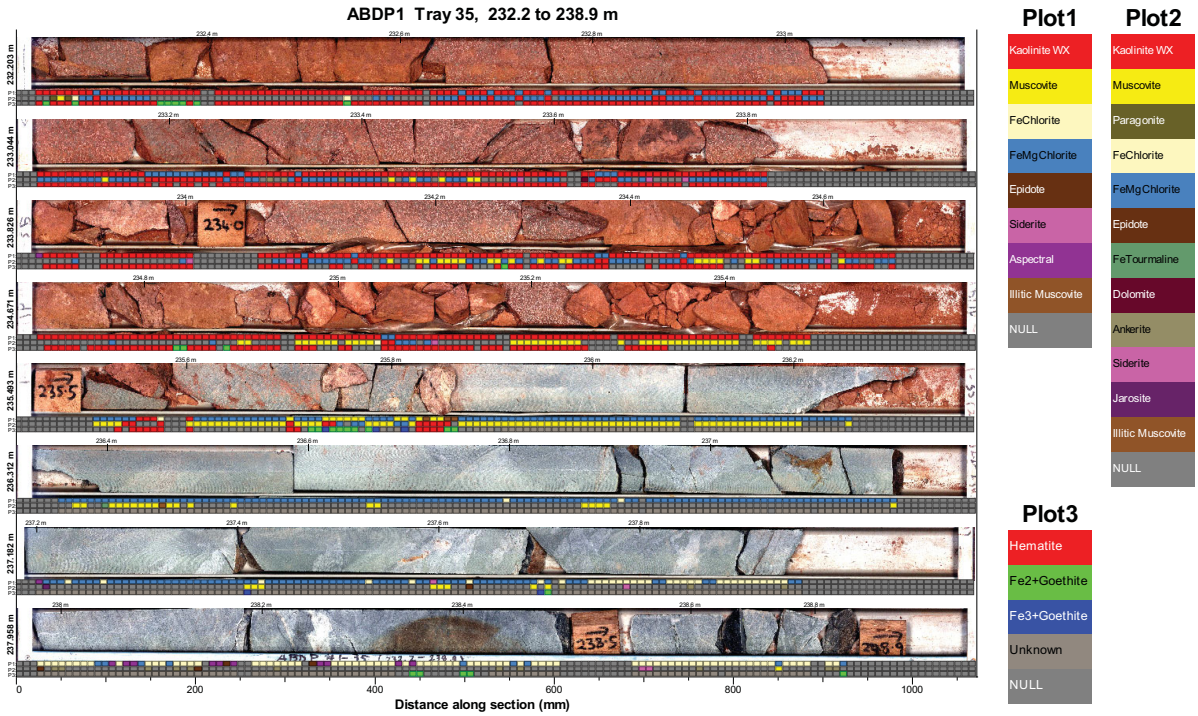

Figure 27. HyLogger-derived mineralogy per 2 metres interval, Cummins Range drillcore

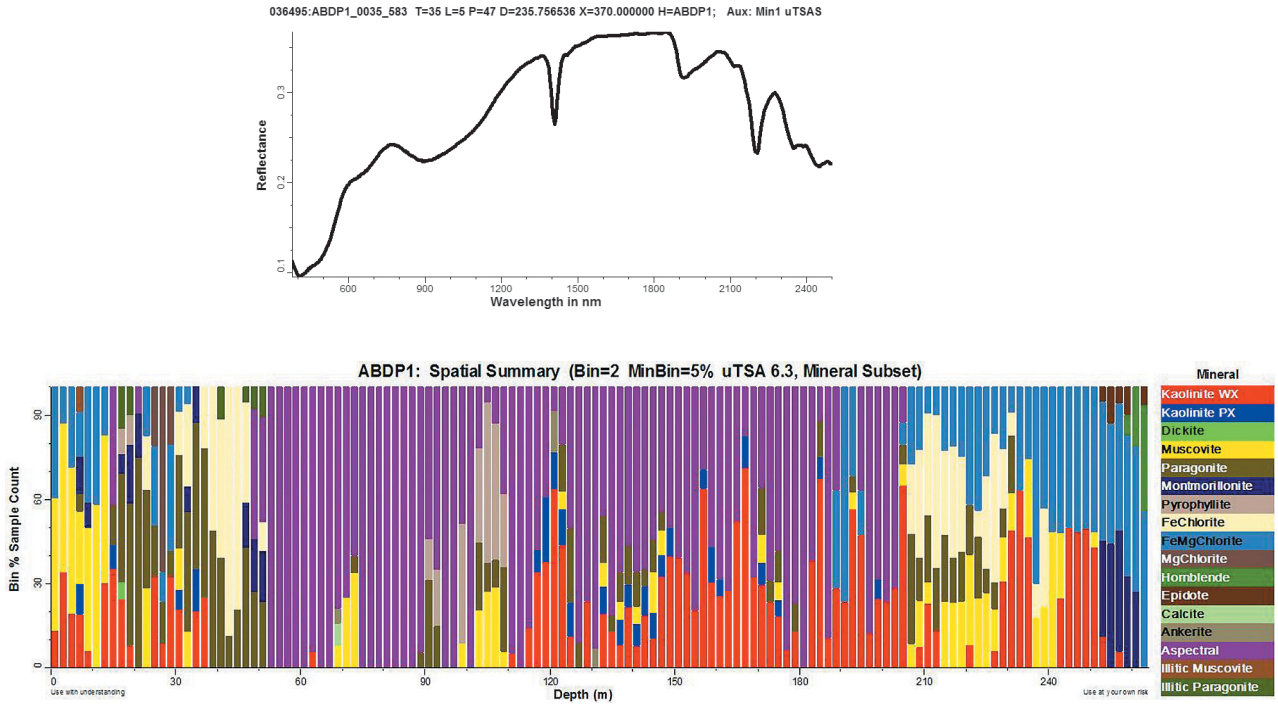

Figure 28. Drillcore from depth 232.2 – 238.9 metres at Marble Bar with mineralogy per 8 mm interval

- Building 3D model of lithology and alteration assemblages for petroleum core from the Canning Basin
- Collaboration with Curtin University and ARRC.

Products 2009–10

- Extended abstract at the GSWA 2010 Extended Abstracts, Promoting the prospectivity of Western Australia (Record)
- Fieldnotes series article (volume 52, October 2009)

Future work

- Installation of thermal infrared (TIR) spectrometer to extend the spectral range and therefore the number of detectable minerals
- Increase in capability of the HyLogger for logging rock chips
- Renewal of SWIR spectrometer
- Scanning of historical Capricorn Orogen drillcore to increase the knowledge of alteration mineralization styles in the area that can provide insights into the fluids source and vectors to gold mineralization
- Analysis of core provided as part of the Co-funded Drilling Program
- Scanning of core relevant to current GSWA projects.

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Inventory of abandoned mine sites

Highlights and activities 2009–10

The inventory, which commenced in 1999–2000, continued to locate and document abandoned mine sites throughout the State to provide baseline data on abandoned mining-related features for decision making by government, community and industry.

- Priority for field inspection is given to abandoned mine sites within 10 km of major towns, 1 km of main roads and selected tourist routes, and within 5 km of smaller towns and communities. About 44% of all abandoned mine sites are in this high-priority category.
- Field work during 2009–10 was conducted in the Southwest area of the State. Localities inspected included the Perth Metropolitan area, Wooroloo, Northam, Bunbury, Collie, Bridgetown, Donnybrook, and Greenbushes. At 30 June 2010, the program had completed the field inspection of 6070 abandoned mine sites (54% of the total), including 90% of the high-priority sites. (Fig. 30).
- Field data entry is via a rugged hand-held PC with integrated GPS receiver capable of locating mine site features such as shafts, to an accuracy of around 10 m (Fig. 29). A total of 561 mine site features and 364 digital photographs were added to the inventory during 2009–10.
- The data were first released publicly in mid-2003, along with Record 2003/9, which documents all aspects of the program. Subsequently the data have been released annually on DVD, including thumbnails of all digital photographs, and an increasing number of historical GSWA bulletins and georeferenced historical maps. The current 'Inventory of abandoned mine sites: progress 1999–2007' DVD contains a total of 189 530 mine site features and 54 030 digital photographs.

Figure 29. Field data entry using Trimble Nomad 800 GL hand-held PC

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

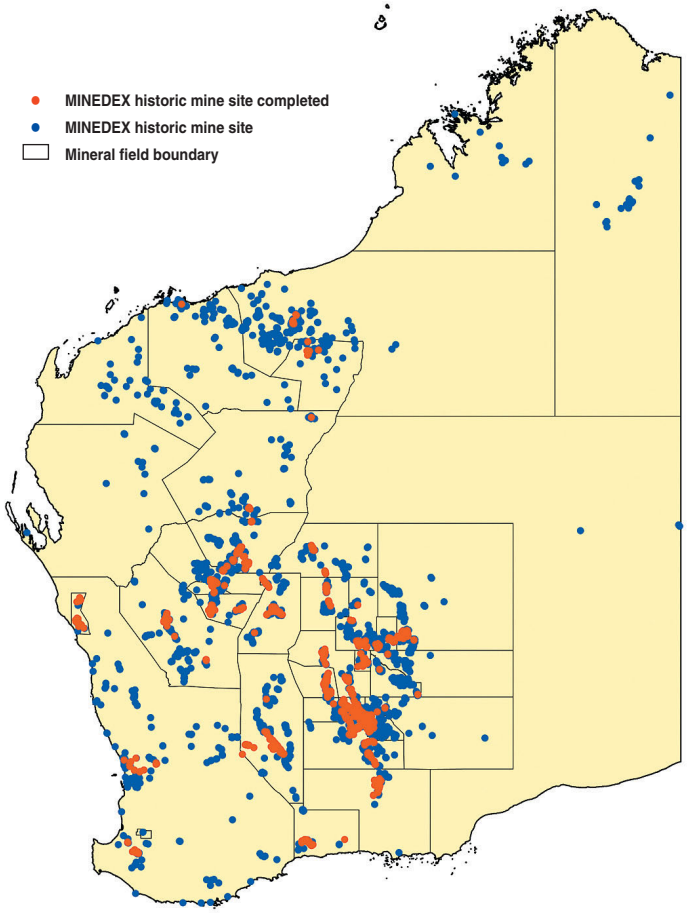

Figure 30. Status of the inventory of abandoned mine sites — MINEDEX MH sites completed as at 30 June 2010

Future work

Complete the inventory for the high-priority abandoned sites in the Southwest region of Western Australia, and the remainder of the Yilgarn, Pilbara, and Kimberley regions.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

EXPLORATION INCENTIVE SCHEME
Exploration and environmental coordination

Highlights and activities 2009–10

Exploration coordination

The 'Reporting Module' was fully integrated within eMiTS and access by external stakeholders to the status of their tenement applications was complete.

