

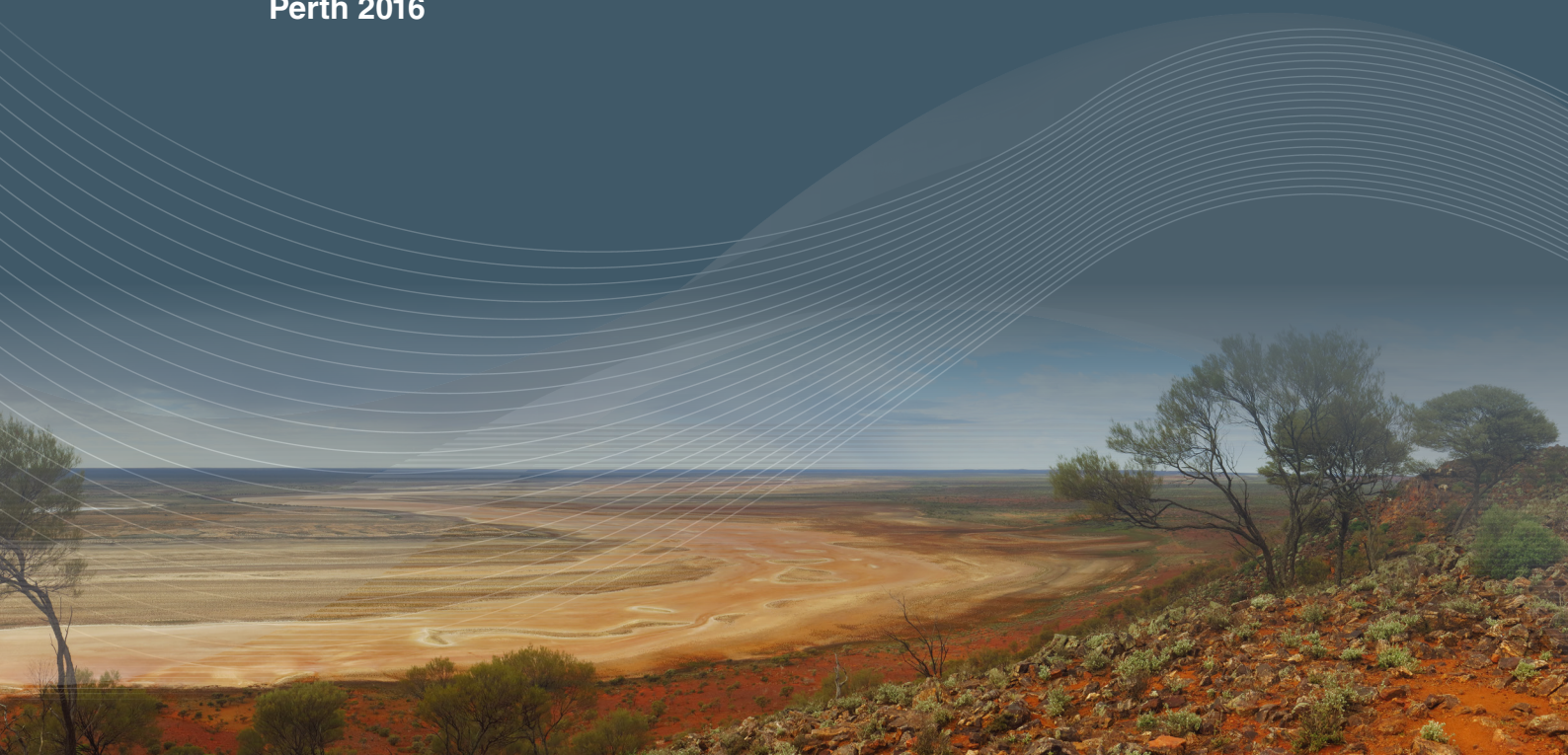


Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2016/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2016–17 AND BEYOND

Perth 2016



**Geological Survey of
Western Australia**



**EXPLORATION
INCENTIVE SCHEME**



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

Record 2016/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2016–17 AND BEYOND

Perth 2016



**Geological Survey of
Western Australia**

MINISTER FOR MINES AND PETROLEUM
Hon Bill Johnston MLA

ACTING DIRECTOR GENERAL, DEPARTMENT OF MINES AND PETROLEUM
David Smith

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Rick Rogerson

REFERENCE

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Further details of geological products and maps produced by the Geological Survey of Western Australia are available from:

Information Centre
Department of Mines and Petroleum
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Facsimile: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications

Contents

Executive summary	1
Part 1 Strategic overview	5
International events	5
National trends	10
State trends	12
Government geoscience trends.....	20
Part 2 Recurrent budget and work program for 2016–17 and beyond	25
Context of the program	25
Achievements 2015–16	26
GSWA's budget 2016–17	27
Part 3 Exploration Incentive Scheme budget and work program for 2016–17 and beyond	39
Outline of the Exploration Incentive Scheme	39
Part 4 Recurrent budget — detailed work programs	47
GS10 Basins and Energy Geoscience	47
GS12 Land Use Geoscience	51
GS14 Commodity and Industry Analysis.....	54
GS20 Mineral Systems Studies.....	56
GS43 Geochemistry and Regolith.....	60
GS45 Pilbara Craton	62
GS47 Gascoyne Province.....	64
GS49 Edmund and Collier Basins and Eastern Capricorn Basins	66
GS52 East Yilgarn (Kalgoorlie Office)	68
GS53 Chief Geoscientist and Terrane Custodians	69
GS54 Geochronology and Isotope Geology	71
GS55 Geophysics and Remote Sensing	74
GS56 North Australian Craton	75
GS57 West Musgrave Province.....	77
GS58 Youanmi Terrane.....	79
GS61 Albany–Fraser Orogen and Eucla Basement Project	81
GS62 3D Geoscience	84
GS63 Tectonic Evolution of the Fortescue and Hamersley Groups.....	85
GS80 Editing and Publishing	87
GS81 Mapping	87
GS82 Graphics	87
GS83 GIS Services	87
GS84 Spatial Systems	87
GS85 Geoscience Promotions.....	87
GS91 Mineral Exploration Information Management.....	89
GS92 Statutory Petroleum Exploration Information.....	92
GS94 and GS96 Core Library Services	94
GS95 HyLogger and the National Virtual Core Library	96
Part 5 Exploration Incentive Scheme — detailed work programs	101
ES01 Exploration and Environmental Coordination.....	101
ES20 Government Co-funded Exploration Drilling.....	102
ES21 Mineral and Exploration Promotion.....	110
ES30 Regional Airborne Surveys.....	111
ES31 Deep Seismic Survey Program	113
ES32 Regional Gravity Surveys.....	115
ES33 Yilgarn Margin Geochemistry	117
ES40 Geology Online	119
ES42 3D Geoscience.....	120
ES43 Mineral Systems Atlas.....	122
ES45 Geological Mapping and Interpretation.....	125
ES46 Enhanced Geochronology and Acquisition of Isotope Data.....	127
ES47 Petroleum, Coal and CO ₂ Geosequestration Program.....	130
ES50 Strategic Industry Research Program	132
References	133

Appendices

Appendix A — GSWA maps, books and datasets released 2015–16.....	137
Appendix B — GSWA external publications on Western Australian geoscience 2015–16.....	141
Appendix C — GSWA organizational structure	144
Appendix D — GSWA collaborative research projects (current and historic) — 30 June 2016	145

Figures

1.	World economic volatility	6
2.	Average monthly commodity prices — July 2004 to June 2016 (dollars of the day)	7
3.	Average monthly A\$/Chinese RMB exchange rate — January 2014 to June 2016	7
4.	Lithium carbonate spot price per tonne (US\$)	9
5.	Global exploration budgets 1994–2015	9
6.	Worldwide non-ferrous exploration budgets by country or region for 2015	9
7.	Sources of foreign investment into Australia’s resource sector for 2014–15	11
8.	Metals and Mining Index and Energy Index — July 2006 to June 2016	12
9.	Mineral IPO (including coal) on the ASX by calendar year	12
10.	Lion Selection Group’s well-known Widdup Cycle	12
11.	Macro-economic indicators and unemployment statistics for WA — June 1990 to June 2016 financial years	13
12.	The three resources cycles in WA (2015)	14
13.	WA production quantity for major commodities 2004–15	16
14.	WA’s trend improvement in the Fraser Institute’s three critical mineral investor perceptions categories	16
15.	Quarterly mineral exploration expenditure in WA	17
16.	Exploration expenditure in WA by financial year by commodity	17
17.	Greenfields mineral exploration expenditure in WA	18
18.	Selected factors contributing to Fraser Institute’s petroleum PPI for WA	18
19.	Annual petroleum exploration expenditure in WA and adjacent Commonwealth Waters	19
20.	Number of new field wildcat wells drilled in State jurisdiction	19
21.	Location of surveys planned by Geoscience Australia in Northern Australia	20
22.	Long-term trends in GSWA’s recurrent salary and non-salary expenditure	30
23.	Specialist groups as a percentage of GSWA staff resources	31
24.	Index map showing 2016–17 planned achievements — 1:100 000 Geological Series maps	33
25.	Index map showing 2016–17 planned achievements — 1:100 000 Geological Information Series (GIS) and Geological Exploration Packages (GEP)	34
26.	EIS budgets since 2008–09	39
27.	EIS-funded airborne magnetic and radiometric surveys	41
28.	Composite map of EIS-funded gravity, seismic, magnetotelluric, airborne electromagnetic, passive seismic coverage	42
29.	EIS-funded planned work program until 2016–17	43
30.	Spectral scanning of core through GSWA’s HyLogger at Carlisle	44
31.	South West Settlement project — location map	52
32.	Land Use Geoscience section — annual referral statistics	53
33.	Breakdown of geochemical analyses according to groups or projects	61
34.	Geographical and tectonic distribution of GSWA samples analysed by SHRIMP	73
35.	Drillhole database: number of drillholes recorded	90
36.	Drillhole database: amount of metres drilled	90
37.	Drillhole database: number of surface geochemistry samples recorded	90
38.	Perth Core Library usage statistics since 2004–05 for number of clients	94
39.	Perth Core Library usage statistics since 2004–05 for petroleum versus mineral clients	94
40.	EIS Co-funded Drilling program — projects offered funding versus projects actually drilled	102
41.	EIS Co-funded Drilling program — schedule of Rounds 6–13	103
42.	EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 12	104
43.	EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 13	106
44.	EIS Co-funded Drilling program — map showing projects offered funding in Rounds 1–13 inclusive	108
45.	EIS diamond drilling versus all other drilling types	109
46.	Regional airborne surveys program	112
47.	Conductivity at 4.5 km depth in the Wyloo Inlier area	114
48.	EIS gravity survey program 2015–16	116
49.	Distribution of GSWA regolith programs	118
50.	Samples collected and/or analysed in 2015–16	128

Tables

1.	Real local currency GDP in 2014 and 2015 for selected trading partners	5
2.	Quantity and value of minerals and petroleum production in WA 2015	15
3.	WA's ranking in Fraser Institute mining company surveys for the period 2009–10 to 2015	16
4.	Pre-competitive geoscience initiatives in Australian geological surveys 2016–17 onwards	21
5.	Fraser Institute's Policy Potential Index — relative rankings, Australian States only	22
6.	Recommendations of the 2012 functional review of GSWA	25
7.	GSWA products 2008–09 to 2015–16	26
8.	GSWA high-level budget for geoscience information	27
9.	GSWA's 2016–17 recurrent budget for both projects and support activities	28
10.	GSWA's 2016–17 recurrent budget, with support budgets distributed pro rata to geoscience activities	29
11.	Distribution of GSWA staff (excluding EIS- and KSCS-funded staff) among specialist groups funded by the CR fund in 2016–17	30
12.	Distribution of recurrent budget to high-level strategic objectives in 2016–17	32
13.	Planned achievements for release in 2016–17	36
14.	Detailed budgets for EIS programs in 2014–15 to 2016–17	40
15.	List of successful applicants for Round 12 of the Co-funded Drilling program	104
16.	List of successful applicants for Round 13 of the Co-funded Drilling program	107

Geological Survey work program for 2016–17 and beyond

Executive summary

Last year (2015–16) was a stellar year for the Geological Survey of Western Australia (GSWA) and the Department of Mines and Petroleum (DMP). In 2015, the Fraser Institute's Annual Survey of Mining Companies (Fraser Institute, 2016) ranked Western Australia the leading jurisdiction worldwide in the headline 'investment attractiveness index' which Western Australia has now achieved twice in the last three years. In addition, Western Australia was also ranked first in the 'Best practice mineral potential index', third in 'Geoscience databases', and eighth in 'Policy perception index'. The rise in Western Australia's performance in these indices since the introduction of the Exploration Incentive Scheme (EIS) in 2009 is nothing short of dramatic.

However, GSWA's activities planned for 2016–17 are (as was the case in 2015–16) in a macro environment characterized by slow growth in China, low commodity prices generally, continued downward pressure on commodity prices, dire shortage of equity raising capacity (particularly of junior explorers), low worldwide exploration budgets and actual expenditure, deferral of capital investment in mining, producers cutting costs to increase margins and to maintain shareholder dividends, and widespread unemployment in the sector. The long boom cycle in commodities since the early 2000s, interrupted briefly by the global financial crisis (GFC) in 2007–08, has unquestionably ended. Making things more difficult for the resources sector now is public perception that the mining boom is over and that the Australian economy needs to re-adjust for life after mining.

However, the biggest challenge for GSWA during 2016–17 remains unchanged from last year, that is, to secure long-term funding for the EIS beyond 30 June 2017 — the current limit of EIS in the budget forward estimates. GSWA is seeking to have the business case for extending EIS approved by the Minister, Treasury and the Department of Regional Development. Early indications are for a switch of funding EIS from Consolidated Revenue (CR) back to Royalties for Regions (RfR). However, the continuation of EIS funding requires approval as part of the 2017 State budget which will occur after the 2017 State Election.

Last year (2015–16) was again a very busy and productive year for GSWA. Using its recurrent and EIS budget of \$28.612 million, 126 planned full-time equivalent (FTE) staff in 2016–17, plus eight FTE contract staff funded from EIS, and short-term fee-for-service contractors, GSWA plans to publish the following flagship products:

Books (Reports, Records, Bulletins)	43
Series maps (1:100 000, 1:250 000)	6
Other maps (including State maps)	18
Digital information packages	18

Other headline deliverables for 2016–17 are to:

- complete construction of the expansion of the storage area of the Perth Core Library, together with enclosing the external viewing area. Prepare a business case for expansion of the storage capacity at the Joe Lord Core Library in Kalgoorlie
- release in full GSWA's field observations and rock database (WAROX). Although parts of it have been released for individual project areas in Geological Information Series packages, this will be the first ever release of the statewide data
- release the first product in the series Digital Core Atlas – Olympic 1, which was drilled by Buru Energy Ltd in the Canning Basin and is an important stratigraphic well for GSWA
- release GSWA's concept and demonstration of the prototype of the Mineral Systems Atlas
- release exploration targeting for BIF-hosted iron ore deposits (joint project with MRIWA)

- release the Explorer's guide for gold in the Yilgarn Craton (Part 3)
- release GSWA's next suite of 3D products — Rocklea Dome and the Albany–Fraser Orogen
- release web-based virtual geological tours created for viewing through Google Earth — 'Marble Bar through the East Pilbara', 'Mafic–ultramafic intrusions of the Youanmi Terrane' and 'Meteorite impact structures of Western Australia'
- release interpretation of the Eucla–Gawler deep seismic reflection survey
- release Explanatory Notes System — West Musgrave Province
- release Western Australia unearthed (part 3): the Paleozoic of Western Australia
- release revised Mineral Resources Bulletin on the Gemstones of Western Australia
- release of TENGRAPH web version using the Geocortex software (that is, similar look and feel to GeoVIEW.WA)
- release of upgrades to the WA Geology mobile application and to the GeoMap.WA software
- upgrade GSWA's 'Data and software Centre' on the DMP website.