The online lodgement of 'expenditure reports' and the online lodgement of 'application for exemption' were completed but not provided to external stakeholders pending legislation changes.

Objectives:

- Integrate the environmental application and approval process into the minerals and petroleum tenement management systems
- Comprehensive tracking of tenement applications through the various approval stages, with online access to metrics by stakeholders
- Online lodgement and processing of tenement applications and associated reporting obligations.

Highlights include:

Milestone	*Completed*
The Reporting Module integrated within eMiTS	July 2009
'Public' access by external stakeholders to the status of their tenement applications	September 2009
'Confidential' access by external stakeholders to the status of their tenement applications	December 2009
Online lodgement of 'expenditure reports'	Complete – pending legislation
Online lodgement of 'application for exemption'	Complete – pending legislation
Enhancements to current EARS system for uranium and geothermal exploration assessment and reporting applications, including the requirement for compulsory rehabilitation for completed uranium exploration programs	June 2010
Online submission of applications for 'programs of work' (minerals exploration) – Phase 1	February 2010
Online submission of applications for 'programs of work' (minerals exploration) – Phase 2	June 2010

Environmental coordination

The online submission of applications for'programs of work' enhancements to EARS system for uranium and geothermal exploration assessment and reporting applications was completed.

Future work

The 2010–11 work program is designed to deliver functionality that will support online tenement applications and Online lodgement – Environmental Applications for Exploration, with the integrated spatial definition of boundaries provided later in the financial year.

The work program for 2011–13 is partially funded for the purposes of consolidation and maintenance for the scope of work provisioned in the first three years of the Exploration Incentive Scheme.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Government Co-funded Exploration Drilling

Highlights and activities 2009–10

Objective: To increase greenfields exploration and new minerals discoveries in Western Australia's under-explored areas by co-funding high-quality, technically and economically sound drilling proposals that promote new exploration and new exploration technologies.

The first round of exploration drilling under the program was undertaken during 2009–10. Of the 35 projects offered co-funding in July 2009, 29 were completed. The co-funding was paid in two tranches, the first on receipt of the interim drilling report and the final payment was made on receipt of the final drilling report and submission of core. The drilling reports have a confidentiality period of three months before release to Open File via the WAMEX database.

The second round of drilling co-funding was opened for applications in February–March 2010. A total of 91 applications was received with 62 offers of co-funding made to the successful applicants. Agreements were distributed to these successful applicants in late June 2010 for drilling projects which were to be undertaken in the financial year 2010–11.

The program, which is scrutinized by a probity auditor for fairness and accountability, is overseen by a committee representing all sectors of the industry and academia. The committee met twice during the year to endorse the process used to select the successful applicants, and to consider changes to guidelines proposed by industry.

Highlights include:

- Completion of 29 co-funded drilling projects funded in the first round of the drilling program. There were a number of interesting results from the 2009–10 drilling program including:
  - Beadell Resources Ltd
    - Handpump prospect gold discovery (Musgrave Province)
    - 60 m @ 0.9g/t including 5 m @ 4.7 g/t gold
  - Toro Energy Ltd
    - Lake Mackay IOCG target
    - Co-funded holes were part of the project which yielded wide intervals of anomalous U_3O_8
  - Gunson Resources Ltd
    - Burkin project
    - Two holes intersecting the basement of the Eucla Basin
  - Encounter Resources Ltd
    - High-grade zinc mineralization intersected at Yeneena project (Paterson Orogen)
    - 28.5% zinc, 2.3% lead and 33.9 g/t silver over 0.1 m within 5 m of end of hole
    - Significant offhole EM conductor approximately 60 m below the bottom of the hole
- Updating of the process to allow online applications, increasing the cap on co-funding for a single deep hole to $200 000, and establishing a separate category of prospectors-only applications.
- Commencement of round 2 of the co-funded exploration drilling program for drilling to be undertaken in 2010–11, with receipt of 91 applications of which 62 were successful in gaining offers of co-funding.

Figure 31. Exploration drilling in Western Australia

Program review—EIS

ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

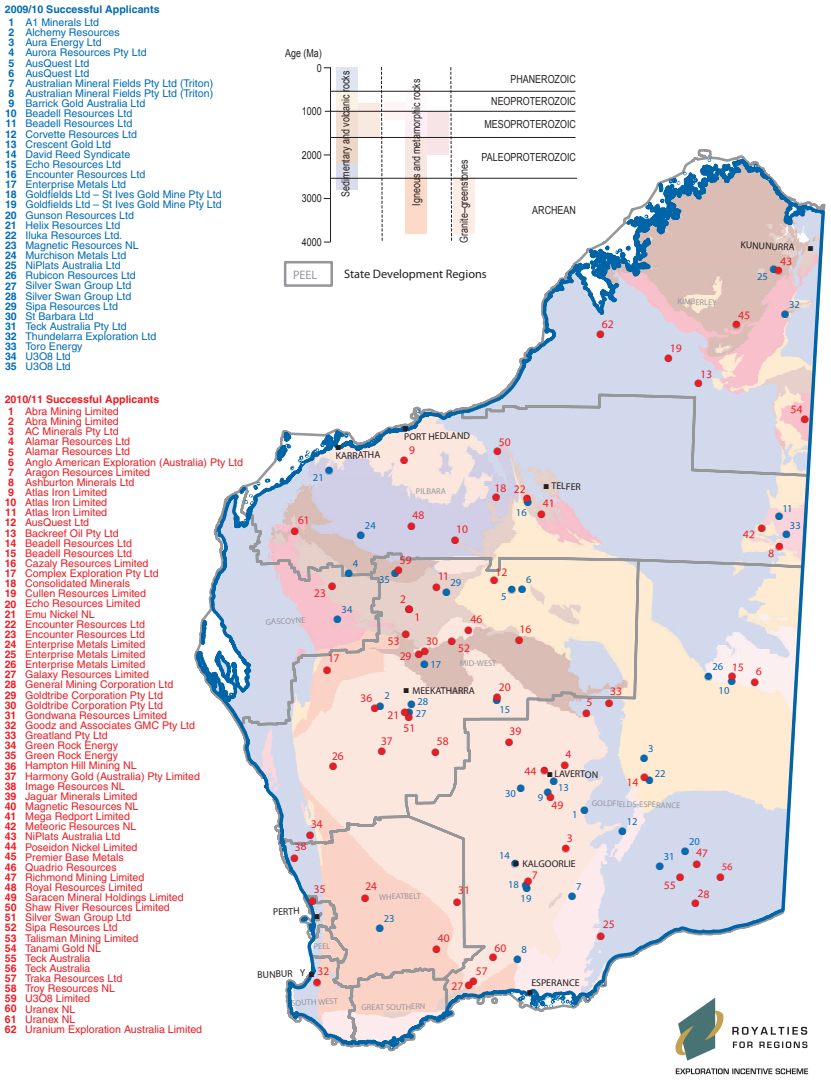

Figure 32. Locations of successful EIS Co-funded Drilling projects, 2009–10 and 2010–11

Products 2009–10

About 60 000 metres of exploration drilling was undertaken in 2009–10. Final drilling reports were prepared for each co-funded project. These reports and the core from the drilling projects are being released to Open File at the end of the relevant confidentiality period.

Future work

Work during 2010–11 will include management of the program including liaising with the exploration companies undertaking the drilling projects, and ensuring that the results of work proposed in the applications is submitted to the Department before co-funding payments are made to companies. Changes to make the program more effective will be evaluated and implemented if approved. The third round of the co-funded drilling program is due to be launched in February 2011 with the evaluation and announcement of successful applicants before the end of June 2011. The program will continue in a similar vein until the end of June 2013.

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Targeted exploration promotion

Highlights and activities 2009–10

In 2009–10 activities mainly focused on attending key international events — primarily the Prospectors and Developers Association of Canada Annual Convention, Trade Show and Investors Exchange (PDAC), Annual China Mining Conference, and Asia Exploration and Mining Seminars. These targeted Chinese, Japanese and Korean investors and were jointly hosted by Austrade and Team Australia.

Other activities included attending national events such as Diggers and Dealers, and Mining 2009 (Brisbane).

Products 2009–10

High impact presentations and exhibition booths featuring posters and a new series of 'commodity flyers' with lists of current explorers and producers in a number of languages were specifically developed for these events.