A major challenge for GSWA in the longer term, and one which will certainly impact on products delivered in future years, is aligning GSWA's work program to obtain maximum leverage from two major external initiatives — the industry-led roadmap of UNCOVER and Geoscience Australia's (GA) Exploring for the Future project in Northern Australia.

Note: all currencies are Australian dollars unless otherwise indicated.

PART 1

STRATEGIC OVERVIEW



International events

Volatility continues

All advanced economies should be benefiting during a period of increasing finance availability, and when interest rates, inflation, and wages growth are all low. However, events in China, slower than expected growth in the US, low commodity prices and uncertainties over the outcome of the vote in the UK over its future as a member of the European Union (EU), have resulted in slower than expected investment and economic growth. As a consequence, the World Bank (World Bank Group, 2016) revised downwards its estimate for 2016 world economic growth from 2.9% in January 2016 to 2.4% in June 2016. In advanced economies, growth in 2016 is expected to be 1.7% – 0.5% less than the World Bank's estimate in January 2016.

On 23 June 2016, voters in the UK voted 52% to 48% to exit the EU. Markets reacted immediately, with the S&P/ASX 200 closing 3.2% lower on 24 June 2016, and the gold price rising to a peak of US\$1358 per ounce or US\$100 higher before dropping to around US\$1320 at day's end. The day after the vote (Friday 24 June), the British Pound dropped about 8% relative to the US\$, raising the potential for a spike in inflation within the UK.

It is too early yet to gauge the medium and longer term economic, political and social impacts of the so-called Brexit. However, some commentators suggest that the negative impacts will be much fewer than the scary hyperbole predicted during the pre-election campaign, and might well turn out to be relatively mild.

There were few highlights for the world's economy during 2015–16. Some resolution of the Greek financial crisis was reached after the Greek Government's brinkmanship about leaving the Eurozone proved unsuccessful, and the German taxpayer underwrote a significant proportion of additional loans associated with the imposition of much-needed austerity measures. By May 2016, the Greek Government finances had improved. However, discussions continued between the Greek Government and the European Union, European Central Bank and the International Monetary Fund about reforms to pension schemes and issues associated with bad debts.

In November 2015, the International Monetary Fund added the Chinese currency renminbi (RMB) to the basket of currencies with Special Drawing Rights, signalling the RMB's new status as a reserve world currency held by central banks. As part of a succession of reforms in late 2015, the Chinese Central Bank also eased the strong link between the RMB and the US Dollar by valuing the RMB against a trade-weighted basket of currencies including the US Dollar, Euro, Japanese Yen, British Pound, Australian Dollar and nine other currencies.

In response to its slower economic growth and the probability of increasing US interest rates, the Chinese Government devalued the RMB in August 2015 by 3% against the US Dollar (from 6.2 to 6.4 RMB to the US Dollar). By mid-June 2016, the US Dollar was buying just less than 6.6 RMB.

China's apparent policy gyrations during 2015 and early 2016 sent mixed signals to resource producers and investors as policy makers continued their attempts to rebalance China's economy from manufacturing to services, with the latter accounting for just over 50% of China's Gross Domestic Product (GDP). This is against a background of the failed attempt to support China's equity market free-fall in 2015, a slowing economy, a risk-laden banking sector, weakness in the property sector, and rising debt. To stimulate the economy, the Chinese Government has increased credit available through commercial banks which have lent to provincial- and local government-level State-owned entities, many of them the inefficient manufacturers that need to be culled. China's real GDP (measured in RMB) increased by around 6.9% in 2015 (Table 1) and inflation was a low 1.4% (Fig. 1b).

Official Chinese statistics released in early April 2016 put the Purchasing Managers' Index (PMI) at 50.2, where anything greater than 50 is positive. Given the PMI has been less than 50 since July 2015 and was 49 in February 2016, it suggests a rise in large company manufacturing. Other official statistics suggested a rise in manufacturing profits in the first two months of 2016. This relatively positive news was supported by increased Chinese demand for some commodities including iron ore.

In 2016, the US economy continues to emerge from the 2009 recession but not as rapidly as many commentators predicted. In 2015, inflation was low (0.1%, Fig. 1b), real GDP grew 2.4% compared to 2014 (Table 1), and the official interest rate was 0.5%, an increase from the 0.25% rate that had applied for the previous four years. The April 2016 employment figures caused some consternation when they remained steady at 5%, but total payrolls grew less than expected.

European growth was insipid with Germany, the UK, and northern Europe generally outperforming southern Europe. Economic growth in 2015 was 2.25% in the UK and 1.45% in Germany (Table 1). However, both countries declined in wealth (from the previous year) measured in US Dollars because their currencies declined relative to the US Dollar (Fig. 1a). Inflation was very low for both countries (0.1 – 0.2%).

Table 1. Real GDP measured in local currency in 2014 and 2015 for selected trading partners. Source: IMF statistics

Country	2014 GDP (real, billion)	2015 GDP (real, billion)	GDP increase (% year on year)
Australia (AUD)	1 603.25	1 642.99	2.47
China (RMB)	55 388.80	59 210.62	6.90
Germany (Euro)	2 734.26	2 773.91	1.45
India (INR)	105 521.50	113 262.44	7.33
Japan (JPY)	526 095.70	528 583.00	0.47
South Korea (KRW)	1 426 540.30	1 463 506.20	2.59
United Kingdom (GBP)	1 749.71	1 789.05	2.25
United States (USD)	15 961.65	16 348.88	2.42

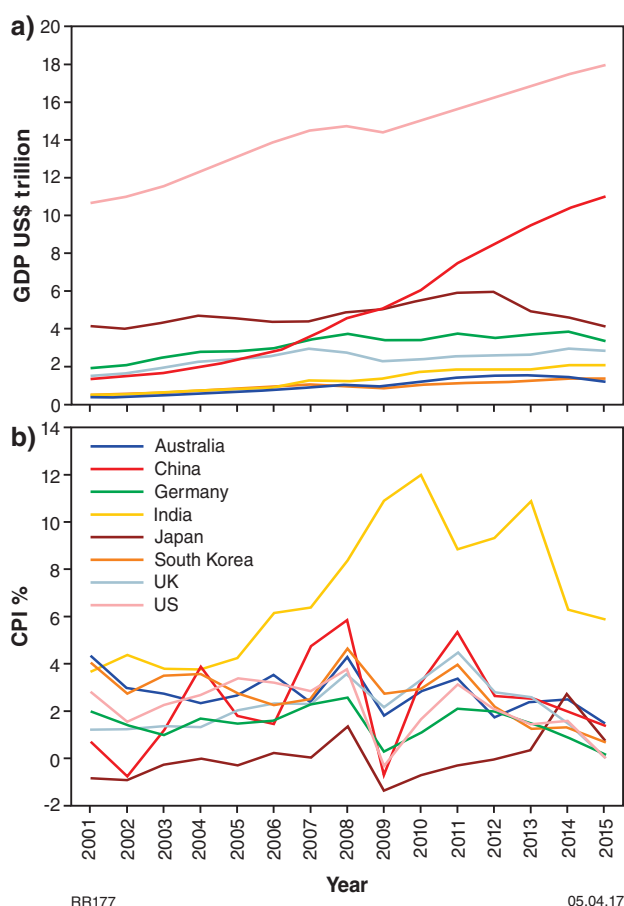


Figure 1. World economic volatility: a) GDP for selected Australian trading partners 2000–15. Data are in current US Dollars converted from domestic currencies using single year official exchange rates. GDP is at purchaser's prices calculated by summing the gross value added by all resident producers in the economy and converting to current US\$; b) CPI% is measured by the consumer price index reflecting the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services
Source: World Bank statistics

Japan introduced a negative interest rate policy in January 2016 as economic growth of 0.47% in 2015 (Table 1) continued to disappoint. Inflation remained low at 0.8% in 2015 (Fig. 1b). The World Bank (World Bank Group, 2016) expects that the stimulus policies implemented in Japan will lead to subdued growth in 2016 and beyond, though the recent rise in the value of the Japanese Yen will continue to impact negatively on exports.

India was the standout economy in 2015 under the leadership of Prime Minister Modi. Real GDP growth was 7.33% in local currency terms (Table 1) and although inflation was still high at 5.9%, this is the lowest it has been since 2006 (Fig. 1b). Domestic demand drives the Indian economy which is being boosted by low oil prices and the government's major road, rail and electricity infrastructure investments.

South Korea's economy grew 2.59% in real local currency terms in 2015 (Table 1) and inflation remained low at 0.7% (Fig. 1b). Korea's economy and exports are dependent on the economic health of China and Japan, neither of which can be relied on at present.

Commodity prices — signs of recovery?

Commodity markets remained subdued during 2015–16 with only two major exceptions — precious metals and lithium — though the price rises in these commodities were for different reasons.

Since July 2015, the Australian Dollar has traded in a relatively narrow band between US\$0.7 and US\$0.77, and €0.62 and €0.68 (Fig. 2) while depreciating against the Japanese Yen as it rose against most other currencies. The Australian Dollar rise to US\$0.77 in April 2016 was in response to stronger Chinese trade data and general market perceptions that commodity markets and the US economy were slowly improving.

Since the August 2015 devaluation of the Chinese RMB, the Australian Dollar has appreciated against the RMB from a low of 4.5 in September 2015 to 4.9 in April 2016 (Fig. 3).

Given the global economic volatility and the general weakness of the Australian Dollar against the US Dollar, gold was the clear major commodity star in Australian Dollar terms during the last year. Even in US Dollar terms gold recovered gradually since its average price low of US\$1068 in December 2015 to an average of US\$1276 in June 2016, boosted by the post-Brexit rise in late June (Fig. 2). Except for its average price of \$1486 in December 2016, the average monthly Australian Dollar gold price has been greater than \$1540 for most of 2015–16, and for seven months of the year has been greater than \$1600 including two months exceeding \$1700. This has translated into a marked acceleration in gold exploration in Western Australia and increased profits for producers that were already benefiting from programs to prune costs over the last three years.

Platinum prices (Fig. 2) have been declining since July 2014 and more steeply than gold, perhaps in response to anti-diesel vehicle publicity in Western Europe and its substitution by palladium in auto catalysts. However, the almost US\$200 rise in the platinum price since January 2016 seems in step with the gold price and suggests that platinum is also being viewed as a store of wealth for investors facing economic uncertainty.

Average monthly base metal (copper, lead, zinc and nickel) prices in US\$ per tonne continue to disappoint despite some commentators over the last several years predicting 'imminent' price rises in response to predicted supply or demand changes. Figure 2 shows that the declining trends in average monthly copper and nickel prices and the generally flat trend in lead prices have continued in 2015–16. The average US\$4694 per tonne copper price in May 2016 equalled a US\$2.13 price per

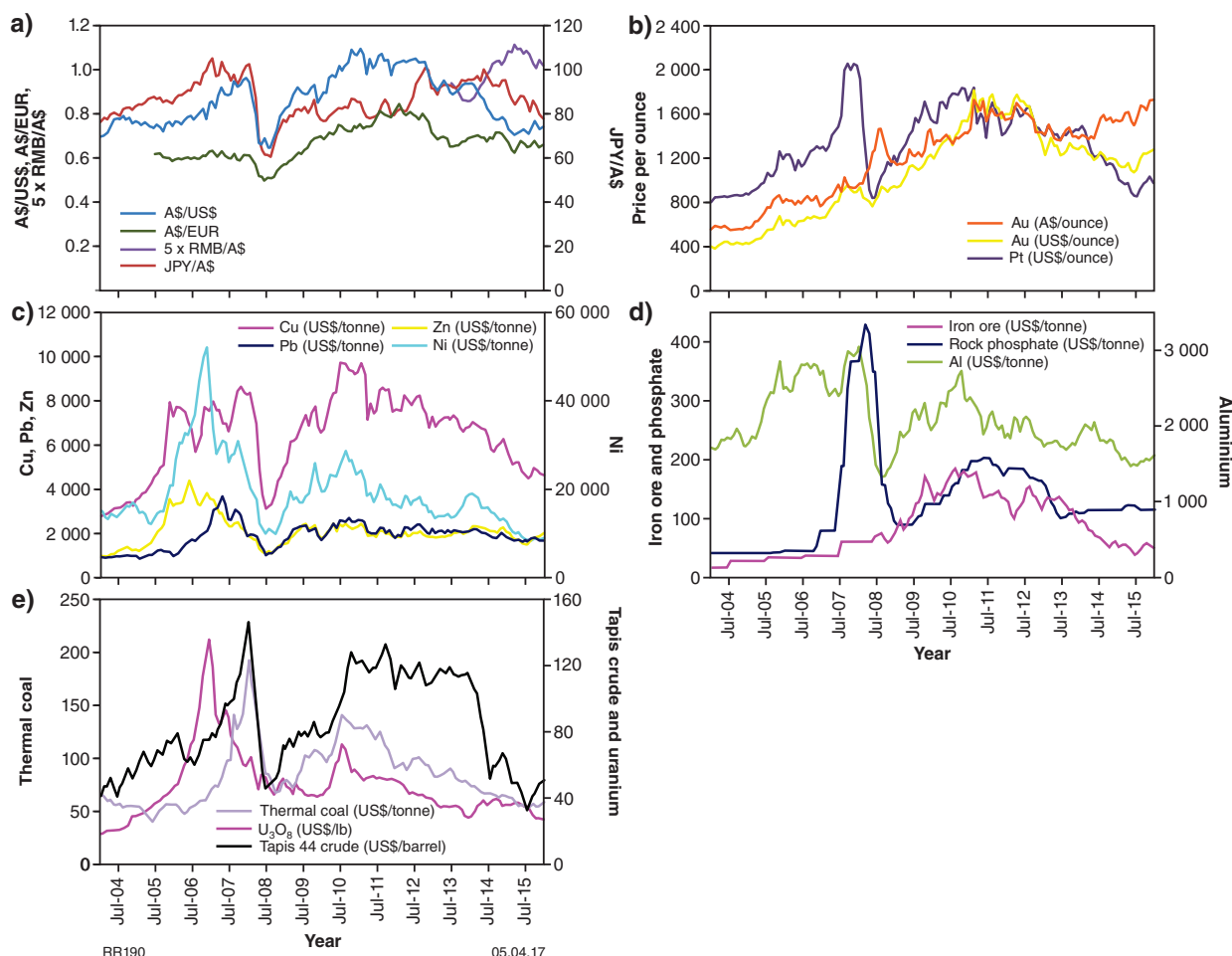


Figure 2. Average monthly commodity prices July 2004 – June 2016 (dollars of the day). All precious and base metal, aluminium, and uranium prices are spot prices collated by the Australian Bureau of Resources and Energy Economics and downloaded from the SNL Energy website (www.snl.com.au). Coal (Australian thermal coal, 12 000 btu/pound, less than 1% sulfur, 14% ash, FOB Newcastle/Port Kembla) and iron ore (62% iron content, fine, spot price delivered Tianjin) prices were sourced from the International Monetary Fund. Rock phosphate prices (Morocco, 70% Bone Phosphate of Lime equivalent, contract) were sourced from the World Bank. The monthly Malaysia Tapis Blend price was derived from the US Department of Energy, Energy Information Administration website (www.eia.doe.gov)

pound after reduced demand by China beginning in 2012, closure of some operations and cost cutting by producers. Most commentators and copper producers think that the copper supply surplus will continue until at least 2018.

Zinc was the standout base metal during the 2015–16 financial year, rising 33% from an average monthly price of US\$1520 per tonne in January 2016 to an average of US\$2026 per tonne in June 2016 (Fig. 2). However, this rise only brings average zinc prices back to the level they were in July 2015 and for a few months previously. Whether this price increase is due to the decline in production or closure of a number of major zinc mines remains to be seen; the long run average monthly zinc price tends to fluctuate around US\$2100 per tonne (Fig. 2).

Nickel prices are so low (Fig. 2) that it is a wonder that more mines have not closed, with analysts estimating that 60% of nickel in early 2016 was being produced below cost price. In May 2007, the average nickel price

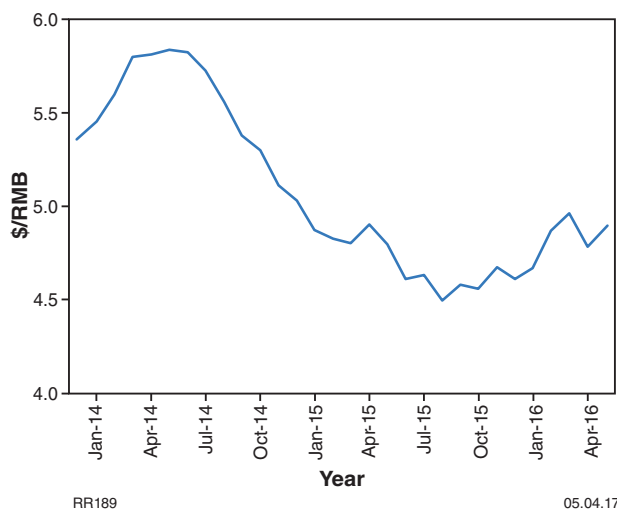


Figure 3. Average monthly A\$/RMB exchange rate from January 2014 to June 2016
Source: Reserve Bank of Australia statistics

was US\$52 179 per tonne (US\$23.67 per pound) before plunging in February–March 2009 to around US\$10 000 per tonne (US\$4.54 per pound). Another average monthly peak of US\$28 840 was reached in February 2011 before the steady decline to US\$8660 per tonne (US\$3.93 or A\$5.37 per pound) in May 2016. The last time the average monthly nickel price has been as low was May 2003. Relatively high nickel stocks on the London Metal Exchange (LME) still exist, putting a dampener on nickel prices, despite a number of nickel producers around the world placing mines under care and maintenance.

Several Western Australian nickel operations including Savannah, Miitel, and Lanfranchi are in care and maintenance, and Quantum's Ravensthorpe mine is rumoured to be subeconomic. However, there have been some capital raisings by nickel companies and project acquisitions (e.g. Talisman and Western Areas acquired Sinclair and Cosmos, respectively, from Glencore, and Independence Group acquired Nova with its takeover of Sirius Resources). This suggests there may be some corporate positioning occurring ahead of the long-awaited sustained increase in nickel prices.

Average monthly iron ore prices (62% Fe) started and ended the 2015–16 financial year at about US\$51.50 per tonne (Fig. 2) but mostly traded in a monthly average range between US\$45 and US\$55 per tonne. December 2015 (US\$39.60) and January 2016 (US\$41.30) were the lowest price months before low inventories in China and the Chinese Government embarked on more infrastructure spending. This combined to stimulate demand and increase prices which peaked at an average US\$59.60 per tonne in April 2016. Alas, most iron ore pundits are predicting a less than US\$50 per tonne price for the latter half of 2016 due to overcapacity in China's iron and steel sector, in part because the Chinese Government has not achieved its plan of shutting more high-cost, polluting steel mills, particularly in Hebei Province.

Further cost cutting by BHP Billiton and Rio Tinto has seen their cash costs drop to around US\$16 per tonne and total costs to around US\$25. The other two large producers, Vale and Fortescue Metals Group, are attempting to reach these cash costs but their total costs are higher. As expected, the Roy Hill mine exported its first ore in December 2015 and plans to ramp up to 55 million tonnes per year.

Until November 2015 (US\$1468 per tonne), average monthly aluminium prices (Fig. 2) continued a long-term trend of decline since late 2014, and some would say an even longer term price decline since July 2011. However, since December 2015, the average monthly aluminium price has risen and by June 2016 was at US\$1594 per tonne, a rise of 8.5%. Whether this price rise is in response to Indonesia's, the Philippine's or India's ban on exports of bauxite, or it reflects demand-driven price rises in a number of other metals, is not known. What is certain is that prices of traded bauxite at Chinese ports have remained buoyant at just below US\$50 per tonne. This at present lucrative so-called 'free bauxite' market, outside of bauxite intended for alumina production, has enticed Alcoa to begin bauxite shipments to China on a trial basis

up to the 500 000-tonne limit imposed by the Western Australian Government.

Average monthly uranium spot prices showed no signs of support, declining from a 2015–16 financial year peak of around US\$37 in September and October 2015 to around US\$27 per month in June 2016. This is the lowest average monthly price since April 2005. It remains to be seen whether the re-starting of another seven reactors in Japan this year, the planned re-start of another 20 by 2020, and the more than 55 reactors under construction have any impact on the uranium price over the next two years. About half of the reactors under construction are located in China.

Thermal coal average monthly prices continued to bounce along the bottom in the 2015–16 financial year, remaining around US\$54–56 per tonne for most of the year. At these levels, the price of thermal coal declined by over US\$10 per tonne compared to the 2014–15 financial year when the average price was US\$67.4 per tonne. In late 2015, the Chinese Government announced a moratorium on approving new coal mines for the next three years beginning in 2016, and measures to reduce production in others. This will reduce domestic oversupply but will probably not result in increased demand for coal imports.

Average monthly Tapis crude prices continued to decline in the 2015–16 financial year reaching in January 2016 their lowest level (US\$32.30 per barrel) since December 2003. Since January 2016, the price has risen over 50% to an average of US\$49.98 per barrel in June 2016. High export levels continued from OPEC countries, and the threat of Iran's re-entry into oil exporting put a dampener on oil prices. Any sustained rise in oil prices will also trigger the re-entry into the market of US shale oil producers that have already cut costs severely, or who have suspended production.

LNG prices remained very low throughout 2015–16 in response to the world glut of seaborne LNG.

The 'battery bubble' continued to impact on the price of a number of specialty metals during 2015–16 including lithium, graphite and cobalt. While graphite flake prices have come off the boil, lithium carbonate prices (Fig. 4) rose exponentially during the latter half of 2015 before reaching US\$22 000 per tonne in March 2016. Between 2009 and early 2015, the lithium carbonate price ranged between US\$4000 and US\$6000 per tonne.

Greenbushes (Talisman Lithium) is the world's largest lithium producer with production at about 400 000 tpa of chemical- and technical-grade spodumene concentrate. Western Australia reinforced its pre-eminence as a lithium producer by re-starting spodumene production at the Mt Catlin mine (General Mining and Galaxy) and beginning production at the Mt Marion (Reid Industrial Minerals) mine near Kalgoorlie. Pilbara Minerals Pilgangoora project, located in the Pilbara, is at feasibility stage and has a total resource of 1.57 Mt (128.6 Mt at 1.22% Li₂O) of Li₂O making it one of the world's largest lithium deposits. The company is aiming to bring the project into production by the end of 2017.

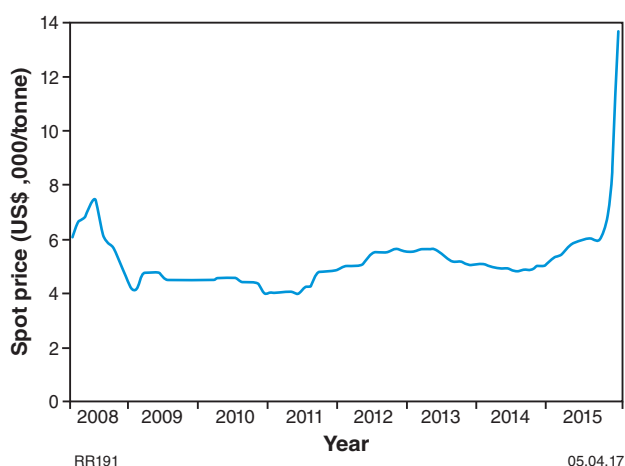


Figure 4. Lithium carbonate spot price (US\$,000) per tonne
Source: Citigroup

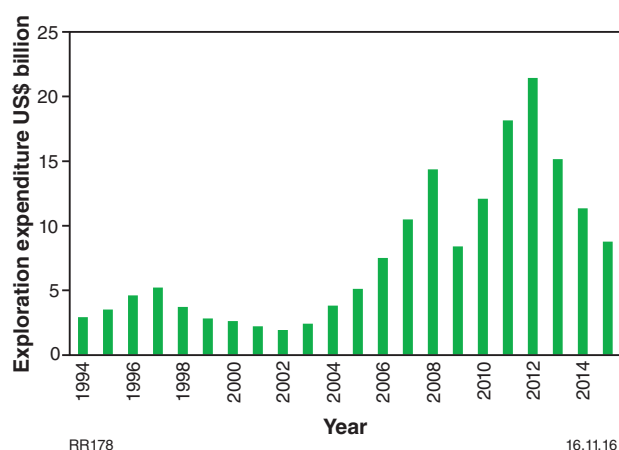


Figure 5. Global exploration budgets 1994–2015. Includes estimated spending on exploration for gold, base metals, platinum group metals, diamonds, uranium (from 2007), silver, rare earth elements, potash/phosphate, and many other hard-rock metals, but specifically excludes exploration budgets for iron ore, coal, aluminium, oil and gas, and many industrial minerals
Source: SNL Metals & Mining (2015)

World mineral exploration budgets remain depressed in 2015

SNL Metals & Mining (2015) revealed that world non-ferrous mineral exploration budgets declined by a further 29.5% in 2015, falling from US\$11.36 billion in 2014, to US\$8.77 billion in 2015 (Fig. 5). Except for 2009 during the global financial crisis, this is the lowest budget since 2006 and only 40.8% of the total 2015 budget of US\$21.5 billion.

Exploration budgets declined in all regions, though Australia's share (12.2%, Fig. 6) of global budgets, and that of the US and Latin America, rose slightly compared with 2014. The budgets of Africa and Canada declined which may be due to more Canadian companies shifting their attention from Africa to Latin America. Latin America accounted for 28.3% of global exploration budgets in 2015, with Africa and Canada almost equal at 13.7% and 13.5% respectively, but with only half Latin America's percentage.

In country terms, Australia (12.2%) had the second highest exploration budget behind Canada (13.5%).

SNL Metals & Mining (2015) statistics show that budgets for gold exploration in Australia were 48% of the total for 2015 (up from 41% in 2014) and that Western Australia accounted for 60% of exploration budgets spend in the country. Australia also had the highest country budget for grassroots exploration (US\$381 million), with Canada close behind at US\$339 million.

The proportion of global budgets allocated to grass roots exploration continued to fall in 2015, with SNL Metals & Mining (2015) reporting that only 29% was directed to early-stage exploration, reflecting a declining trend from the years prior to 2004 when it made up around 50% of global budgets.

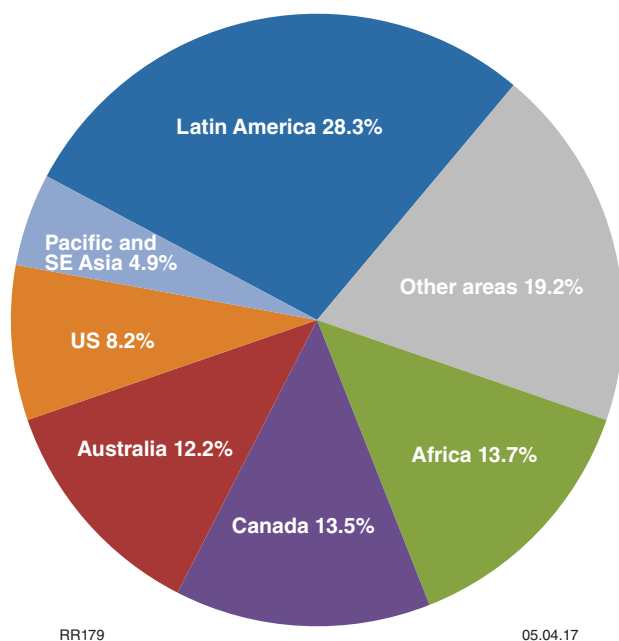


Figure 6. Worldwide non-ferrous exploration budgets by country or region for 2015, presented as a percentage of annual worldwide exploration. In addition to excluding iron ore, this graph excludes expenditure on aluminium, coal, and most industrial minerals
Source: SNL Metals & Mining (2015)

Canada continues support for mineral industry

The 2016 Canadian Federal budget brought down in March contained good news for the mineral industry — the renewal of the Mineral Exploration Tax Credit until March 2017. In response to the budget announcement, the Prospectors and Developers Association of Canada said that renewal of the tax credit sends an important signal to investors that the government understands the importance of Canada's junior mining sector.

Other mineral industry support measures in the budget included: additional support for skills training in Aboriginal communities; a boost to infrastructure spending in remote and regional Canada; and increased funding for clean energy technology from which the mining industry could benefit.

South America and Africa still attract interest

In 2015, SNL statistics recorded that 50 and 90 Australian Securities Exchange (ASX)-listed companies had exploration budgets in Central and South America, and Africa respectively, which was a decrease compared to 2014.

The investment climate in Africa did not improve during 2015–16, showing a general retreat from the continent by cash-strapped Australian-based juniors. High infrastructure costs, changing fiscal regimes and in some jurisdictions, a lack of security of exploration and mining tenure have combined in a way that has seen many potential mining projects fail to develop in the last investment cycle. Iron ore projects in particular have suffered as rapidly expanded production infrastructure in Western Australia and Brazil, and falling iron ore prices, has meant greenfields projects in Africa cannot be developed (e.g. Simandou and Mbalam-Nabeba) in the medium term or could not compete on price.

Several African nations created uncertainty by announcing changes to mining policy settings during the last year. The Democratic Republic of the Congo, after announcing a review of its 2002–03 mining legislation with the aim of increasing the government's fiscal take from the country's successful copper mining industry, did an about-face in February 2016 when it announced that it would maintain the existing policy stance. Likewise, Zambia wound back some of the large increases in royalty rates it had previously announced. Kenya, a country with an undeveloped mining sector, announced increases in royalty rates and a 10% free buoyed interest in projects for the government.

On a more positive note, both South Africa and Burkina Faso introduced environmental policies that required producing companies to make provision for mine rehabilitation and closure either by way of a bank guarantee (South Africa) or contributing to a number of specific-purpose funds managed by the government (Burkina Faso).

Peru is the standout mining investment-friendly jurisdiction in Latin America and has benefited enormously from stable policies with over 20 projects involving Western Australia-based companies. With a change to a more investor-friendly government, Argentina also made a number of positive changes including amendments to capital movement controls, exchange rate mechanisms, and import controls. The new government also removed export taxes on mineral products and appointed an experienced former Secretary of Mining to oversee these and future policy changes.

The first extraterrestrial mining policy was announced by the US in November 2015 when both houses passed a bill to facilitate mining of asteroids by domestic companies and individuals. Although the bill, named the *Space Act 2015*, may contravene United Nations treaty obligations, it was signed into law by the president in late November 2015.

National trends

At the end of the 2015–16 financial year, Australia's population had climbed to 24 million (Western Australia's population was just above 2.6 million), inflation was 1% for the year, GDP for the year ending March 2016 was up 3.1% seasonally adjusted, interest rates were low, the unemployment rate was 5.8% and the Australian Dollar was buying US\$0.74. The Commonwealth Government's 'Pre-election Economic and Fiscal Outlook 2016' (Commonwealth of Australia, 2016) reported that Australia is well into the transition from its resources capital investment phase into other more broadly based drivers of growth. Resources investment was expected to decline a further 25.5% in 2016–17, but the negative impact of this on GDP was expected to be moderated by the growth in iron ore and LNG export volumes over the next few years.