Objective: Promotion of mineral exploration investment in Western Australia to encourage and enhance mineral exploration and discovery in Western Australia. WA mineral promotion mission is through a cooperative approach to the promotion of mineral exploration investment in Australia by Team Australia.

Future work

Similar promotional events will be the focus of future work programs which will continue to be undertaken in cooperation with Team Australia and will expand to cover more key Asian economies including India and Taiwan.

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Stratigraphic drilling

Highlights and activities 2009–10

While no drilling was undertaken by GSWA during this year, two geological sections of most interest to GSWA from Kingsway Sally May 2 well stratigraphic drilling in the Canning Basin, through the Bongabinni and Acacia formations, were acquired during the year. Analyses were also undertaken on these cores.

In addition, core of the Noonkanbah formation from south of Warrimbah near the Fitzroy River, was also acquired.

Products 2009–10

- Bongabinni core and analyses released

Objective: To improve the current knowledge of the southern Perth, Eucla, and Canning Basins.

Future work

Work during 2010–11 will include piggyback drilling in the Canning Basin to test the Noonkanbah formation to determine its seal capacity for CO_2 storage.

Coring in the southern Perth Basin will test the Lesueur Sandstone for reservoir properties, and the lower 'shale' member of the Eneabba Formation for seal capacity.

In future years, it is planned to undertake stratigraphic drilling on the Crossland Platform and in the Eucla Basin.

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Regional geophysical surveys

Highlights and activities 2009–10

- In this first year of the Exploration Incentive Scheme (EIS), nine separate surveys in the Eucla and Canning Basins were completed with the acquisition and release of a total of approximately 908 000 km of data.
- Three regional gravity surveys were carried out (South Yilgarn Margin — 6125 stations; Southern Cross — 6354 stations; North Gascoyne — 7292 stations) and the data from these released.
- Contracts were let for ten new airborne surveys to complete the coverage of the Eucla, Officer, and Canning Basins; and for three regional gravity surveys in the southern Gascoyne, the Sandstone area, and in the northern Albany–Fraser region.
- An airborne gravity and gravity gradiometry test range was established at Kauring near York in collaboration with Rio Tinto Exploration and Geoscience Australia (<www.ga.gov.au/minerals/kauring>).

Objective: To provide regional geophysical surveys (airborne magnetics and radiometrics, ground gravity) to assist industry in mineralization targeting and to support GSWA programs of regional and detailed geological mapping and analysis.

Products 2009–10

See Figure 33 for survey areas in which data were acquired and released.

Future work

- In 2010–11, the ten airborne surveys contracted in the Eucla, Officer and Canning Basins will be completed with the acquisition and release of an estimated 1.1 million line-km of data.
- Completion of the new gravity surveys contracted in the areas in the Gascoyne (9700 stations), Sandstone (6300 stations), and Albany–Fraser (9200 stations) will add a further 25 200 new gravity stations to the National Database.

See Figure 34 for programmed survey areas in 2010–11.

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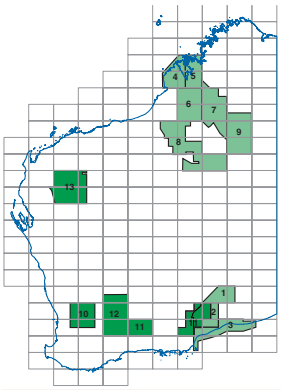

Figure 33. Survey areas — data acquired and released

ID	*Area/Name*	*Resolution*	*Size*
Airborne Magnetic/Radiometric Surveys			
1	Seemore 2009	200 m; E/W	90 011
2	Naretha 2009	200 m; E/W	124 876
3	Eucla Coast 2009	200–400 m; N/S	121 645
4	Broome 2009	400 m; N/S	76 447
5	Yampi–Derby 2009	400 m; N/S	68 015
6	Mt Anderson – McLarty Hills 2009	400 m; N/S	99 200
7	Central Canning 2009	800 m; N/S	91 700
8	Crossland–Noonkanbah 2009	400 m; N/S	111 874
9	Cornish–Helena 2009	400 m; N/S	124 015
Ground Gravity Surveys			
10	Cunderdin 2009 (data release)	2.0 km grid	7 494
11	South Yilgarn Margin (2 parts)	2.5 km grid	6 125
12	Southern Cross	2.5 km grid	6 354
13	Gascoyne North 2010 (released 2010/11)	2.5 km grid	7 29

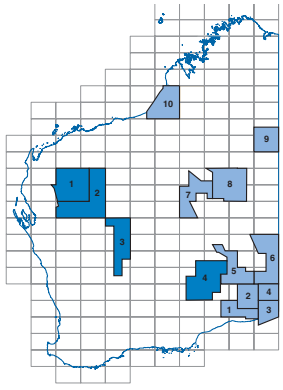

Figure 34. Programmed survey areas 2010–11

ID	*Area/Name*	*Spacing*	*Size (km)*
Airborne Magnetic/Radiometric Surveys		**(line spacing)**	**(line-km)**
1	Madura 2010	200 m; E/W	103 000
2	Loongana 2010	200 m; E/W	114 000
3	Eucla 2010	200 m; N/S	88 000
4	Forrest 2010	200 m; N/S	75 000
5	Jubilee 2010	200 m; N/S	180 000
6	Waigen–Mason 2010	400 m; N/S	113 000
7	Madley–Herbert 2010	400 m; N/S	95 000
8	Morris–Cobb 2010	400 m; N/S	135 000
9	Stansmore 2010	200–400 m; N/S	114 000
10	Lagrange–Munro 2010	400 m; N/S	103 000
Ground Gravity Surveys			
1	Gascoyne North 2010 (data release)	2.5 km grid	7 292
2	Gascoyne South 2010	2.5 km grid	9 700
3	Sandstone 2010	2.5 km grid	6 300
4	Albany–Fraser North 2010	2.5 km grid	9 200

ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Deep seismic survey program

ANSIR NATIONAL RESEARCH FACILITY FOR EARTH SOUNDING
Australian Government Geoscience Australia
AuScope

Highlights and activities 2009–10

During 2009–10 two deep crustal reflection seismic surveys were completed by Terrex Seismic with the acquisition managed by Geoscience Australia under the National Geoscience Agreement (Fig. 36). The completion of these surveys was brought forward into 2009–10 due to delays in starting the joint GSWA – Geoscience Australia Kidson–Paterson survey.

- The Capricorn deep crustal seismic reflection survey was carried out during April and May 2010, and consisted of three lines totalling 579 km across the Capricorn Orogen, which aimed to determine the nature of the sutures between Paleoproterozoic crust and the Archean Yilgarn and Pilbara Cratons. The Capricorn survey was acquired as an Australian National Research Facility for Earth Sounding (ANSIR) project jointly funded with AuScope (National Earth Science Infrastructure Program).
- The Youanmi deep crustal seismic reflection survey was carried out during May and June 2010, and consisted of three lines totalling 677 km. Carrying on from the end of the Capricorn Survey and crossing both the Narryer Terrane, and the Murchison and Southern Cross domains of the Youanmi Terrane, this line ended east of Leinster.

Objective: To provide an understanding the evolution of the West Australian lithosphere, and the localization of large-scale mineral systems, by carrying out deep crustal seismic reflection surveys and associated magnetotelluric (MT) and gravity surveys along transects that cross the West Australian, North Australian and South Australian Cratons, and the intervening Neoproterozoic and Phanerozoic basins.

Future work

A seismic survey will be acquired by GSWA over the Musgrave Orogen after Geoscience Australia completes a long line across the Officer Basin. GSWA will provide logistical support to the acquisition of an MT survey funded by AuScope along the line of the Capricorn seismic survey. Geoscience Australia will complete acquisition of magnetotelluric data for the acquisition of the MT data for the Youanmi survey.

Geoscience Australia will carry out processing of reflection data from the Capricorn survey and it is planned to hold the first interpretation workshop in April 2011, with the publication of a record to coincide with a second interpretation workshop in June 2011.

Further seismic surveys are planned across the southeastern margin of the Yilgarn Craton in 2012.

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Figure 35. Terrex Seismic seismic vibrators at work in the Hamersley Basin

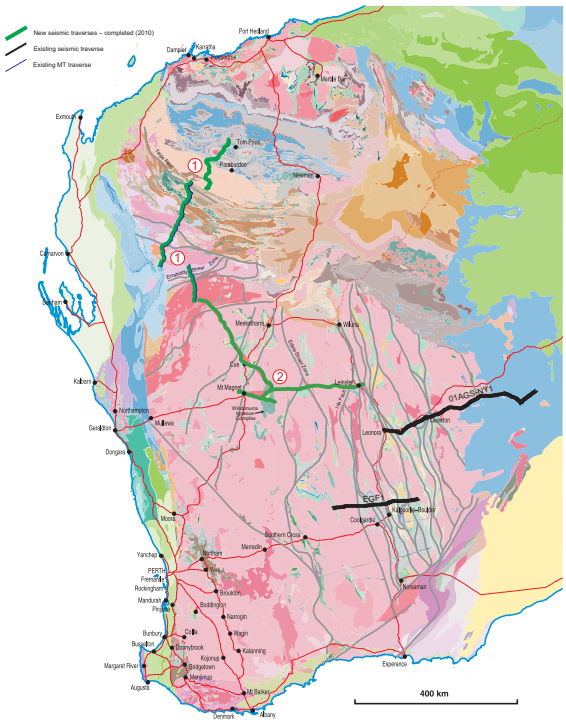

Figure 36. Deep crustal seismic reflection survey lines acquired in 2009–10: 1. Capricorn; 2. Youanmi

Yilgarn margin geochemistry

Figure 37. Helicopter-supported regolith sampling, East Wongatha area

Objective: To enhance the exploration potential of the Yilgarn Craton margin by provision of geochemical data for regolith, complemented, where appropriate, by other data, such as regolith maps.