Australia reaches agreement with trading partners

After negotiations lasting almost 10 years, 12 Circum-Pacific countries including the US, Australia, Canada, Japan, Mexico, Malaysia, Singapore, Vietnam, and Peru reached agreement late in 2015 over terms in the Trans-Pacific Partnership (TPP) — essentially another free-trade agreement. China was not involved in negotiations. The fact that parliaments in all countries will need to endorse the TPP means that it will not come into force for some time, perhaps never given the resistance some US politicians have expressed on the basis that more domestic jobs will be lost. While there is some benefit for Australia's resources producers in terms of eliminating resource import and export tariffs in some countries (Peru, Malaysia and Vietnam), the main benefit would be in the export of Australian resource services and investment.

The Commonwealth Government signed nuclear cooperation agreements with the United Arab Emirates (April 2014) and India (November 2015). These

agreements increase to 23 the number of bilateral nuclear cooperation Agreements in force, covering 41 countries to which Australian companies can export uranium intended for peaceful purposes.

Foreign investment edges up in 2014–15

In its 2015 annual report, the Foreign Investment Review Board (FIRB) revealed there was a 19% headline rise in foreign resource investment in 2014–15 (\$26.6 billion) compared to 2013–14 (\$22.4 billion). The number of proposals dropped from 248 in 2013–14 to 182 in 2014–15 (Foreign Investment Review Board, 2015). While China was again the largest investor at 36.9% (Fig. 7a), Australia became the second largest investor (25.3%) because an Australian resident resource company made a joint investment with a foreign investor or made an investment into a new business with a foreign government investor. North America was the third largest investor with almost 22% of the invested value (Fig. 7a). After its \$3.3 billion splurge in 2013–14, Japan invested only \$766 million in 2014–15.

Investment in oil and gas dominated (Fig. 7b) making up 46.9% (\$12.49 billion), the highest value since 2008–09. 'Other', services to production and exploration and other non-metallic minerals totalling \$5.17 billion, contributed the second largest proportion. That proportion is the largest it has been since at least 2008–09. Copper-gold, coal, iron ore and other metallic minerals made up the remainder. In 2014–15, foreign investment into uranium and bauxite ceased.

In a speech at Mines and Money London in December 2015, a senior executive of the China International Capital Corporation stated that Chinese investors were now looking at commodities not produced in large quantities in China, and particularly identified copper, gold, graphite and some minor metals. She also said that copper deposits need to be in the millions of tonnes, and gold deposits should be at least three million ounces to attract Chinese interest. She encouraged juniors to approach Hong Kong- or Shanghai-listed Chinese groups for partners in development because raising equity was easier than with either Australian or Canadian exchanges.

While in Japan in 2015, the Department of Mines and Petroleum (DMP) executives heard firsthand from Japanese conglomerate companies that they were looking to Australia, and Western Australia in particular, for more sources of minerals and energy resources, using a variety of sourcing strategies including direct foreign investment, project joint ventures, offtake and combinations of offtake. GSWA will increase its promotional efforts in Japan.

Equity makes a comeback

The Standard & Poor's – Australian Securities Exchange (S&P/ASX) Metals and Mining Index and Energy Index continued to fall in the first half of 2015 (Fig. 8). However in January 2016, the Metals and Mining Index began a

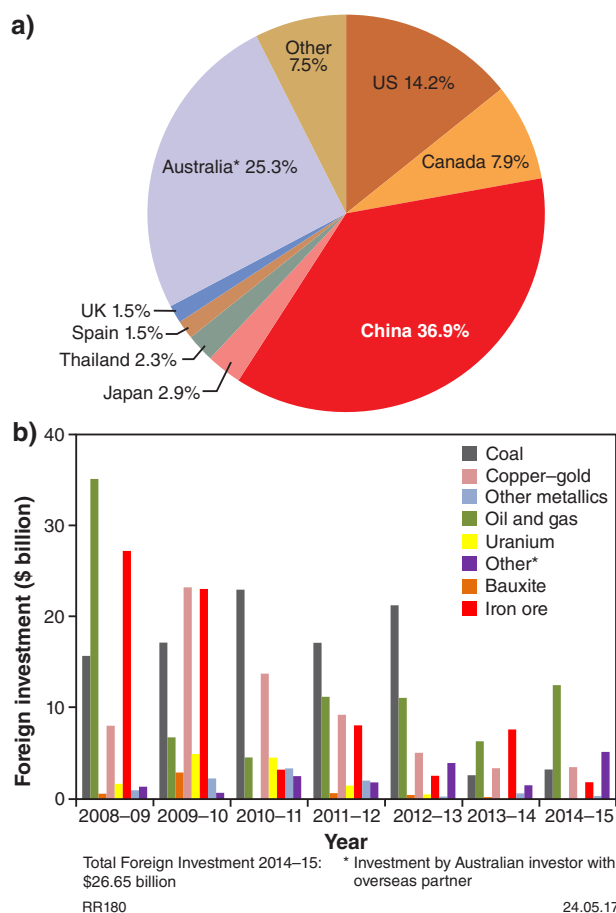


Figure 7. Foreign investment: a) sources of foreign investment into Australia's resources sector for 2014–15; b) investment into different commodity groups from 2008–09. Other metallic commodities consist of nickel, zinc, lead, silver, and rare earth elements. Other* includes services to production and exploration and other non-metallic metals
Source: Foreign Investment Review Board (2015)

steady rise and by 30 June 2016 was at 2335, 42% over its 20 January nadir of 1639. Interestingly, the Energy Index also marked its lowest point of 6792 on 20 January 2016, but rose only 22.9% to 8349 on 30 June 2016.

There were 725 mineral entities listed on the ASX at the end of July 2015, but by the end of June 2016, 690 remained, a 5% decline over 11 months. Listed energy entities dropped from 256 to 233 in the same period, a larger reduction of 10%. Delistings and backdoor listings that subsequently changed the company's Global Industry Classification Standard (GICS) took their toll on the number of listed resources entities. Backdoor listings took on a variety of flavours including information-communications technology, renewable energy, entertainment, food, and pharmaceuticals. Towards the end of the 2015–16 financial year, a small number of mineral companies that previously focused on a particular commodity changed their names to reflect a new focus — lithium.

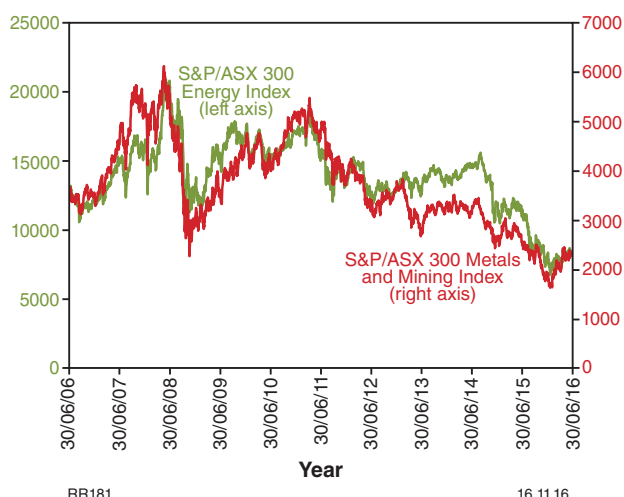


Figure 8. S&P/ASX Metals and Mining Index and Energy Index from July 2005 to June 2015
Source: S&P statistics

After a dismal 2014–15 in which there were only three initial public offerings (IPO) of mineral shares, there was a doubling in 2015–16 to six, with four of these related to the battery bubble — lithium and graphite. Figure 9 shows there were three IPO in 2015, and four in the first six months of 2016 which reflects the increase in equity returning to the ASX materials (mineral exploration and mining) category.

The rising tide of equity couldn't have come too soon for many struggling juniors. At the end of the 2015–16 financial year, SNL statistics reveal that 36% (212) of about 600 ASX-listed mineral exploration and mining entities required to lodge Listing Rule 5B cashflow statements had less than \$500 000 in cash and 23.5% (141) had less than \$250 000.

It was suggested in the Geological Survey work program for 2015–16 and beyond (GSWA, 2015) that the mineral investment cycle was at about 4 on the Widdup Cycle (Fig. 10) at the end of June 2015. One year later, at the end of June 2016, there is abundant evidence in the form of mergers and acquisitions, enhanced investments by private equity groups, IPO and private placements that gold and lithium investment reflects 7.30 to 8 o'clock on the Widdup Cycle with other commodities, probably a little behind at 6 o'clock, but rising rapidly.

State trends

Western Australian economy still struggling

Western Australia's economy continues to struggle, with 2013–14 and 2014–15 showing declines in State Final Demand and rising unemployment from the 2012–13

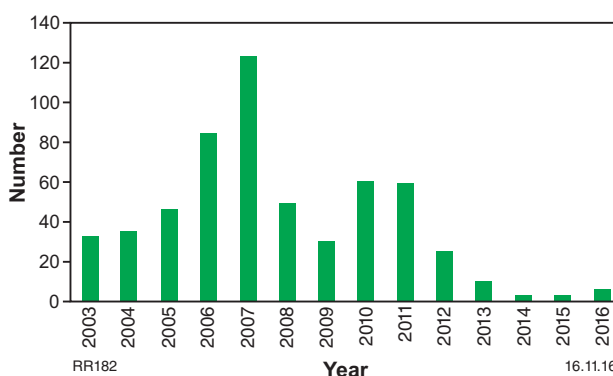


Figure 9. Mineral IPO (including coal) on the ASX by calendar year. Note that the 2015 statistic is for the six months ending 30 June and that the graph does not include companies listed on the ASX that are already listed on a securities exchange overseas



Figure 10. Lion Selection Group's well-known Widdup Cycle named after the group's founder
Source: modified from Lion Selection Group (2014)

financial year (Fig. 11). Average annual unemployment rose to 6% for the 2015–16 financial year, the highest it has been since the 2001–02 financial year at the beginning of the last commodity supercycle. However, Gross State Product (GSP), which includes net exports, has continued to rise fuelled by the value of rising volumes of iron ore and LNG production, albeit at lower prices than prevailed four years previously.

In its economic and fiscal outlook for the 2016–17 Western Australian State budget, the Department of Treasury (2016) predicted State Final Demand to decrease for a fourth consecutive year in 2016–17 but also forecast growth in GSP of 1.25% in 2016–17 and 2.5% in 2017–18 based on the rising value of resource exports. Although commodity exports and prices are increasing, royalty

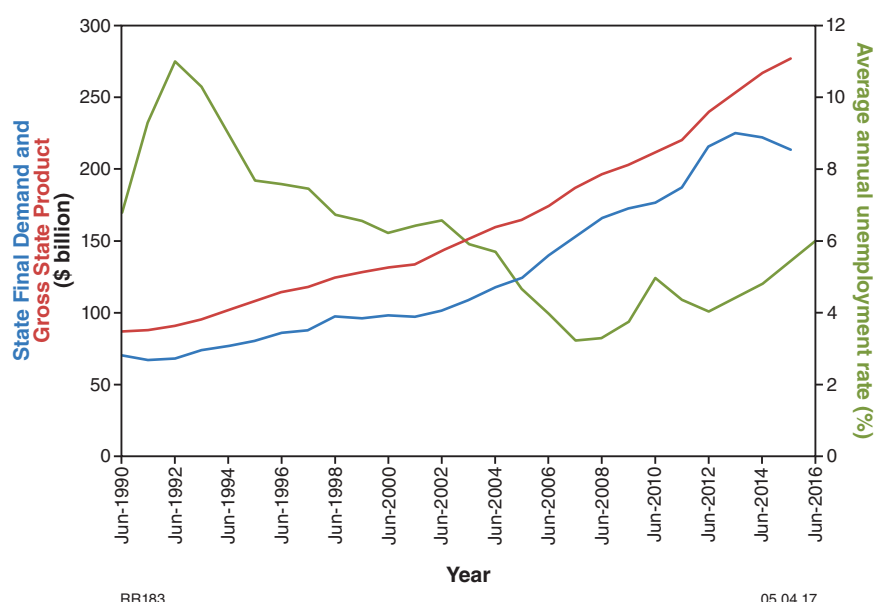


Figure 11. Macro-economic indicators (chain volume basis) and unemployment statistics for Western Australia for financial years ending in June 1990 to June 2016. Note that State Final Demand and Gross State Product for the 2015–16 financial year were not available when this Record was being compiled
Sources: Economic statistics were derived from ABS Catalogue 5220; employment statistics from ABS Catalogue 6202.0

receipts are still down on the values recorded early in this decade and this, together with Western Australia only receiving 30.3% of its population share of GST reimbursements from the Commonwealth means that government revenue is very tight. State royalty income is expected to be 15% of State revenue in 2016–17 (Department of Treasury, 2016) based on an average iron ore price of US\$47.7 per tonne and a crude oil price of US\$44.4 per barrel.

For the Western Australian Public Service, this means reduced appropriations and recruitment restrictions at a time when DMP, in particular, has a higher level of staff losses due to the retirement of the baby-boomer surge in its staff age demographic.

Department of Treasury (2016) forecasted a further decline in Final State Demand in 2017–18 before a 1% increase in 2018–19 when GSP is also predicted to rise by 2.5%.

Resource industry production value declines in 2015–16

Total mineral and petroleum exploration expenditure declined in 2015 to \$2.46 billion (Fig. 12), down 39.3% compared to 2014, with petroleum exploration accounting for the bulk of the total decline. Capital investment (Fig. 12) into new production and export capacity also declined from \$46.9 billion in 2014 to \$42.3 billion in 2015 as construction of the Gorgon LNG and Roy Hill projects were almost at completion. Nevertheless, this is a significant level of investment, buoyed by a ramp-up of construction activities at the Wheatstone LNG project site.

Table 2 and Figure 12 show that the State's mineral and petroleum production value declined sharply by 20% from \$114.15 billion in 2014 to \$91.32 billion in 2015 in response to lower commodity prices. Gold and alumina were the only major commodities to increase in production value, with the bulk of the total decline in production value compared to 2014 due to iron ore (–23.5%) and petroleum (–27.5%). Together, iron ore and petroleum (includes LNG) made up 73.6% of Western Australia's 2015 resource production value.

Other commodities that recorded increases in production value included coal, gem and semiprecious stones, gypsum, heavy mineral sands, and silica sand. In 2015, nickel, base metals, and manganese suffered declines in production value compared to 2014.

The production value of construction materials halved, and the value of limesand and limestone production declined 12% in 2015 compared to 2014, probably due to lower domestic construction activity reflected in lower State Final Demand.

The physical production of mineral and petroleum from 2004 to 2015 in Western Australia is shown in Figure 13. Production of iron ore, zircon, diamond, coal and crude oil increased in 2015 while other commodities (alumina and gold) maintained production levels recorded in 2014. Copper and nickel production declined in 2015 compared to 2014, the latter due to several nickel projects closing or going into care and maintenance due to low nickel commodity prices.