Highlights and activities 2009–10

- Generation of multi-element geochemical data for 835 regolith samples collected at a density of 1 sample per 16 km^2 from the East Wongatha area, on the eastern Yilgarn Craton margin bordering the Gunbarrel Basin and Albany–Fraser Orogen.
- Production of a regolith–landform map of the East Wongatha area as a complement to multi-element regolith geochemical data.
- Pilot study to identify the optimum size fraction and analytical approach to analysis of sand-dominated regolith on the Yilgarn Craton margin as a precursor to the East Wongatha regolith geochemistry project.
- Generation of regolith–landform coverage for the Lockier and Pink Hills 1:100 000 scale map sheets as a complement to bedrock mapping.

Products

- Multi-element geochemistry of regolith from the East Wongatha area (released as part of the East Yilgarn digital database update)
- Regolith–landform map of the East Wongatha area (released as part of the East Yilgarn digital database update)

Future work

- Collaboration with CSIRO to extend hydrogeochemical sampling of the northern Yilgarn Craton to the Murgoo (SG50–14), Belele (SG50–11) and Byro (SG50–10) 1:250 000 Geological Series map sheets.
- Extension of the Yilgarn laterite geochemistry database to the Murgoo (SG50-14) 1:250 000 scale map sheet
- Collaboration with CET and CSIRO to investigate the three-dimensional chemistry of the regolith on the Yilgarn Craton – Albany–Fraser Orogen margin.

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Geology online

Highlights and activities 2009–10

- Redevelopment of the field observation database (WAROX)
- Commencement of the development of the Virtual Geology online application
- Development and deployment of the bibliographic database (Reference Manager)

Objective: To improve the integration of GSWA's online data and the creation of new databases and data services linked to current and future spatial data layers.

Future work

In 2010–11, work will continue on the following projects:

- Populate the WAROX database and complete the Desktop and Reports applications
- Completion of the Virtual Geology desktop, DVD and online applications, and undertake data migration
- Develop the catalogue database (KitCat) and build the desktop application.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Modernize petroleum information delivery system

Highlights and Activities 2009–10

- Development of the new WAPIMS database ensuring all current interoperability of the WAPIMS core system and related applications is maintained
- Mapping replacement applications and data to the current data ensuring all DMP customizations of the data are included
- Customization (as necessary) of the replacement applications to meet DMP's current operating environment
- Migration of all data into the new application

Objective: To upgrade the Department of Mines and Petroleum's Western Australian Petroleum and Geothermal Information Management System (WAPIMS) to provide a more streamlined data submission and release system for the petroleum industry.

- Upgrade of other core WAPIMS applications to ensure compatibility with the new data entry and loading applications.

Future work

- Acceptance Testing and Training Plan
- Handover and Warranty Phase.

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3D geoscience

Highlights and activities 2009–10

- Training was provided for a field geologist in structural geophysics and 2D and 3D modelling. In support of this training, and to assist in the interpretation of prospective bedrock under sedimentary basin cover and thick regolith, OasisMontaj geophysical processing software was purchased, which includes an application for 2D cross section modelling. Licences for GoCad, a 3D modelling package, have also been purchased.
- A magnetotelluric survey was carried out across the southern part of the Southern Cross Domain of the Youanmi Terrane of the Yilgarn Craton in collaboration with the Centre for Exploration Targeting (CET) at UWA. This provided additional information on the structure of the crust and subcontinental lithospheric mantle in this region, which is the subject of an ongoing GSWA mapping program, and an ARC Linkage research project with CET.

Centre for EXPLORATION TARGETING

THE UNIVERSITY OF WESTERN AUSTRALIA
Achieving International Excellence

Objective: To construct 3D maps and models at a range of scales by integrating surface geology information with geophysical data (magnetics, gravity, seismic, magnetotellurics) using potential field inversions and forward modelling. These methods will test the validity of geological interpretations at depth. Crustal-scale structures focus fluid flow within the crust, influencing the style and distribution of mineralization. 3D maps and models can be used to visualize structural architecture to generate new exploration targets.

Future work

3D mapping and model building is an emerging field that requires specialist geophysical, geological and programming skills that are highly sought after and for which the available pool of potential applicants is limited. Unfortunately GSWA has been unsuccessful in attracting a suitably experienced Manager or Senior Geoscientist.

As an alternative to the direct employment of 3D geoscience specialists, and with the intention of encouraging the training of a geoscientist with the necessary skills, GSWA will contribute to the establishment of the Centre of Excellence for Core to Crust Fluid Systems (CCFSCoE), which will have nodes at Macquarie University, Curtin University and The University of Western Australia. Geophysical imagery gives us snapshots of the deep Earth that carries the imprints of past processes. Most giant ore bodies are generated by lithosphere-scale deep plumbing systems that concentrate fluids, energy and metals into specific sites, many of which are related to sites of fossil subduction zones. These systems are not uniformly distributed in time and space,

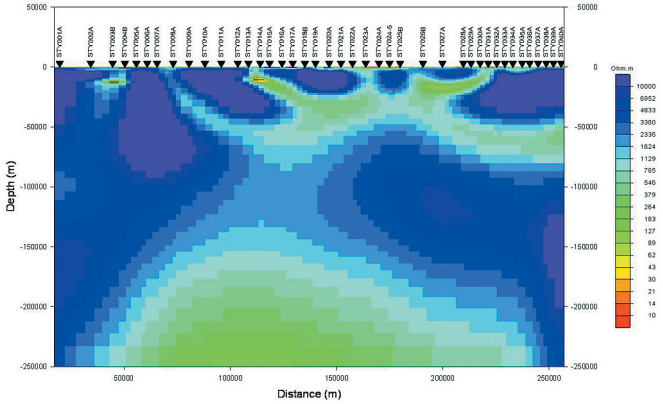

Figure 38. Southern Cross magnetotelluric survey (image courtesy of M Dentith, CET)

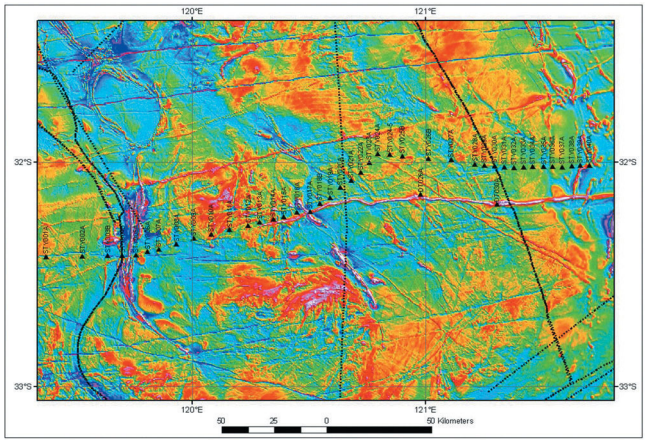

Figure 39. MT stations (from Hyden in the west to Norseman in the east) plotted on a magnetic anomaly image of the southern part of the Southern Cross Domain of the Yilgarn Craton (image courtesy of M Dentith, CET)

but are tied to the coupled evolution of the crust, mantle and hydrosphere. Therefore, understanding the evolution of these fluid systems in time and space, and detecting their traces at depth, is critical to understanding how the Earth's crust and its resources have evolved, and to improving exploration strategies for mineral and energy resources. In collaboration with GSWA, the CCFSCoE will develop an understanding of the crustal structure and mantle architecture and type in the northwest Yilgarn Craton, making use of GSWA seismic, magnetotelluric, magnetic and gravity data, leading to construction of 3D models of the crust and mantle in that region.

In addition, support will be given to an innovative Australian Research Council Linkage project with CET on *Multiscale Dynamics of Ore Body Formation* that will develop a model for hydrothermal mineralizing systems from the scale of the Earth's lithosphere down to the scale of an ore body. The goal is to define measurable parameters that control the size of such systems and that can be used as mineral exploration criteria. The project will explore the hypothesis that lithospheric structural architectures associated with old craton margins are sites for the influx of CO_2 into the lithosphere, controlling metal sources. At the mineralizing site diagnostic features result from strong interaction between deformation, fluid flow, thermal transport and chemical reactions. The dynamics of the Albany–Fraser Orogen, and links to the formation of the Tropicana gold ore body, will be investigated as part of this study in 2010–11.

A magnetotelluric line is planned in collaboration with CET that will extend the Southern Cross line, fill in data already collected across the Albany–Fraser Orogen, and extend eastwards to image the crust and mantle beneath the Eucla Basin. GSWA projects identified as having suitable datasets, or for which data collection is planned for further modelling include the west Musgrave, west Arunta, and Capricorn Orogen.

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Mineral drillhole database

The mineral drillhole database is a relational database that will store the drill collar locations, downhole geology, downhole survey and the related downhole geochemistry. It will store all the data submitted digitally to DMP and will ultimately allow spatial searching of the drill collars and related data. It will also be integrated with other GSWA online databases, e.g. WAMEX and WA Geology, and will improve the online information service to all DMP customers.

Highlights and activities 2009–10

- The mineral drillhole database was designed and developed in the first half of 2010 and is currently undergoing the final stages of development and testing.

Objective: To develop and populate a database containing the mineral drillhole information reported by exploration companies in Western Australia.