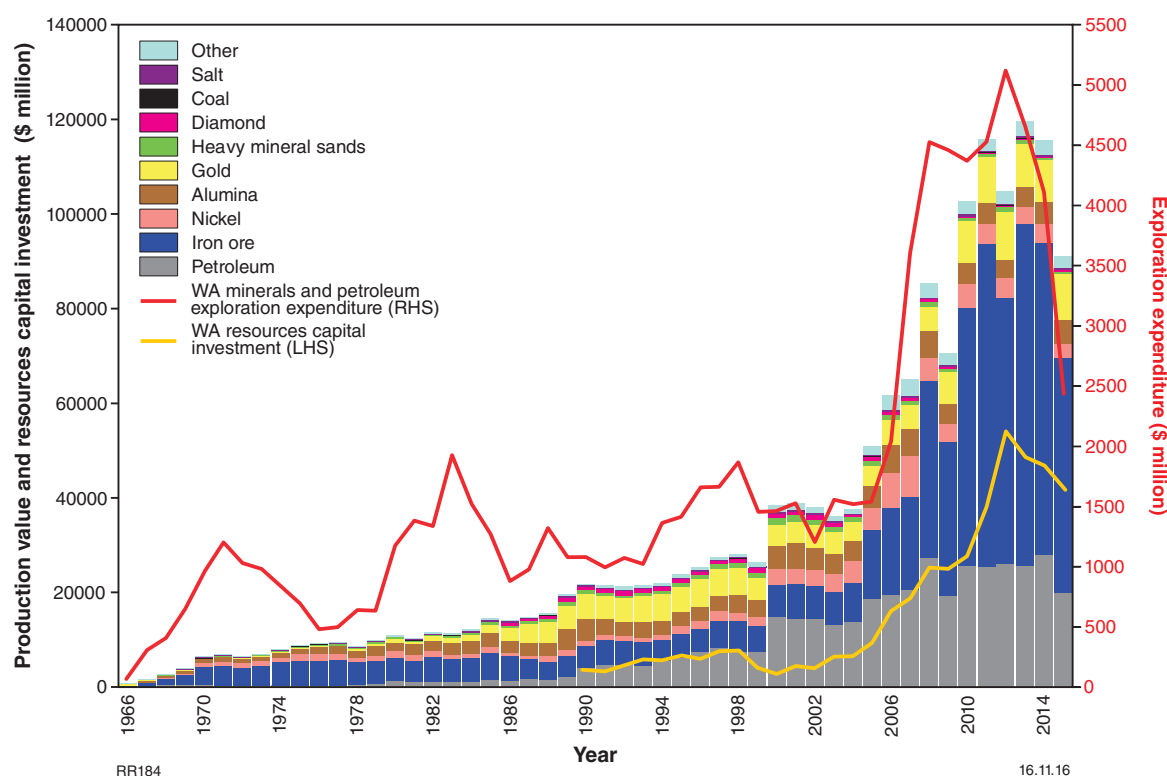


Figure 12. The three resources cycles in Western Australia (2015 Australian Dollars)
Sources: Value of resource production and exploration expenditure statistics from DMP; capital investment statistics from the Australian Bureau of Statistics

With gold production in 2015 almost the same as in 2014, the increase in gold exploration activity in the last two years has not yet translated into higher production.

Western Australia regains the title of world's top investment destination

In 2015, the Fraser Institute's Annual Survey of Mining Companies (Fraser Institute, 2016) ranked Western Australia the leading jurisdiction worldwide in the 'investment attractiveness index' which takes mineral potential and policy indicators into account. While the State also topped this index in 2013, it dipped to fifth place in 2014, probably due to uncertainties created by the extensive consultation associated with a much-needed review of royalty rates (Table 3). Although the review recommended a number of changes, the Minister for Mines and Petroleum decided to defer making any changes during the current low commodity price period and promised extensive consultation before implementation of the recommendations.

Western Australia's improvement in the policy potential index and the quality of geoscience database category over the last six years, as shown in Figure 14, has been gratifying, reflecting a whole-of-government and DMP effort respectively.

One category where Western Australia and other Australian jurisdictions need to improve is in the 'uncertainty concerning disputed land claims'.

Australia's ranking in ResourceStocks (2015) was not as strong as in the Fraser Institute survey, although it improved from 12th in 2014 to 10th out of 68 national jurisdictions in 2015. Sweden topped the survey in 2015, with Canada and the US coming in fourth and fifth respectively. Among a total of 19 Canadian and Australian States, Western Australia was ranked 11th, but the highest Australian jurisdiction. If considered a country, and ignoring all more highly ranked Canadian provinces, Western Australia would have ranked sixth in the world.

Mineral exploration spend shows signs of recovery

In the June quarter 2016, Western Australia's mineral exploration expenditure was \$220 million seasonally adjusted (Fig. 15), the highest quarterly expenditure since the December quarter 2014–15. This pleasing result means that the low point in the exploration funding cycle is behind us, although the June 2016 quarter result is a little over one-third of June quarter 2012 expenditure of around \$640 million — the highest ever quarterly exploration expenditure in Western Australia. In general terms as the level of Western Australia's exploration expenditure has declined since June 2012, the proportion of Australian

Table 2. Quantity and value of minerals and petroleum production in Western Australia 2015

COMMODITY	UNIT	2014–15		2015–16	
		QUANTITY	VALUE	QUANTITY	VALUE
ALUMINA AND BAUXITE	t	13 771 412	5 022 721 218	13 941 288	4 939 245 356
BASE METALS					
Copper metal	t	184 299	1283 101 493	190 829	1160 261 953
Lead metal	t	59 248	136 949 662	6 040	14 602 646
Zinc metal	t	77 831	197 040 406	80 208	189 594 217
TOTAL BASE METALS		321 379	1 617 091 561	277 077	1 364 458 816
CHROMITE	t	0	0	0	0
CLAYS	t	17 670	1 043 438	21 969	1 104 708
COAL	t	6 553 064	306 733 911	6 890 951	336 466 825
CONSTRUCTION MATERIALS					
Aggregate	t	1 963 871	69 239 676	1 360 859	42 863 658
Gravel	t	193 968	2 161 823	200 934	2 264 091
Rock	t	1 746 693	47 505 138	304 395	4 685 177
Sand	t	6 042 214	56 115 401	3 547 485	38 359 044
TOTAL CONSTRUCTION MATERIALS			175 022 038		88 171 969
DIAMONDS	ct	10 387 926	342 313 664	13 868 048	353 736 681
DIMENSION STONE	t	21 250	2 892 731	3 752	2 086 202
GEM & SEMI-PRECIOUS STONES	kg	720 552	1 391 303	238 395	615 981
GOLD	kg	193 230	9 110 506 190	194 927	10 036 159 891
GYPSUM	t	577 079	11 801 996	551 910	13 371 056
MINERAL SANDS					
Garnet	t	299 022	n/a	251 162	n/a
Ilmenite	t	88 048	18 068 861	172 895	42 445 442
Leucoxene	t	16 656	14 325 490	18 413	16 729 550
Zircon	t	181 607	134 680 430	162 578	121 027 820
Other	t		320 748 221		358 503 049
TOTAL MINERAL SANDS			487 823 002		538 705 861
IRON ORE	t	718 822 363	54 367 366 632	756 526 398	48 385 254 500
LIMESAND–LIMESTONE–DOLOMITE	t	5 056 331	52 321 342	4 049 678	42 765 535
MANGANESE ORE	t	800 985	n/a	423 317	143 843 484
NICKEL INDUSTRY					
Cobalt	t	6 036	210 567 512	5 470	174 468 048
Nickel	t	183 320	3 169 605 001	175 722	2 181 363 111
Palladium and platinum byproduct	kg	464	13 380 730	687	16 656 441
TOTAL NICKEL INDUSTRY			3 393 553 243		2 372 487 600
PETROLEUM					
Condensate	kl	6 753 213	3 528 826 231	6 775 142	2 397 646 227
Crude oil	kl	7 952 478	4 567 638 161	7 685 922	3 042 849 325
LNG	t	20 447 845	13 817 042 487	20 955 641	10 767 668 144
LPG – butane and propane	t	553 055	405 565 516	531 595	249 059 073
Natural gas	,000m ³	9 875 339	1 820 197 055	10 223 641	1 910 464 453
TOTAL PETROLEUM			24 139 269 449		18 367 687 221
SALT	t	11 726 606	374 622 315	10 974 721	336 253 755
SILICA–SILICA SAND	t	483 809	17 927 564	580 938	15 386 305
SILVER	kg	151 130	96 323 316	154 226	100 453 697
TIN–TANTALUM–LITHIUM		n/a	251 051 748	362 853	213 069 830
OTHER (Includes vanadium, manganese, rare earth elements, spongolite and talc)			507 533 600		343 080 010
TOTAL VALUE			100 279 310 262		87 850 561 799

Table 3. Western Australia's ranking in Fraser Institute mining company surveys for the period 2009–10 to 2015

	Ranking relative to jurisdictions worldwide							Ranking relative to Australian jurisdictions						
	2009–2010	2010–2011	2011–2012	2012–2013	2013	2014	2015	2009–2010	2010–2011	2011–2012	2012–2013	2013	2014	2015
Number of jurisdictions	72	79	93	96	112	122	109	7	7	7	7	7	7	7
Policy Perception Index	19	17	12	15	6	10	8	3	2	1	1	1	1	1
Best Practices Mineral Potential Index	21	7	11	6	2	8	1	4	1	1	1	1	1	1
Investment attractiveness index*	17	7	5	4	1	5	1	4	1	1	1	1	1	1
Quality of geological database	20	17	8	10	11	5	3	7	6	3	4	3	2	1

NOTE: * Formerly 'Composite policy and best practices mineral potential index'

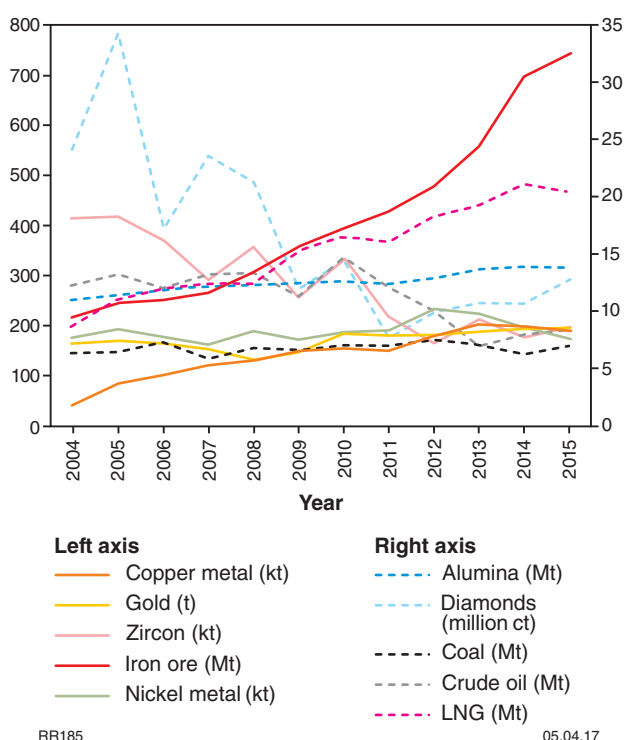


Figure 13. Western Australian production quantity for major commodities 2004–15 (Australian Dollars of the day)
Source: DMP statistics

exploration expenditure focused on our State has increased from around 57% to almost 64% recorded in the June quarter 2016, comfortable above its long-term average.

Exploration expenditure on gold and to a lesser extent iron ore accounted for a large component of Western Australia's June quarter increase, with gold accounting for \$110.6 million or 48.5% of the \$228.2 million (original dollar terms) June quarter increase (Australian Bureau of Statistics, 2016). Figure 16 shows that in 2015–16, gold exploration expenditure exceeded that of iron ore for the

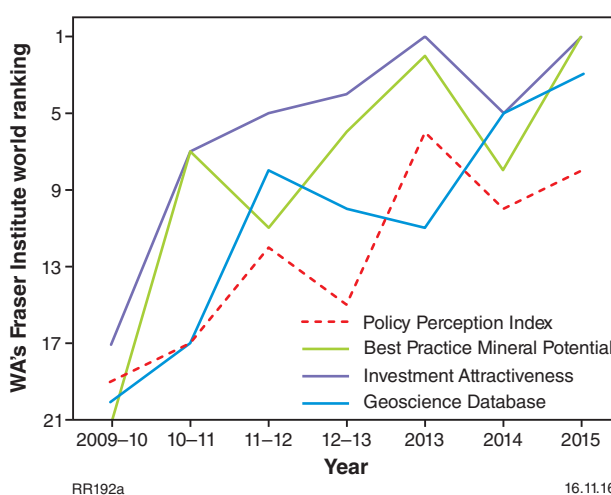


Figure 14. Western Australia's trend improvement in the Fraser Institute's three critical mineral investor perceptions categories since 2009–10

first time since 2005–06 when a number of gold explorers morphed into iron ore explorers. Anecdotal evidence suggests that expenditure on lithium exploration has also increased markedly but this is not apparent in Australian Bureau of Statistics (ABS) quarterly releases where it is included in 'Other'. In the June quarter, expenditure on uranium exploration slumped to \$2.3 million, although typically \$5–9 million per quarter for many years. Base metal exploration including nickel declined further in 2015–16 (Fig. 16).

Expenditure on what the ABS (2016) calls 'new deposits' rose to \$65.3 million (original dollar terms), the highest it has been since the December quarter 2014–15. At this level, it is 29% of quarterly total mineral exploration. Figure 17 shows that this proportion has been trending gently upwards for almost three years as total exploration has plunged. It is hoped that this trend represents a shift towards greenfields exploration, a close proxy of 'new deposits' exploration, as we begin a new exploration cycle.

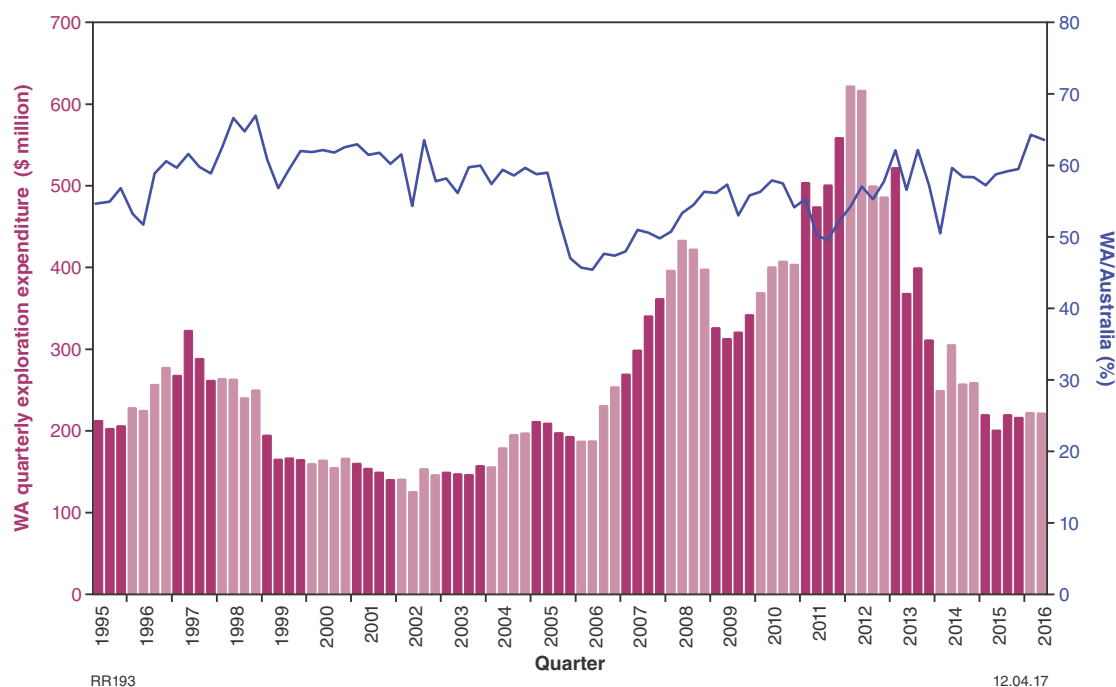


Figure 15. Quarterly mineral exploration expenditure in Western Australia (seasonally adjusted June 2016 Australian Dollars)
Source: Australian Bureau of Statistics

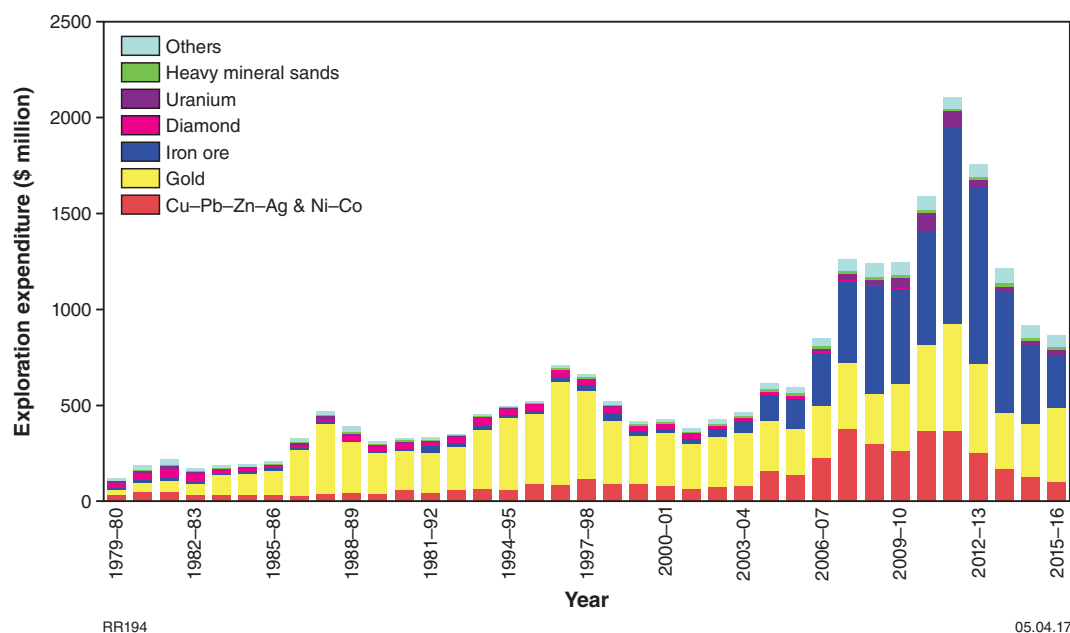


Figure 16. Exploration expenditure in Western Australia by financial year by commodity (Australian Dollars of the day)
Source: Australian Bureau of Statistics

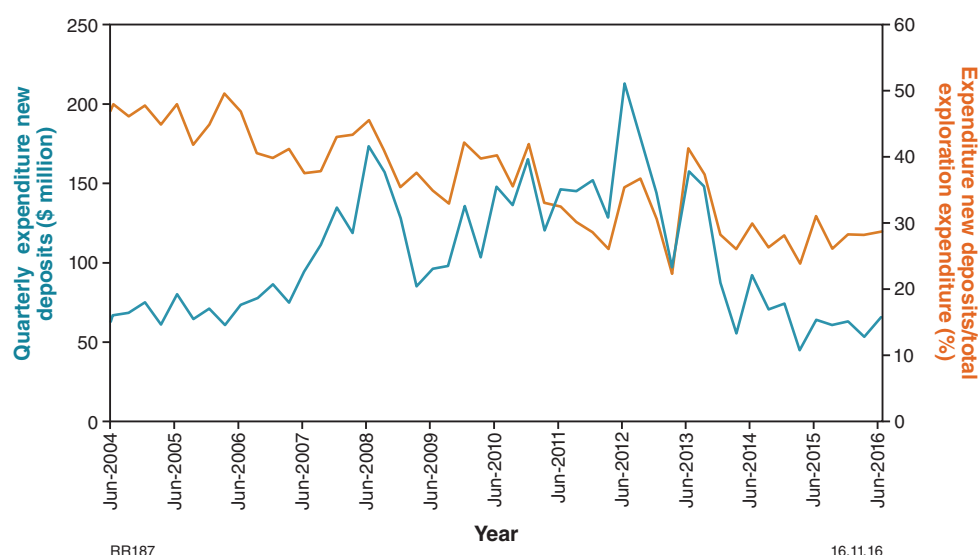


Figure 17. Greenfields mineral exploration expenditure in Western Australia in original dollar terms and as a proportion of total expenditure (Australian Dollars of the day)
Source: ABS statistics

Investors rank Western Australia's petroleum investment climate

The Fraser Institute's 2015 annual survey of jurisdictional investment attractiveness (Fraser Institute, 2015) included the responses of 439 executives and managers in the petroleum sector which was sufficient to evaluate 126 national and subnational jurisdictions. There were encouraging but mixed results for Western Australia and DMP in the survey which once again revealed that investors continue to value highly DMP's petroleum-related databases (Fig. 18) including the Western Australian Petroleum Information Management System (WAPIMS) and the related Petroleum and Geothermal Register (PGR). Unfortunately, the survey questionnaire was largely completed prior to the launch of the much improved WAPIMS database.

The survey calculates a multifactor Policy Perception Index (PPI) for each jurisdiction which is derived from the scores for each of the 16 factor questions capturing investor perceptions of conditions affecting investment decisions and provides a comprehensive assessment of each jurisdiction. Western Australia's PPI and some of its components are shown in Figure 18.

In 2015, Western Australia's PPI showed a pleasing upward trend meaning that overall our investment attractiveness increased. Factors that contributed to this included fewer respondents being deterred by our environmental regulations, trade barriers and taxation factors. Western Australia ranked 33rd for PPI out of the 126 jurisdictions surveyed in 2015 and ranked second in Australian jurisdictions after South Australia. Between 2009 and 2014, Western Australia was ranked 56th, 21st, 37th, 40th, 49th and 50th respectively for the PPI.

However, a higher proportion of respondents in 2015 were deterred by red tape issues including the factors 'Administrative competency', 'Cost of compliance' and 'Regulatory duplication and inconsistencies'. It is possible that compliance issues for companies operating in marine areas off Western Australia's coast where Commonwealth and State jurisdictions impinge could be contributing to these perceptions of administrative complexity — particularly where production infrastructure such as pipelines cross jurisdictional boundaries.

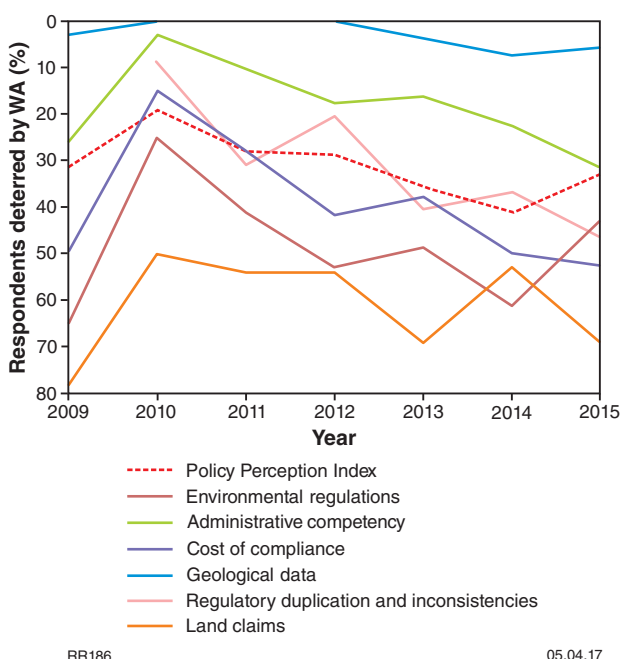


Figure 18. Selected factors contributing to Fraser Institute's petroleum PPI for Western Australia

In 2015, 69% of respondents who commented on Western Australia were deterred by land claims, which could include indigenous land claims and difficulties in accessing non-urban land in the Perth Basin.

Western Australia's petroleum exploration spend slumps in 2015–16

Although there is evidence that mineral exploration expenditure is increasing, Western Australia's headline — including adjacent Commonwealth Waters — petroleum exploration expenditure in 2015–16 slumped to \$1297.4 million, down 37.6% from \$2080.3 million

in 2014–15 (Fig. 19). June quarter 2016 expenditure was only \$212.2 million (Australian Bureau of Statistics, 2016). However, for the 2015–16 financial year, Western Australia's expenditure increased to 73% of the Australian total petroleum exploration spending, up from 54.6% in 2014–15. This represents the second highest proportion of Australian expenditure.

The year 2015 was very good for the drilling of new field wildcats (NFW) in Western Australia, with a total of six in the Canning Basin (Olympic 1, Praslin 1, Senagi 1, Sunbeam 1, Theia 1, Victory 1) and three in the Perth Basin (Irwin 1, Waitsia 1, Red Gully North 1). This equals the number drilled in 2012, and putting aside the 11 drilled in 2010, the last time nine NFW were drilled was 2004 (Fig. 20).

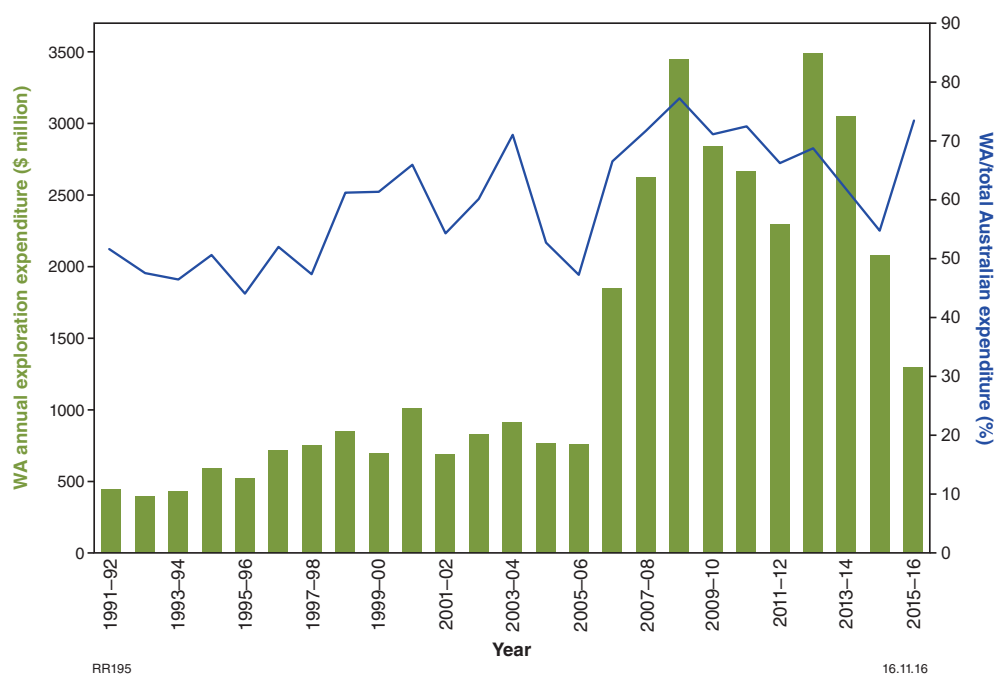


Figure 19. Annual petroleum exploration expenditure in Western Australia and adjacent Commonwealth Waters and Western Australia's proportion of nationwide expenditure (Australian Dollars of the day 2015–16)
Source: ABS statistics

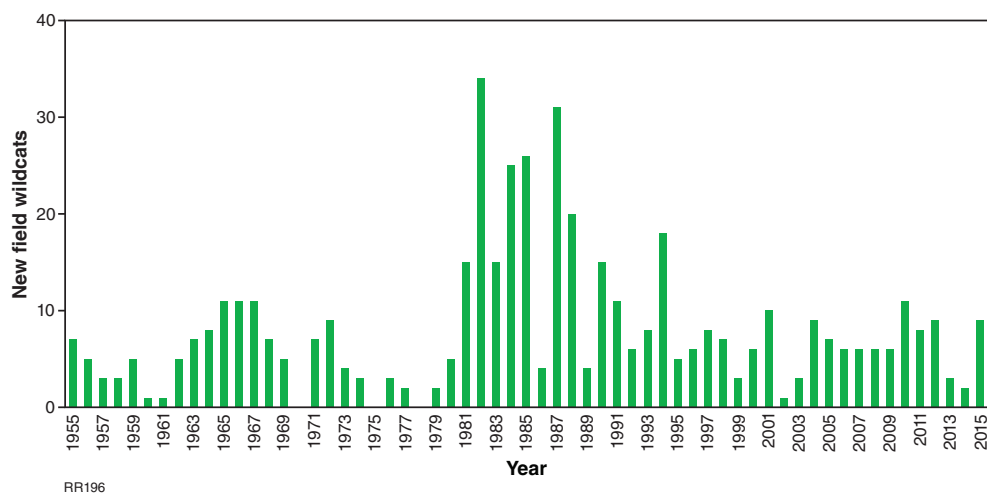


Figure 20. Number of new field wildcat wells drilled in State jurisdiction for period 1955 to 2015
Source: DMP statistics

Government geoscience trends

Geoscience Australia gets funding boost

Exploring for the Future is a major new investment in the acquisition of pre-competitive geoscience information involving expenditure by Geoscience Australia (GA) of \$100.5 million over four years, from 2016 to 2020.

The geoscience program focuses on tropical Northern Australia, though it does include a small area — the Coompana area (Fig. 21) in South Australia, beneath the eastern Eucla Basin.

Minerals (\$41.315 million), Energy (\$27.915 million), and Groundwater (\$31.304 million) work programs are funded, with the Northern Territory receiving most of the Energy program funding. All surveys are aligned to high-priority UNCOVER mineral exploration activities, including those for Energy and Groundwater programs, and in addition, the main Groundwater survey in Western Australia focuses on the Fitzroy Valley Water-for-Food locality.

All of GA's programs (Fig. 21) in Western Australia are planned for the first two years as follows:

- groundwater: Fitzroy Valley groundwater resources (Year 1)

- minerals: gravity and electromagnetic surveys in the Kimberley region (Year 1)
- minerals: broad-spaced crust and upper mantle structure survey north from the Tropic of Capricorn (AusLAMP project, Year 2).

The entire area of Northern Australia will be surveyed over the four-year period. GA will analyse the isotopic composition of rocks and minerals as an aid to determining prospectivity, build a 3D model of the geological architecture, and undertake a broad-scale resource assessment. GSWA has been undertaking similar activities using Exploration Incentive Scheme (EIS) funding.

GA and GSWA have cooperated over many years to jointly fund pre-competitive geoscience surveys in Western Australia, and particularly large geophysical and geochemical surveys.

State geoscience initiatives continue

Most Australian jurisdictions (Table 4) have ongoing geoscience initiatives that are in line with the National Mineral Exploration Strategy endorsed by the Council of Australian Governments' (COAG) Energy Ministers in 2013. Unfortunately, current economic and fiscal issues in South Australia have led to suspension of funding for the Plan for Accelerating Exploration (PACE) although the opening of South Australia's new core library facility in early 2016 will be a major boost to the mineral and petroleum exploration sectors in that State.