Future work

- A system will be developed to track the importation of the drilling datasets from the WAMEX database into the mineral drillhole database.
- Population of the mineral drillhole database will commence in January 2011.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Geological mapping program

Highlights and activities 2009–10

During 2009–10, work concentrated on the Kimberley region and the Capricorn Orogen. These areas, along with the basement to the Eucla Basin and the Central Desert, are under-explored due to their remoteness, land access issues, and the lack of up-to-date pre-competitive datasets.

Highlights include:

- In the Kimberley region, much of the work consisted of capturing analogue data from first and second edition mapping (e.g. field site locations, notes, photographs, structures, samples, and petrography) into GSWA's databases so these data can be used in a GIS environment (see North Australian Craton project).
- In the Capricorn Orogen, work concentrated on mapping bedrock and regolith in the eastern part of the Mesoproterozoic Edmund and Collier Basins, and interpreting regolith in the western part of the Paleoproterozoic Gascoyne Province to complement bedrock mapping (see Edmund and Collier Basins field mapping).
- Staff on the project presented an in-house workshop on regolith mapping, and provided advice to several mapping projects regarding interpretation of the regolith (see Geochemistry and regolith).

Objective: To undertake regional geological mapping of bedrock and regolith, and the interpretation, from geophysical data, of bedrock under thin soil and sedimentary basin cover in remote greenfields areas of Western Australia.

Products 2009–10

- See Edmund and Collier Basins field mapping
- See Geochemistry and regolith

Future work

Work during 2010–11 will include:

- Compilation of solid geology layers for six 1:100 000 Geological Series map sheets in the east Kimberley for incorporation into a GIS data package
- Completion of field site capture from first and second edition mapping across the Kimberley and Tanami regions into GSWA's WAROX database
- Regolith coverage for five 1:100 000 map sheets in the Gascoyne Province, and for five 1:100 000 map sheets in the Tanami region
- Compilation of a regolith atlas to aid the mapping and interpretation of regolith in Western Australia
- Bedrock and regolith interpretations for several 1:100 000 map sheets in the eastern part of the Edmund and Collier Basins, and completion of a solid geology for the Edmund 1:250 000 map sheet area.

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Figure 40. Panoramic view of granites of the 1865–1850 Ma Paperbark Supersuite from Inglis Gap, west Kimberley

ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Enhanced geochronology and acquisition of isotope data

Highlights and activities 2009–10

- In situ monazite dating has yielded significant results for sedimentary rocks in the Capricorn region. Samples of the Mt Augustus Sandstone yielded dates of c. 1670–1800 Ma, interpreted as detrital ages, and a range of younger dates, including significant groups at c. 1300 and 1000–950 Ma, interpreted as metamorphic ages. Broadly similar results were obtained for sandstone samples from the Yilgatherra Formation of the Edmund Group, with dates of c. 1690 Ma from detrital cores, and dates of c. 1400–1300 Ma and c. 1150 Ma from metamorphic rims. These results indicate the existence of a c. 1400–1300 Ma metamorphic event which may be related to hydrothermal polymetallic mineralization in the Capricorn region.
- About 1500 zircons, from more than 100 samples, were analysed for Lu–Hf isotopes in 2009–10. The samples were chosen strategically from the Gascoyne and Musgrave Provinces, the western Arunta and Albany–Fraser Orogens, the Murchison and Southern Cross Domains of the Yilgarn Craton, and the Edmund, Officer, and Canning Basins. New results for the Albany–Fraser Orogen indicate that Paleoproterozoic evolution of the Biranup Zone involved addition of juvenile (mantle-derived) material to rifted Archean crust of the Yilgarn Craton, and help to clarify the geodynamic setting of gold mineralization, including the Tropicana deposit. Results for the Gascoyne Province indicate episodic juvenile additions into the crust, and confirm an exotic origin for the Glenburgh Terrane prior to final suturing of the West Australian Craton. The results are adding a new and exciting dimension to GSWA geological publications.
- More than 170 whole-rock samples were submitted for Sm–Nd isotope analyses in 2009–10. These are from under-explored areas in Western Australia, including the Gascoyne and Musgrave Provinces, the western Arunta and Albany–Fraser Orogens, the Murchison and Eastern Goldfields regions of the Yilgarn Craton, and the Edmund and Kimberley Basins. Results have been received for most samples, disseminated to GSWA projects, and made available on the GSWA website. The data obtained so far are proving highly valuable in understanding crustal architecture and geological evolution in the targeted areas.

Objective: This project enhances GSWA's geochronology program by the addition of in situ dating of phosphate minerals, Lu–Hf isotope analyses of zircon and baddeleyite, and Sm–Nd isotope analyses of whole-rock samples. These data contribute directly to our understanding of crustal evolution and mineralization in Western Australia.

Products 2009–10

- Downloadable tables of isotope data are available on the GSWA website through GeoVIEW.WA (www.dmp.wa gov.au/geochron)

Contributions to:

- Explanatory Notes for the Gascoyne Province
- The Glenburgh Orogeny as a record of Paleoproterozoic continent–continent collision (Record)
- Several peer-reviewed journal articles and conference abstracts.

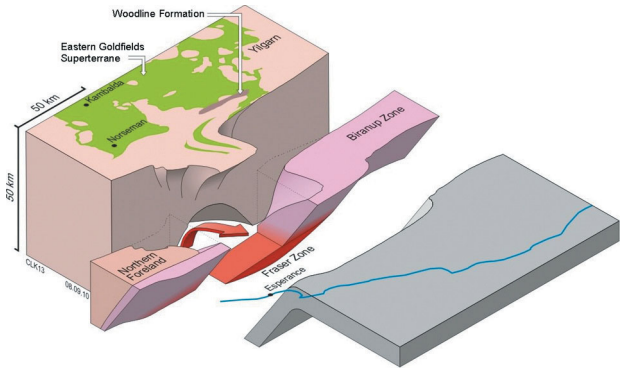

Figure 41. Schematic diagram illustrating possible deep crustal architecture of the Yilgarn Craton margin and Biranup and Fraser Zones. The Eastern Goldfields Superterrane, with a depleted-mantle keel, directed mantle flow into interaction with the basal Biranup Zone to produce Fraser Zone lithologies. Mantle flow may have been triggered by compression on the margin. Slab roll-back on the Yilgarn margin led to asthenospheric upwelling and significant juvenile addition to unradiogenic Archean crust. Following this, compression and extrusion uplifted the lower crustal rocks of the Fraser Zone, possibly between Stages I and II of the Albany–Fraser Orogeny.

Future work

- Acquisition of data for the Yilgarn and Pilbara Cratons, Gascoyne and west Musgrave Provinces, Albany–Fraser and Capricorn Orogens, and the Kimberley, Edmund, and Canning Basins
- Temporal and hafnium isotopic evolution of the Glenburgh Terrane basement: an exotic crustal fragment in the Capricorn Orogen (Record)
- Inferences on crust-mantle interaction from Lu–Hf isotopes: a case study from the Albany–Fraser Orogen (Record)
- Contributions to GSWA publications.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Unconventional energy program

Highlights and activities 2009–10

- A scoping study was undertaken to report on determining the coal resources of the Perth and Collie basins and their suitability for either CBM or UCG production.
- Collaborative research agreements were negotiated and signed in preparation for research projects commencing in 2010–11, to be undertaken with WA:ERA, Curtin University, and The University of Western Australia.

Objective: To provide for the growing energy requirements of Western Australia by the collection of pre-competitive data to assist in determining the State's alternative energy sources.

Future work

Ongoing studies for the unconventional energy program will include:

- A three-year study on the shale gas potential of the Perth Basin, with Curtin University
- Further studies, in collaboration with the Geothermal Centre of Excellence, on geothermal resources in Western Australia
- Studies, in collaboration with WA:ERA, on tight gas in the Perth Basin
- A review of the coal resources of Western Australia, and their suitability to the extraction of coal bed methane and use in underground coal gasification.

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Strategic industry research

Highlights and activities 2009–10

- The first MERIWA exploration project to be supported by the EIS money, 'Northeast Yilgarn Biogeochemistry Project' was approved by the MERIWA Board at its November 2009 meeting. The project will evaluate plant samples (mulga: *Acacia aneura*) collected throughout the northeast Yilgarn Craton, with the aim of detecting the presence of certain minerals that release ions into the groundwater, which are taken up by these plants.
- Preparation of agreements with CSIRO for the funding of three Embedded Researchers under the Western Australian Researcher Initiative.

Objective: To support the rapid transfer of new geoscience concepts, skills and technologies into the Western Australian minerals exploration industry.

Future work

In 2010–11, the three projects to be undertaken by embedded researchers will commence, while additional funding to MERIWA will continue to support research projects identified by the MERIWA board as relevant to supporting greenfields exploration within Western Australia.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Indigenous Land Use Agreement for petroleum airborne geophysical surveys

Highlights and activities 2009–10

- The development of a draft Terms Sheet specifying the parties, timing, agreement area, subject matter, and layout of an Indigenous Land Use Agreement.
- The identification of the airborne geophysical survey parameters and the low impact on-ground activities for inclusion in the ILUA.
- The resolution of a proposed negotiation timeframe for each of the identified native title parties in the Central Desert Region.
- Presentation by Central Desert Native Title Service (CDNTS) of the ILUA concept to the Birriliburu Working Group and Traditional Owners.