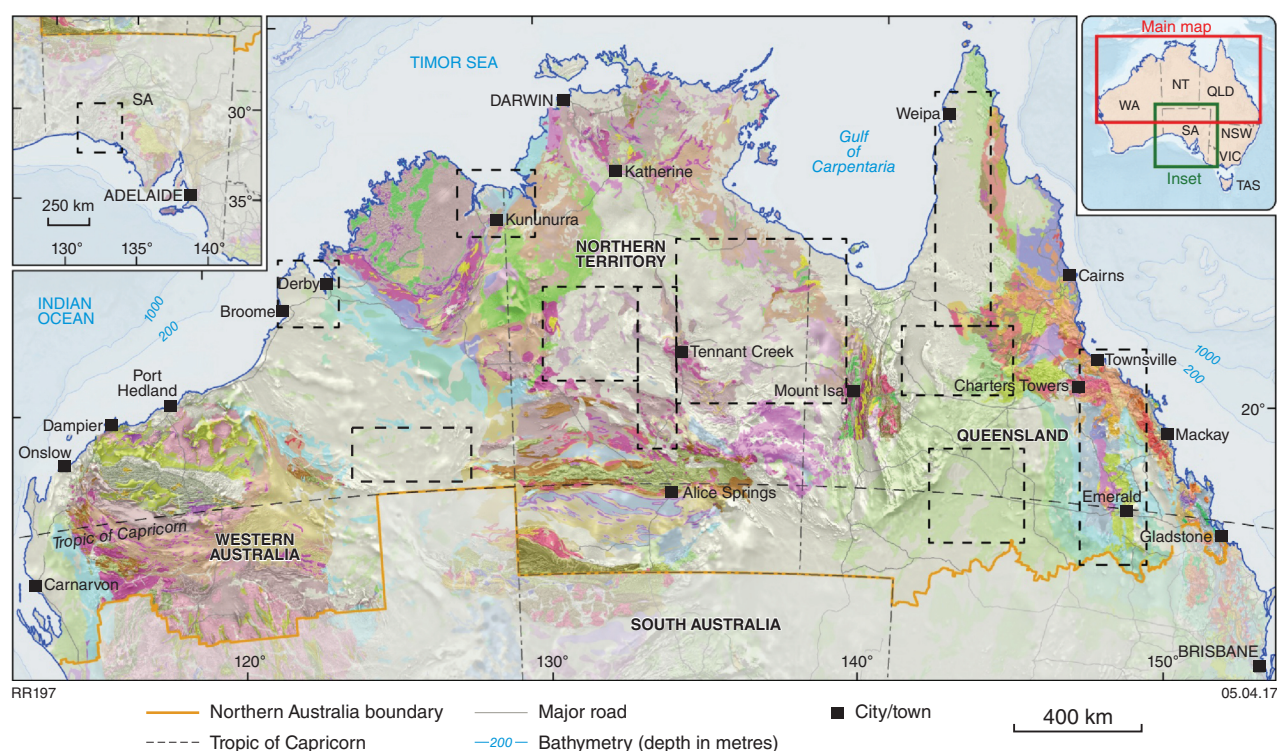


Figure 21. Map of Northern Australia showing the location of planned surveys (from Geoscience Australia). The boundaries of individual surveys are indicative only and may change following further analysis and consultation with stakeholders

Table 4. Pre-competitive geoscience initiatives in Australian geological surveys 2016–17 onwards

Jurisdiction and initiative	Funding
New South Wales	
<i>New Frontiers Initiative</i> : variety of projects from year to year but main focus is on regional geophysics and modern geoscience mapping, including mineral system mapping, and 3D models	Ongoing based on Annual Rental Fees from mineral tenements
Victoria	
<i>Securing Victoria's Earth Resources</i> : pre-competitive geosciences, overseas promotion, project facilitation	\$6 million per year ending in 2016–17
<i>TARGET</i> : co-funding of company exploration drilling, modern geological mapping, mineral systems analysis, and geoscience information delivery	\$15 million over four years 2014–15 to 2017–18
South Australia	
<i>PACE Copper</i> : airborne magnetic and radiometric, electromagnetic, magnetotelluric, geochemical surveys, mineral systems drilling, gravity survey	\$7 million in 2016–17
Northern Territory	
<i>CORE (Creating Opportunities for Resource Exploration)</i> : geophysical surveys, collaborative drilling and geophysics, resource potential surveys, information delivery online, and overseas promotion	\$5.95 million per year until 2018
Tasmania	
Gravity, magnetotellurics, geochronology, geoscience mapping and new 3D models	\$100 000 in 2016–17
Western Australia	
<i>Exploration Incentive Scheme Phase 2</i> : collaborative drilling, geophysical surveys, 3D geoscience mapping, geochemistry funded by Consolidated Revenue Fund	\$30 million over three years 2013–14 to 2016–17
<i>Exploration Incentive Scheme Phase 3</i> : similar to above but funded from Royalties for Regions	\$30 million over three years beginning 2017–18

All jurisdictions with initiatives, except Tasmania, offer funding for collaborative exploration drilling and some co-fund company exploration activities such as geophysics and geochemistry. Most also undertake regional geophysical surveys including in some cases magnetotelluric (MT) and seismic. However, the amount of systematic, field-based regional geoscience mapping undertaken continues to decline in most states, with the exception of Western Australia.

Only NSW has put the ongoing funding of its geological survey activities on a secure footing by hypothecating tenement rentals.

The relative rankings of the Australian states, as measured by the Fraser Institute in terms of its policy potential index are shown in Table 5.

More flesh to be added to UNCOVER framework

UNCOVER is an initiative that was established as a result of the Australian Academy of Science's (the Academy) 2010 Theo Murphy Think Tank which led to the preparation of a report (UNCOVER Group, 2012) under the aegis of the Academy that outlined the broad areas of research and other activities required to revitalize greenfields exploration in Australia.

At the request of the mineral industry and supported financially by industry and governments across Australia, the AMIRA Project 1162 developed the first phase of a roadmap (AMIRA International, 2015) summarizing the

critical pre-competitive geoscience and research required to find the buried Tier 1 and larger Tier 2 ore deposits that would be the economic future of Australia's mineral industry. The report identified seven critical geoscience strategies that need to be addressed. They are to:

- recognize Australia's terrane-scale fertility under cover including favourable geodynamics and metallogeny
- map, at national scale, 3D whole lithospheric terrane-scale architecture from mantle to surface
- better predict spatial distribution of mineral systems under barren cover
- increase ability to detect and locate camp and deposit levels of mineral systems within the economic search space under cover
- improve early evaluation and ability to map the size, strength and geospatial level within mineral systems to predict potential economic endowment under cover
- confidently vector to depositional sites within upper levels of mineral systems to locate economic ore
- establish as early as possible (and with the least expenditure) the potential size, orientation, average grade, style and metallurgy of mineralization, to enable preliminary judgment on economic potential.

A few industry players, geological surveys across Australia and CSIRO have subsequently funded Phase 2 of the Roadmap process that aims to provide detail on the geoscience projects, both pre-competitive and research, that are required to address the objectives of UNCOVER.

Table 5. Fraser Institute's Policy Potential Index — relative rankings, Australian States only

Fraser Institute ranking	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013	2014	2015	2016
1	SA	SA	SA	SA	SA	NT	WA	WA	WA	WA	WA (9)
2	QLD	TAS	NT	NT	WA	SA	SA	SA	SA	SA	SA (21)
3	TAS	NT	WA	WA	NSW	QLD	NT	NT	TAS	NT	NT (22)
4	VIC	WA	NSW	NSW	NT		VIC	QLD	NT	QLD	TAS (32)
5											QLD (36)
6											VIC (42)
7	WA										NSW (66)

UNCOVER underpins two of the critical building blocks of the National Mineral Exploration Strategy – Pre-competitive Geoscience Information and the National Geoscience Research initiative. The successful business case for the extension of the EIS from 2017 to 2020 was strongly influenced by the need to produce pre-competitive datasets and information relevant to priority UNCOVER focus areas.

Industry Growth Centres established

The Industry Innovation and Competitiveness Agenda was announced by the Commonwealth Government in October 2014 and focuses on providing the right economic incentives to enable businesses to grow. One of the initiatives under the agenda was the establishment of six Industry Growth Centres, two of which were named as Mining Equipment, Technology and Services (METS); and the other four as Oil, Gas and Energy Resources.

Subsequently, METS Ignited and the National Energy Resources Australia (NERA) were formed as not-for-profit vehicles to implement the policy initiative in these two industry sectors which are well established in Perth. NERA includes uranium and coal as well as petroleum resources and has nodes in Perth and Brisbane while METS Ignited is headquartered in Brisbane.

As part of its overseas promotional activities, GSWA has provided advice to overseas METS companies enquiring about establishing operations in Western Australia, and using EIS funding, engages METS companies to undertake geophysical and geochemical surveys and other specialist studies.

Rising optimism for service sector and employment?

The current downturns in commodity prices, capital investment and exploration expenditure have negatively impacted on the resource services sector including the METS subsector and the petroleum services sector. Unemployment has risen not only among construction workers but also among mineral and petroleum industry professionals.

Geologists, and particularly exploration geologists, are some of the leading professional canaries in any downturn. The Australian Institute of Geoscientists (AIG) reported in May 2016 that unemployment among its members was at 19.5% and a further 23.4% indicated they were underemployed. However, recruitment consultants have been reporting rising demand for resource industry professionals including geologists during the first half of 2016, albeit from a low base. This evidence of rising employment among geologists is further evidence that the worst may be behind Western Australia's mineral exploration and mining sector.

PART 2

RECURRENT BUDGET AND WORK PROGRAM FOR 2016–17 AND BEYOND

Context of the program

Progress in implementing recommendations of 2012 GSWA review

The functional review of GSWA undertaken in 2012 (Economics Consulting Services, 2012) strongly endorsed GSWA's programs funded out of both Consolidated Revenue (CR) and Royalties for Regions (RfR), and made 12 recommendations (Table 6).

Most of these recommendations have been accepted and implemented (where possible) in previous years. However, as updated in the 'Implementation plan' column of Table 6, further progress was made in 2015–16. Previously, the most difficult recommendation to implement was the recruitment of a new Manager Energy Geoscience. GSWA

took advantage of the current downturn in the oil and gas industry to re-advertise the position and was successful in recruiting Deidre Brooks. It is the only position within GSWA that has an Attraction and Retention Incentive (bonus payment) attached, making it GSWA's most highly paid position.

Other strategic achievements during 2015–16 included:

- finalizing the business case for renewed funding of EIS beyond 2016–17
- aligning GSWA's work program with the industry-led roadmap of UNCOVER and with GA's Exploring for the Future project in Northern Australia.

Given the high costs involved, extension of EIS programs to survey the geology of frontier areas within the State's territorial sea will depend on additional funding (as well as the magnitude of the funding) after the current indicated end of the EIS in June 2017.

Table 6. Recommendations of the 2012 functional review of GSWA

Recommendation	GSWA response	Implementation plan
1. Develop a new funding model applicable beyond 2016 that recognizes the dependence of the WA economy on the resources industry and the cost of modern geoscience programs	Accept	EIS3 funding for 2017–18 and beyond (budget forward estimates) approved, but returning to Royalties For Regions
2. Develop a staff development and recruitment strategy to address the age profile of GSWA with plans for succession	Accept	Already implemented: currently being addressed in graduate program and ongoing recruitment of new staff in geoscience, geological and cartographic groups (within DMP limits on FTE staff and budget)
3. Develop a strategic plan that reflects the goals of the government and articulates a vision for a geoscience knowledge framework for WA	Accept	Was developed as part of business case for extension of EIS beyond 2016–17, and strategic plan is being aligned with the evolving industry roadmap of UNCOVER and GA's Exploring for the Future in northern Australia
4. Undertake a review of energy geoscience in the department to raise its profile and increase its capacity given the emerging importance of this sector and the changes taking place in the industry in relation to unconventional gas and carbon sequestration	Accept	Already implemented: review of Petroleum Division found no overlap between geoscience activities in that division with GSWA. Good collaboration exists at a technical level between the two divisions
5. Develop post-NOPTA arrangements to ensure that geoscience information is not lost to the State	Accept	Already implemented: NOPTA–GA–GSWA agreements signed in late June 2013. GSWA's new WAPIMS system will display Commonwealth historical information too
6. Recruit a Chief Petroleum Geologist for the Executive Team	Accept	New chief petroleum geologist recruited in early 2016
7. Approach GA to provide specialist people to engage on joint work programs, particularly on unconventional gas	Accept	Already implemented: GSWA engages with GA on a number of energy geoscience-related issues including Canning Basin drilling and deep seismic, and WAPIMS
8. More closely integrate the work of the Mineral Systems section with the regional mapping teams and research collaborators to produce integrated tectonic and metallogenic syntheses of terranes	Accept	Already implemented: review of Mineral Resources section in GSWA has resulted in a model involving assignment of a mineral geologist to each mapping team
9. Extend EIS programs to cover geology beneath the territorial sea	Accept	Will be built into future programs if funding is provided for geophysical programs in shallow marine areas
10. Move to digital online lodgement of exploration reports to streamline submission and assessment of company reports, and their inclusion in WAMEX	Accept	Already implemented: online report-writing system was released in February 2015. Its use is still optional
11. Increase transparency of the EIS collaborative drilling award process to ensure greater clarity of reasons for approvals	Accept in part	Already implemented: information on the process is documented on the DMP website, but specific applications are commercially sensitive to applicants and remain confidential. Applicants who were unsuccessful will be given, on request, reasons they were unsuccessful
12. Consider working with industry, researchers and the exploration services industry in developing Perth into a 'global centre of exploration excellence'	Accept in part	Ongoing: GSWA is joining the National Resource Sciences Precinct which already consists of CSIRO, Curtin University and The University of Western Australia. This adds pre-competitive geoscience to the NRSP

Achievements 2015–16

In 2015–16, GSWA maintained the high-level output of products funded from both CR and the EIS (Table 7). A full list of GSWA products released for the year is included as Appendix A. ‘Series maps’ and ‘Maps — other’ were produced entirely by funding from CR whereas all geophysical data surveys were funded by the EIS. Other product categories were produced from a mix of CR and EIS funding. In addition, there were a further 54 papers published externally on Western Australia’s geoscience where at least one author was a GSWA staff member (Appendix B).

The main headline numbers of products released during 2015–16 were similar to 2014–15. However, the Weighted Total Published Product (WTPP), one measure of GSWA performance, rose to 140 during 2015–16 (previously 124 in 2014–15) (Table 7). The rise in WTPP was mainly due to the slight increase of geophysical data released relative to the previous year — 110 000 km of airborne magnetic data, a total of 28 690 ground gravity stations, and 287 km of deep crustal seismic data and its interpretation.

The high levels of EIS funding of around \$20 million per year finished in 2013–14. That occurrence contributed to GSWA’s WTPP peaking at values of 170–190 for several years (2009–10 to 2013–14). The drop in EIS funding to around \$10 million since 2014–15 meant that GSWA has remained productive and output oriented, with WTPP annual scores of around 120 to 140. Prior to EIS, WTPP for GSWA was well below 120, which serves as a timely reminder of the large amount of new pre-competitive data obtained by EIS funds.

Other significant target deliverables set for 2015–16 and their status at year end include:

- a business case supporting the continuation of the EIS. *Business case finalized and submitted to DMP’s Minister, Treasury, and Department of Regional Development*
- release of a new WAPIMS search facility for public users (in time for the Petroleum Open Day,

4 September 2015) and a full remodelling and rewrite of the internal WAPIMS updating application for release by 30 June 2016. This is the major IT project for GSWA for 2015–16 which has received additional corporate funding. *Released on time (May 2016) and on budget, which was a significant achievement for a major IT project*

- inclusion of Landgate’s land cadastre and composite photomosaic as extra layers in GeoVIEW.WA. *Completed*
- expansion of the Perth Core Library. Funding was approved for construction of extra storage capacity, together with enclosing the external viewing area; construction should start in late 2015 and be completed in late 2016. This is DMP’s only major capital works project for 2015–16 and uses mostly DMP corporate capital funds. However, the project to enclose the external viewing area at Carlisle has received funding support from the Commonwealth, with this support amounting to about 50% of the costs for that portion of the redevelopment project. *Construction remains on track for completion in October–November 2016*
- start of a \$2 million stratigraphic drillhole in the Canning Basin using funding from GA. The concept of GSWA drilling a single drillhole for the funds available was abandoned, so the program was switched to undertaking additional work on petroleum systems and CO₂ geosequestration potential based on multiple wells being cored by the petroleum industry during 2015–16 and beyond. *Progressing steadily; several reports in preparation.*

The challenges remaining for GSWA include:

- creating a compelling story for an extension of EIS funding beyond June 2017 and beyond the State General Election of March 2017
- aligning GSWA’s work program to obtain maximum leverage from the industry-led roadmap of UNCOVER and GA’s Exploring for the Future project in Northern Australia

Table 7. GSWA products 2008–09 to 2015–16

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16
Books ^(a) (Reports, Records etc.)	26	36	52	35	39	39	39	40
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	8	10
Maps — other (includes geophysical maps)	17	11	8	14	17	20	19	18
Digital information packages	19	21	17	18	11	20	20	16
1000 line-km of airborne geophysical data (EIS) ^(b)	398	908	720	768	1157	588	0	110
Weighted Total Published Product	118	170	188	174	173	187	124	140

NOTES: (a) Plus 54 external publications

(b) Plus release of 28 690 gravity points and 287 km of deep crustal seismic

- continuing to integrate 3D mapping into existing processes and product mix while maintaining production levels of traditional high-quality 2D products
- developing a workable Mineral Systems Atlas for Western Australia
- managing the transitioning-out of GSWA's high-productivity baby boomers
- managing the large number of short-term fee-for-service staff in GSWA who are funded through both the recurrent operational budget and EIS
- lobbying for capital funds to expand the Joe Lord Core Library at Kalgoorlie.