Objective: To negotiate an Indigenous Land Use Agreement (ILUA), Body Corporate Agreement with the Birriliburu native title holders to enable the grant of applications for Special Prospecting Authorities with Acreage Options under the *Petroleum and Geothermal Energy Resources Act 1967* (WA) (PGERA) for low impact exploration activities. The objective was to streamline approval processes for low impact exploration activities by removing the requirement to refer individual applications to the future act process of the *Native Title Act 1993* (Clth).

Future work

In early 2010, DMP identified that the Birriliburu determination area hosted the potential for unconventional gas, and that exploration acreage would be released through the competitive bid process under the PGERA. Consequently, the ILUA negotiations were placed in abeyance pending the outcome of the acreage release process, which closed in August 2010.

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Geothermal heritage clearance agreement

Highlights and activities 2009–10

- The hosting of a Land Access Workshop for the holders of geothermal energy title
- Attendance at the Gnulli Working Group Meeting in Carnarvon for the purpose of explaining geothermal energy exploration and to discuss the concept of a land access and cultural heritage agreement
- The facilitation of planning meetings between DMP, State Solicitor's Office (SSO) and Yamatji Marlpa Aboriginal Corporation (YMAC) in respect of the Exploration Incentive Scheme funding agreement and the concept of land access and cultural heritage agreements

Objective: To develop Regional Land Access and Cultural Heritage Agreements for the purpose of geothermal energy exploration in the Mid-West region of Western Australia.

- Ongoing communication and consultation with member companies of Australian Geothermal Energy Association (AGEA) with exploration title interests in the South West and Mid-West regions.

Future work

By close of 2010–11, it is intended that the cultural heritage and land access agreements will be finalized with the Gnulli, Ngaadju and Amangu Native Title Parties.

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ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Access to determined lands

Highlights and activities 2009–10

- Signed Land Access Agreement between the Western Desert Lands Aboriginal Corporation on behalf of the Martu people and GSWA for the conduct of geological mapping and sampling
- Near completion of a Memorandum of Understanding between the Kimberley Land Council Aboriginal Corporation and GSWA for land access and heritage protection in the Kimberley Region
- Successful agreement at a meeting with Traditional Owners and GSWA for it to work in the Nykinana–Mangala native title claim area
- Successful agreement at a meeting with Traditional Owners and GSWA for geochemical sampling over the Tjurabalen native title determination area
- Completion of a regional heritage survey in the East Wongatha area in cooperation with Traditional Owners and the Central Desert Native Title Services area, prior to a regional geochemical survey program
- Completion of heritage surveys in the Mimbi Falls area in cooperation with the Gooniyandi native title claimants and the Kimberley Land Council Aboriginal Corporation.

Objective: Establishing networks to promote good working relationships with Aboriginal and community interests, and hence gaining long-term and sustainable land access for GSWA throughout Western Australia.

Future work

Future activities include:

- Agreements with and assistance by Traditional Owners to complete the abandoned mine site surveys in the East Kimberley, Cosmo Newbury and Mulga Queen areas
- Preparations for and the completion of heritage surveys associated with the Kidson Sub-basin Deep Crustal Seismic Survey across the Canning Basin
- Ongoing heritage surveys in the East Kimberley area to support GSWA mapping and sampling activities
- Undertaking heritage protection in association with geological mapping in the Canning Basin in cooperation with the Martu people and the Western Desert Lands Aboriginal Corporation
- Heritage surveys in the Pilbara, in conjunction with the Agouron Institute geoscientific drilling program assisted by the Yamatji Marlpa Aboriginal Corporation and Traditional Owners
- Consultation with Traditional Owners and Shire Councils for the Yilgarn–Officer–Musgrave Deep Crustal Seismic Survey along the Great Central Road
- Continue to build a good working relationship with Traditional Owners and their representative bodies with emphasis on the remote parts of Western Australia.

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Mineral community awareness program

Highlights and activities 2009–10

- Community awareness activities in Kalgoorlie, Leonora, Wiluna, Menzies and Laverton
- Distribution of printed material in regional communities and via the DMP website.

Future work

- Further community awareness activities in regional communities.

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Objective: To enhance community awareness of the benefits to the community resulting from mineral exploration activity, and of the safety and health issues associated with exploration.

Figure 42. Community information session in Leonora

Figure 43. Information display at Wiluna (October 2009)

ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Mineral regional heritage agreement land access and exploratory titles on determined lands

Objective: The initiative is designed to expedite Indigenous approvals for mineral prospecting and exploration in regional and remote Western Australia by the negotiation of a model agreement for determined lands that facilitates Aboriginal heritage surveys ahead of ground-disturbing work.

Highlights and activities 2009–10

- Engagement with Central Desert Native Title Service (CDNTS), the Chamber of Minerals and Energy (CME), and Association of Mining and Exploration Companies (AMEC) with respect to possibility of reaching a standard agreement [potentially an Indigenous Land Use Agreement (ILUA)] for the grant of exploratory mineral titles and land access within the Birriliburu Determination Area (Birriliburu Lands)
- CME and AMEC identified key industry issues that would need to be addressed in Birriliburu's benchmark agreement template Birriliburu Land Access and Mineral Exploration Agreement (LAMEA)
- Emergence of a 'Whole of Government' approach to native title land management issues to be negotiated as part of the claim resolution process and where native title has already been determined had particular implication for Central Desert negotiations because of the interrelationship between post determination negotiations, i.e. Birriliburu and consent determination mediations undertaken by the Office of Native Title (ONT)
- Arising from the evolution of the 'Whole of Government' process, and the potential for confusion and overlap of issues to arise, DMP deferred further negotiations with CDNTS at least until the broader Government land management approach is developed, which is expected in the first half of 2011
- DMP began engagement with Ngaanyatjarra Land Council (NgLC) with respect to the possibility of reaching a standard agreement [potentially an Indigenous Land Use Agreement (ILUA)] for the grant of exploratory mineral titles and land access within NgLC Determination Areas (Ngaanyatjarra Lands).

Future work

- Negotiation meetings are planned for the third quarter 2010–11 between DMP, NgLC, CME and AMEC to identify key industry issues that would need to be addressed in a Ngaanyatjarra Lands Benchmark Agreement template.

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Appendices

Products and services

In 2009–10, there was continued focus on providing better access to, and management of, geoscience data, including the commencement of geoscience database migration from Oracle to SQLServer.

Development of a number of image datasets were added to GeoVIEW.WA, and web-based access to geochronology data was improved. The evaluation of web-based map viewer software, to replace GeoVIEW.WA, continued.

The development of a number of new applications were initiated, including GeoMAP.WA, a free GIS viewer to visualize and analyse GSWA geoscience information distributed on DVD and USB drives; and WAROX, an application designed to assist in the acquisition of field observations, also underwent redevelopment.

In collaboration with CSIRO, and as part of the AuScope project, the implementation of the Virtual Core Library and Earth Resources data models and web-based delivery systems began.

In 2009–10, GSWA published:

- 24 geological maps, including 13 Geological Series maps
- 36 geoscientific Bulletins, Reports, Explanatory Notes, Records, and other papers
- 22 digital information packages
- 907 783 line-km of airborne geophysical data.

Posters and promotional materials were prepared for the following conferences:

- APPEA 2010
- APPEX London 2010
- AusIMM Uranium Conference 2010
- Australian Nickel Conference 2009
- Australian Uranium 2009
- Australian Uranium Summit 2010
- Diggers & Dealers 2009
- Geothermal Energy Conference 2009
- Good Oil Conference 2009
- GSWA Open Day 2010
- Iron Ore Conference 2009
- Mining 2009
- MinSands 2009 Conference
- NAPE 2010
- NewGen Gold 2009
- PDAC 2010
- Petroleum Open Day 2009
- RIU Explorers 2010
- SPWLA 2010
- WALIS Forum

Maps, reports, and datasets released in 2009–10

Geological maps

1:100 000 Geological Series Maps

CALYIE 1:100 000 Geological Series map *by HN Cutten*

CANDOLLE 1:100 000 Geological Series map (2nd edition) *by AM Thorne, DMcB Martin, SP Johnson, S Sheppard, and HN Cutten*

DOROTHY HILLS 1:100 000 Geological Series map *by SS Romano, M Pawley, CM Doyle, and SA Jones*

FINLAYSON 1:100 000 Geological Series map *by P Evins, H Howard, RH Smithies, and WD Maier*

JUTSON 1:100 000 Geological Series map *by M Pawley and CE Hall*

LIGHTFOOT 1:100 000 Geological Series map *by CE Hall, MP Doublier, and S Wyche*

MILGUN 1:100 000 Geological Series map (2nd edition) *by CP Swager, JS Myers, and AM Thorne*

MULGABIDDY CREEK 1:100 000 Geological Series map *by M Pawley*

STRAWBRIDGE 1:100 000 Geological Series map *by CE Hall*

TANGADEE 1:100 000 Geological Series map *by AM Thorne*

TOPPIN 1:100 000 Geological Series map *by SS Romano*

YAMARNA 1:100 000 Geological Series map *by M Pawley*

1:250 000 Geological Series Map

MARBLE BAR 1:250 000 Geological Series map (3rd edition) *by AH Hickman*

Resource Potential for Land use Planning

Aboriginal land, conservation areas, mineral and petroleum titles, and geology, Western Australia — 2010 *by IR Roberts*

Iron ore deposits of the Yilgarn Craton 2010 *by RW Cooper and DJ Flint*

Major resource projects Western Australia —2010 *by RW Cooper*

WA mines operating and under development 2010 — Western Australia *by RW Cooper*

Arrowsmith, Titanium–Zircon mineralization *by C Strickland*

Dandaragan, Titanium–Zircon mineralization *by C Strickland*

Gingin, Titanium–Zircon mineralization *by C Strickland*

Hill River, Titanium–Zircon mineralization *by C Strickland*

Mingenew, Titanium–Zircon mineralization *by C Strickland*

Perth–Wooroloo, Titanium–Zircon mineralization *by C Strickland*

Wedge Island, Titanium–Zircon mineralization *by C Strickland*

Publications

Reports

Report 106 Geochemistry, geochronology and petrogenesis of Mesoproterozoic felsic rocks in the west Musgrave Province, Central Australia, and implications for the Mesoproterozoic tectonic evolution of the region *by RH Smithies, HM Howard, PM Evins, CL Kirkland, DE Kelsey, M Hand, MTD Wingate, AS Collins, EA Belousova and S Allchurch*

Report 107 A review of mid-Carboniferous to Triassic stratigraphy, Canning Basin, Western Australia *by AJ Mory*

Report 108 The Paleoproterozoic Capricorn Orogeny: intracontinental reworking not continent–continent collision *by S Sheppard*

Maps, reports, and datasets

Records

2009/1 Geological Survey work program for 2009–10 and beyond

2009/11 Microbialites of Lake Thetis, Cervantes, Western Australia — a field guide *by K Grey and NJ Planavsky*

2009/12 A kinematic, metamorphic, geochemical and geochronological framework for intracratonic reworking in the western Musgrave Block, Central Australia *by Tom Raimondo*

2009/13 Age constraints and deformation history of the Shag Hill mylonites, western Musgraves *by Michael Belperio*

2009/14 Complex strain in mylonites from the western Musgraves, north of the Mann Fault, Western Australia *by Althea Walker-Hallam*

2009/15 Using calculated pseudosections in the system NCKFMASHTO and SHRIMP U–Pb zircon dating to constrain the metamorphic evolution of the Latitude Hills paragneisses, West Musgrave Province, Western Australia *by Rodney J King*

2009/16 Age and geochemistry of the Alcurra Suite and implications for orthomagmatic mineralization during the Giles Event *by H Howard, RH Smithies, CL Kirkland, P Evins, and MTD Wingate*

2009/17 Procedure for legacy point and data capture *by S Sheppard, RE Green, TR Farrell, and L Kelly*

2009/19 U–Pb and Hf analysis of detrital zircons: implications for provenance of the Earaheedy Basin, Capricorn Orogen *by KJ Matonia*

2009/21 Hydrogeochemical mapping of northeast Yilgarn groundwater *by DJ Gray*

2009/23 Intracontinental orogenesis in the heart of Australia: Structure, provenance and tectonic significance of the Bentley Supergroup, Western Musgrave Block, Western Australia *by P Coleman*

2009/24 Age constraints and structure of the Cohn Hill Shear Zone, Western Musgraves Block, Central Australia *by A Sen*

2010/2 GSWA 2010 extended abstracts

2010/5 The Glenburgh Orogeny as a record of Paleoproterozoic continent–continent collision *by SP Johnson, S Sheppard, B Rasmussen, MTD Wingate, CL Kirkland, JR Muhling, IR Fletcher, and E Belousova*

2010/7 Application of SWIR spectroscopy in very low-grade metamorphic environments: a comparison with XRD methods *by MP Doublier, A Roache and S Potel*

2010/9 The application of abandoned mine site data to the interpretation of regional geology and gold mineralization in the Kalgoorlie Terrane, Western Australia *by WO Ormsby*

2010/11 Mineral exploration drilling of Lot 352 Anzac Drive, Kalgoorlie: a site required for industrial development *by CJ Kojan*

2010/12 In situ U–Pb monazite and xenotime geochronology of the Abra polymetallic deposit and associated sedimentary and volcanic rocks, Bangemall Supergroup, Western Australia *by B Rasmussen, IR Fletcher, JR Muhling, C Gregory, AM Thorne, HN Cutten, F Pirajno, and A Hell*

2010/13 Management plan for state geoheritage reserves *by K Grey, IR Roberts, J Bevan, AH Hickman, and MJ Van Kranendonk*

1:100 000 Explanatory Notes

Explanatory notes for the Gascoyne Province *by S Sheppard, SP Johnson, MTD Wingate, CL Kirkland, and F Pirajno*

Geology of the Coongan 1:100 000 Geological Series sheet *by MJ Van Kranendonk*

Non-series books

2008–09 GSWA Annual Review

Discovery trails to early Earth — a traveller's guide to the east Pilbara of Western Australia *by Martin Van Kranendonk and Jean Johnston*

Geology of James Price Point, Broome, Western Australia

Overview of mineral exploration in Western Australia for 2008–09 *by PB Abeysinghe and DJ Flint*

GSWA calendar 2010

GSWA Fieldnotes v. 51, 52, 53, 54

GSWA guide for authors

GSWA guide for editors

GSWA guide to editing maps

Datasets

1:100 000 Geological Information Series

East Yilgarn GIS 2010 update

Murchison GIS 2009 update

Western Capricorn Orogen GIS 2009 update

West Musgrave GIS 2010 update

Data Package

Mineral occurrences and exploration activities of the Peak Hill area *by I Ruddock, EPW Peiris, LY Hassan, and W Ormsby*

Quality controlled seismic data of the Southwest Canning Basin

Non-Series Digital Products

GSWA 2010

1:250 000 geology mosaic of Western Australia, 2010

1:100 000 geology mosaic of Western Australia, 2010

Compilation of geochronology 2010

Products DVD 2008–09

Geothermal acreage release May 2009

WA Petroleum Acreage Release September 2009

Prospectivity of State Acreage Release Area L10–1, Lennard Shelf, Canning Basin *by JH Haworth*

Prospectivity of State Acreage Release Areas T10–1, Perth Basin *by JH Haworth*

Prospectivity of State Acreage Release Areas L10–2 and L10–3, Bangemall Supergroup *by JH Haworth*

Geothermal Release Whole of State April 2010

Prospectivity of State acreage release areas L09–3 and L09–4, Wagen and Lennis areas, Officer Basin

State petroleum acreage release May 2010

Prospectivity of State Acreage Release Areas L10–4 and L10–5, Blake Sub-basin, Officer Basin *by JH Haworth*

Maps, reports, and datasets

1:100 000 Geological Exploration Package

West Arunta GEP 2009 update

Data Layer

East Wongatha regolith map *by SA McGuinness*

Geophysics

Gravity

Cunderdin 2009 (7494 stations)
South Yilgarn Margin 2009 (6125 stations)
Southern Cross 2010 (6354 stations)

Aeromagnetics

Broome (N Canning 1) 76 447 km
Central Canning 91 700 km
Cornish–Helena (E Canning 2) 124 015 km
Crossland–Nookanbah (E Canning 1) 111 874 km
Eucla Coast (Eucla 6) 121 645 km
Mt Anderson – McLarty Hills (N Canning 3) 99 200 km
Naretha (Eucla 2) 124 876 km
Seemore (Eucla 1) 90 011 km
Yampi–Derby (N Canning 2) 68 015 km

Drilling

Co-funded drilling (59 787 m)
Stratigraphic drilling (237 m)

External publications by GSWA authors 2009–10

Bodorkos, S, Stern, RA, Kamo, S, Corfu, F and **Hickman, AH** 2009, A natural reference material for quantifying SIMS instrumental mass fractionation of Pb isotopes during zircon dating: EOS, Transactions AGU, 90 (52), Fall Meeting Supplement, Abstract V33B–2044.

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Demoux, A, Kroner, A, Badarch, G, Jian, P, TomurHuu, D and **Wingate, MTD** 2009, Zircon Ages from the Baydrag Block and the Bayankhongor Ophiolite Zone: Time Constraints on Late Neoproterozoic to Cambrian Dubduction and Accretion-related Magmatism in Central Mongolia: Journal of Geology, v. 117, p. 377–397.

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Grey, K and Sugitani, K 2009, Palynology of Archean microfossils (>3.0 Ga) from the Mount Grant area, Pilbara Craton, Western Australia: further evidence of biogenicity, Special issue on World Summit on Ancient Microscopic Fossils, University of California, Los Angeles *edited by* JW Schopf, MR Walter, D Bottjer: Precambrian Research, v. 173, p.60–69.

Sugitani, K, **Grey, K**, Nagaoka, T, Mimura, K and Walter, MR 2009, Putative Archaean microfossils (>3.0 Ga) from the Mount Goldsworthy and Mount Grant area in the Pilbara Craton, Western Australia: Taxonomic reinterpretation and implications of ancient biotic diversity and evolution, Special issue on World Summit on Ancient Microscopic Fossils, University of California, Los Angeles edited by JW Schopf, MR Walter, D Bottjer: Precambrian Research, v. 173, p. 50–59.

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Open day posters

GSWA Open Day posters 2010

Albany–Fraser Orogen
Amadeus Basin
Bentley Supergroup Musgrave Province
Canning Basin
Canning Geophysics
Capricorn–Youanmi Seismic Lines
Central Yilgarn
Commodity Industry Analysis
Core Library – Hylogger
Cue to Mount Magnet archean granites
Cunderdin Image
Edmund Collier
Elliott Creek Capricorn
Exploration Statistics
Geochemistry
Geochronology
HMH West Musgrave
Igneous Complexes
Kimberley
Milgun, Calyie, Tangadee
Minnie Springs, Gifford Creek
Mount Phillips
Murchison Domain
Musgrave Province
NE Yilgarn space–time
New Extent Eucla
Petroleum Prospectivity February 2010
Pilbara Craton
Radiometric grid merge 2009
Regolith Mapping East Wongatha
South Yilgarn
Southern Cross
Southern Yilgarn Magneto Survey
SWIR spectroscopy
WA Hotspots January 2010
WACoast
West Musgrave IBG East
West Musgrave IBG West

Liaison Committee

Geological Survey Liaison Committee (GSLC)

The Geological Survey Liaison Committee (GSLC) meets twice a year to review progress and advise on future work programs for GSWA. The two technical subcommittees provide comment and provide advice in each of the special areas for consideration by the GSLC.

Geological Survey Liaison Committee members

Richard Sellers (Chair)	Director General, DMP
Tim Shanahan	The University of Western Australia
Mark Woffenden	Curtin University of Technology
Robbie Rowe	CME
Peter Onley	Golder and Associates Pty Ltd
Beverley Ronalds/Steve Harvey	CSIRO
Bryan Smith	AMEC
Mike Sayers	APPEA
Neil Williams	Geoscience Australia
Tim Griffin	GSWA
Rick Rogerson	GSWA
Ian Tyler	GSWA
Stephen Bandy	GSWA

Technical subcommittees

Mineral exploration technical subcommittee

Bryan Smith (Chair)	AMEC
Peter Cawood	The University of Western Australia
Cam McCuaig	Centre for Exploration Targeting
Peter Kinny	Curtin University of Technology
Richard Blewett	Geoscience Australia
Chris Yeats	CSIRO
Leigh Bettenay	Consultant
Don Boyer	Midas Resources Ltd
John Hronsky	Western Mining Services
Robbie Rowe	CME (Barrick Gold of Australia Ltd)
Sudipta Nag	BHP Billiton Iron Ore
Ivor Roberts	DMP
Ian Tyler	GSWA
Roger Hocking	GSWA
Paul Morris	GSWA
Margaret Ellis	GSWA
Ann Fitton	GSWA
Stephen Bandy	GSWA

Petroleum exploration technical subcommittee

Mike Sayers (Chair)	APPEA
David Anthony	Origin Energy
Moira Wilson	Curtin University of Technology
Cecilia D'Ercole	PESA
Clinton Foster	Geoscience Australia
David Haig/David Lumley	The University of Western Australia
Cedric Griffiths	CSIRO Petroleum/ARRC
Andy Padman	APPEA (Arc Energy Limited)
Jenny Mikucki	Chevron Australia Pty Ltd
Bevan Warris	Empire Oil and Gas NL
Peter Southgate	Geoscience Australia
John Libby	New World Energy
Aaron Bunt	PESA (Chevron)
Raj Singh	Origin Australia
Rick Rogerson	GSWA
Jeff Haworth	GSWA
Felicia Irimies	GSWA
Reza Malek	DMP

Acronyms and abbreviations

Acronyms and abbreviations

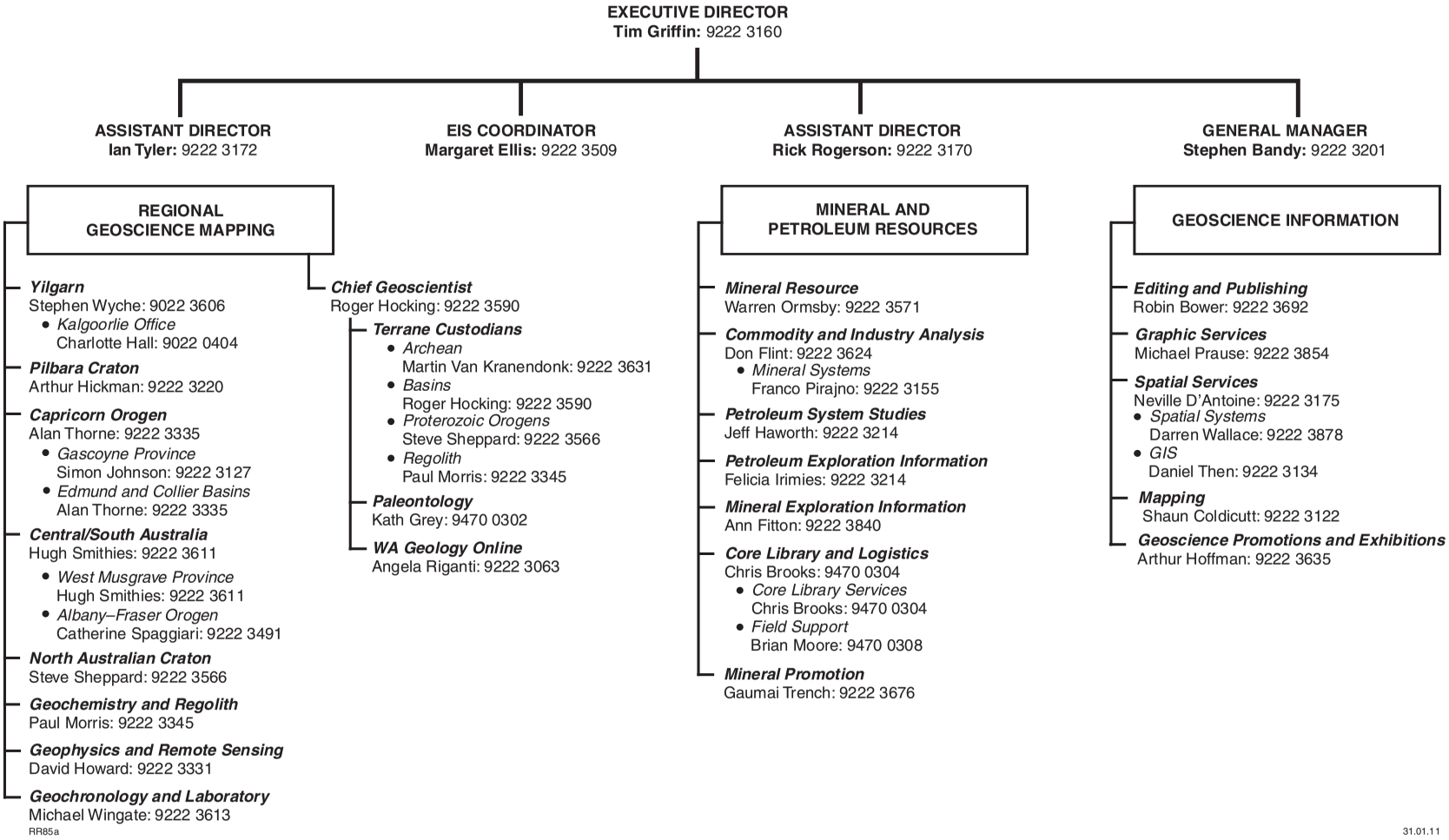
AAPG	American Association of Petroleum Geologists
ABS	Australian Bureau of Statistics
AIG	Australian Institute of Geoscientists
AMEC	Association of Mining & Exploration Companies (Inc.)
AMIRA	Australian Mineral Industries Research Association
ANU	Australian National University
APPEA	Australian Petroleum Production & Exploration Association Limited
ASEG	Australian Society of Exploration Geophysicists
ASX	Australian Securities Exchange
ArcIMS	Arc Internet Map Server
AusIMM	The Minerals Institute
AuScope	National Earth Science Infrastructure Program
BHPB	BHP Billiton
BRGM	Bureau de recherches géologiques et minières
CIAT	International Center for Tropical Agriculture
CME	Chamber of Minerals and Energy of Western Australia Inc.
CRC LEME	Cooperative Research Centre for Landscape Environments and Mineral Exploration
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSIRO-AGE	CSIRO-Australian Geochemical Exploration joint venture
DEC	Department of Environment and Conservation
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EXACT	Western Australian mineral exploration activities database
GA	Geoscience Australia
GeoVIEW.WA†	GSWA's integrated geoscience information system
GIS	Geographic Information System
GPS	Global Positioning System
GSA	Geological Society of Australia

GSLC	Geological Survey Liaison Committee
GSWA	Geological Survey of Western Australia
IUGS	International Union of Geological Sciences
JORC	Joint Ore Reserves Committee of The Minerals Institute, Australian Institute of Geoscientists, and Minerals Council of Australia
Landgate	Department responsible for land and property information
Landsat TM	Landsat Thematic Mapper
MAGIX	Mineral Airborne Geophysics Information eXchange
MERIWA	Minerals and Energy Research Institute of Western Australia
MINEDEX	DoIR's mines and mineral deposits information database
MCMPR	Ministerial Council for Mineral and Petroleum Resources
NASA	National Aeronautics and Space Administration
NCRIS	National Collaborative Research Infrastructure Strategy
NGA	National Geoscience Agreement
NTGS	Northern Territory Geological Survey
PDAC	Prospectors and Developers Association of Canada
PESA	Petroleum Exploration Society of Australia
pmd*CRC	Predictive Mineral Discovery Cooperative Research Centre
SGTSG	Specialist Group on Tectonics and Structural Geology of Geological Society of Australia
SHRIMP	Sensitive high-resolution ion microprobe
SLIP	Shared Land Information Platform in Western Australia
SRTM	Shuttle Radar Topography Mission
TENGRAPH†	DMP's electronic tenement-graphics system
UWA	The University of Western Australia
WACHEM	Western Australian inorganic geochemistry database
WAMEX†	Western Australian mineral exploration database
WAPIMS	Western Australian petroleum information management system database
WAROX	Western Australian field observation database
WASM	Western Australian School of Mines

NOTE: †GeoVIEW.WA, WAMEX, and TENGRAPH are registered Trademarks of DMP

Organizational structure

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



Further details of geological publications and maps produced by the
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