GSWA's budget 2016–17

The government's 2016–17 budget brought down in May 2016 was a change in tradition in that it no longer revealed a specific net appropriation for geoscience information — the service that supports the outcome of encouraging the exploration and discovery of mineral and energy resources and informed planning in Western Australia. It did, however, show the \$10 million component within the DMP budget that is allocated to the EIS, including the popular and widely recognized Co-funded Drilling program.

GSWA contributes to State planning by virtue of Section 16 (3) of the *Mining Act 1978* that provides for the Minister for Mines and Petroleum to approve all changes of land use for leases and transfers under the *Land Administration Act 1997*. This requires that GSWA analyse the mineral and energy prospectivity of the land parcel and potentially consult with impacted exploration and production tenement holders.

The budget shown in previous editions of the Work Program (in earlier equivalents of the current Table 8) showed the total recurrent (or headline) funding for GSWA, inclusive of DMP corporate overheads. However, Table 8 now shows the budget amount allocated by DMP to GSWA as the discretionary funding for salaries plus operational funding. The difference is due to the fact that employee overheads (superannuation) and public utilities are paid centrally by DMP; GSWA also contributes to DMP overheads including finance, human resources, information technology, building rental and other corporate costs.

Overall, the squeeze on government spending (particularly on salaries) continues, with 40% of a person's salary and related on-costs removed from the DMP budget when a staff member retires or resigns from the department. This generally equates to a '2-for-1' rule, that is, two people need to retire or resign before one person can be recruited.

Table 9 shows GSWA's 2016–17 recurrent operational budget for both projects support activities.

Table 10 shows GSWA's 2016–17 recurrent operational budget after support areas are distributed pro rata to geoscience information-producing projects.

In 2016–17, funding for the EIS is again \$10.0 million per year. The government has recognized the early successes of the EIS by extending funding to 2016–17. However, EIS funding in forward estimates of the current budget shows EIS apparently finishing in June 2017; GSWA is preparing a business case for extension of EIS beyond then — either by funding from CR or from a return to Royalties for Regions.

As the government's 2016–17 budget no longer revealed a specific net appropriation for geoscience information, there is no specific allocation to GSWA in the budget forward estimates (2017–18 to 2019–20). The next State General Election is scheduled for March 2017.

Staffing related to base funding 2016–17

For 2016–17, salaries will continue to account for about 72% of GSWA's CR funding, which is basically unchanged from the 73% in 2015–16.

Table 11 shows planned staffing of 126.0 FTE in 2016–17. This compares with actual staffing of 124.9 FTE in 2015–16, so staffing numbers remain strictly controlled. The squeeze on government spending (particularly on salaries) continues, with a combination of an imposed salary limit for GSWA, further 'efficiency dividends', and where (since January 2015) 40% of a person's salary and related on-costs are removed from the DMP budget when a staff member retires or resigns from the department. This generally equates to a '2-for-1' rule, that is, two people need to retire or resign before one person can be recruited. This, of course, means that there is pressure for the replacement to be a less experienced person or for them to be employed only part time. GSWA has taken the opportunity, where possible and where appropriate, to move selected staff from EIS funded to recurrent-budget funded positions.

Table 8. GSWA high-level budget for geoscience information

	2013–14*	2014–15	2015–16	2016–17
	\$m	\$m	\$m	\$m
Consolidated Revenue Fund				
Base funding (recurrent budget)	18.158	19.294	19.488	18.612
Kimberley Science and Conservation Strategy (KSCS)	1.039	—	—	—
Exploration Incentive Scheme	24.194	11.075	10.00	10.00
Total budget	43.391	30.369	29.488	28.612

NOTE: Budget allocation for GSWA for each financial year; excludes DMP corporate overheads; does not reflect final end-of-year actual expenditure. Budget includes small special allocation from Department of Premier and Cabinet for the South West Settlement project

Table 9. GSWA's 2016–17 recurrent budget for both projects and support activities

SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE — RECURRENT BUDGET ALLOCATIONS					
2015–16 Budget \$,000	Project and support activities Operational sections/Cost centres Description	2016–17 allocations			Div Plan FTE
		Salary \$,000	Non- salary \$,000	Total \$,000	
	3101 — Executive and Administrative Support				
675	GS01 Executive team	665	28	693	4.0
361	GS02 Executive support	313	18	331	3.8
1036	Subtotal cost centre 3101	978	46	1024	7.8
	3102 — Minerals and Petroleum Resources				
1501	GS10 Basins and Energy Geoscience	1400	256	1656	11.5
897	GS12 Land Use Geoscience	848	75	923	7.0
913	GS14 Commodity and Industry Analysis	556	314	870	5.0
672	GS20 Mineral Systems Studies	617	62	679	6.0
0	GS77 Mining Act Section 16(3) Referrals Information system development	0.0	53	53	0
0	GS79 MINEDEX/Royalties Information system development	0.0	105	105	0
3983	Subtotal cost centre 3102	3421	865	4286	29.5
	3103 — Regional Geoscience Mapping				
281	GS43 Geochemistry and Regolith	151	24	175	1.0
148	GS45 Pilbara Craton	151	0	151	1.0
273	GS47 Gascoyne Province	246	17	263	2.0
142	GS49 Edmund and Collier Basins	119	21	140	1.0
472	GS52 East Yilgarn (Kalgoorlie Office)	207	223	430	2.0
504	GS53 Chief Geoscientist and Terrane Custodianship	486	68	554	4.0
724	GS54 Geochronology and Isotope Geology	492	245	737	4.6
342	GS55 Geophysics and Remote Sensing	270	75	345	2.0
191	GS56 North Australian Craton	102	0	102	1.0
313	GS57 West Musgrave	0	0	0	0.0
593	GS58 Youanmi Terrane	508	96	604	4.0
313	GS61 Albany–Fraser Orogen and Eucla basement project	233	102	335	2.0
360	GS62 3D Geoscience	347	0	347	3.0
0	GS63 Tectonic evolution of the Fortescue and Hamersley Groups	127	97	224	0.9
4656	Subtotal cost centre 3103	3439	968	4407	28.5
	3104 — Logistics and Field Support				
1 264	GS70 Field Support	311	1053	1364	4.0
1 264	Subtotal cost centre 3104	311	1053	1364	4.0
	3105 — Geoscientific Editing and Publishing				
0	GS78 Geoscience Information and Resource Centre	0	98	98	0
928	GS80 Editing and Publishing	822	234	1056	8.4
764	GS81 Mapping	700	57	757	8.0
252	GS82 Graphics	256	0	256	3.0
695	GS83 GIS Services	580	51	631	6.0
971	GS84 Spatial Services	501	544	1045	5.0
401	GS85 Geoscience Promotions	335	70	405	3.0
4011	Subtotal cost centre 3105	3194	1054	4248	33.4
	3106 — Geoscientific and Exploration Information				
947	GS91 Mineral Exploration Information Management	605	146	751	6.5
1115	GS92 Statutory Petroleum Exploration Information	716	133	849	9.0
826	GS94 Core Library Perth	416	431	847	6.0
412	GS95 HyLogger and the Virtual Core Library	119	257	376	1.0
393	GS96 Core Library Kalgoorlie	157	262	419	2.0
3693	Subtotal cost centre 3106	2013	1229	3242	24.5
18643	GSWA BUDGET	13356	5215	18571	127.7

Table 10. GSWA's 2016–17 recurrent budget, with support budgets distributed pro rata to geoscience activities

Cost centres Projects and support activities		2015–16 Total \$,000	2016–17 Fully attributed budget			Div Plan FTE
			Salary \$,000	Non-salary \$,000	Total \$,000	
SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE						
Encouragement of exploration and discovery of mineral and petroleum deposits and informed land use planning						
Publish maps, reports and datasets to maintain an up-to-date geological framework of the State and its mineral and petroleum resources. Maintain an archive of statutory mineral and petroleum exploration information and samples						
Regional Geoscience Field Mapping						
GS43	Geochemistry and Regolith	588.4	265.7	79.5	345.2	2.1
GS45	Pilbara Craton	301.7	265.7	55.5	321.2	2.1
GS47	Gascoyne Province	580.4	475.4	128.0	603.4	4.3
GS49	Edmund and Collier Basins	295.7	233.7	76.5	310.2	2.1
GS52	East Yilgarn (Kalgoorlie Office)	779.4	436.4	334.0	770.4	4.3
GS55	Geophysics and Remote Sensing	649.4	499.4	186.0	685.4	4.3
GS56	North Australian Craton	344.7	216.7	55.5	272.2	2.1
GS57	West Musgrave	603.5	0.0	0.0	0.0	0.0
GS58	Youanmi Terrane	1207.7	966.8	318.0	1284.8	8.6
GS61	Albany–Fraser Orogen and Eucla basement project	620.4	462.4	213.0	675.4	4.3
GS62	3D Geoscience	921.0	691.1	166.5	857.6	6.4
GS63	Tectonic evolution of the Fortescue and Hamsersley Groups	0.0	230.2	146.9	377.2	1.9
Subtotal		6892.3	4743.4	1759.4	6502.8	42.7
Petroleum System Studies and Exploration Information						
GS10	Basins and Energy Geoscience	3289.8	2719.0	894.2	3613.2	24.7
GS92	Statutory Petroleum Exploration Information	2271.4	1313.6	713.1	2026.7	15.7
Subtotal		5561.2	4032.6	1607.3	5639.9	40.4
Mineral Resource Services and Exploration Information						
GS12	Land Use Geoscience	1393.3	1278.6	250.1	1528.7	11.2
GS14	Commodity and Industry Analysis	1310.0	863.6	506.2	1369.8	8.0
GS20	Mineral Systems Studies	1563.3	1305.2	395.0	1700.2	12.9
GS91	Mineral Exploration Information Management	2023.1	1132.7	696.9	1829.6	12.6
Subtotal		6289.7	4580.0	1848.3	6428.3	44.6
TOTAL GSWA BUDGET		18743.2	13356.0	5215.0	18571.0	127.7
Support activities						
GS01	Executive Team		Distributed pro rata to all projects			
GS02	Executive Support		Distributed pro rata to all projects			
GS53	Chief Geoscientist and Terrane Custodianship		Distributed pro rata to all mapping and resource projects			
GS54	Geochronology		Distributed pro rata to all mapping and petroleum geology projects			
GS59	Geology Online		Distributed pro rata to all mapping and resource projects			
GS70	Logistics and Field Support		Distributed pro rata to all mapping and petroleum geology projects			
GS80	Mining Act Section 16(3) Referrals		Distributed pro rata to all mapping and resource projects			
GS77	Geoscience Information and Resource Centre – ISD		Distributed pro rata to all mapping and resource projects			
GS78	MINEDEX/Royalties		Distributed pro rata to all mapping and resource projects			
GS79	Editing and Publishing		Distributed pro rata to all mapping and resource projects			
GS81	Mapping		Distributed pro rata to all projects			
GS82	Graphics		Distributed pro rata to all projects			
GS83	GIS Services		Distributed pro rata to exploration Information projects			
GS84	Spatial Services		Distributed pro rata to exploration Information projects			
GS85	Geoscience Promotions		Distributed pro rata to exploration Information projects			
GS94	Core Library Perth		Distributed pro rata to Land Use Geoscience (GS12)			
GS95	HyLogger and the Virtual Core Library		Distributed as per Spatial Services (GS84)			
GS96	Core Library Kalgoorlie		Distributed pro rata to Commodity and Industry Analysis (GS14)			
			GS99 excepted from pro rata distribution			
			KS01 and KS02 excepted from pro rata distribution			

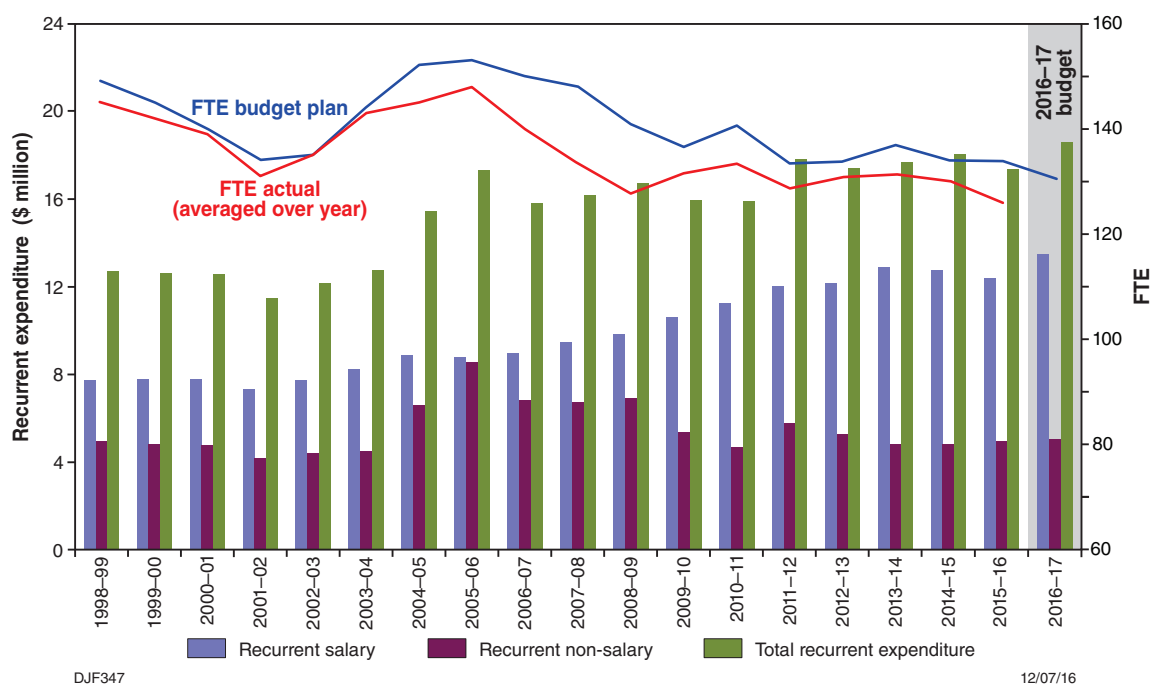
Table 11. Distribution of GSWA staff (excluding EIS- and KSCS-funded staff) among specialist groups funded by the Consolidated Revenue fund in 2016–17

Specialist group	Actual FTE 2013–14		Actual FTE 2014–15		Actual FTE 2015–16		Planned FTE 2016–17	
	FTE	%	FTE	%	FTE	%	FTE	%
Geoscientists	72.1	54.9	73.1	56.6	73.1	57.7	73.4	58.2
Cartographers and GIS specialists	26.0	19.8	26.0	20.1	26.0	19.9	24.0	19.0
Other (technical and field support, data entry, administrative support)	33.3	25.3	31.3	23.3	31.3	22.5	28.6	22.7
Total	131.4	100	130.4	100	124.9	100	126.0	100

The staffing data of Table 11 exclude EIS staffing, where a limit of an additional eight positions are available and where contracts are tied in duration to the duration of assured and predicted EIS funding. Table 11 also excludes the short-term fee-for-service staff that are funded by either the recurrent operational or EIS budgets.

Figure 22 illustrates the 25-year trends in GSWA's recurrent expenditure and employment. Staff numbers in GSWA decreased as the mining boom progressed — falling from a peak of 148 full-time staff in 2005–06 to 128 in 2008–09 — with the fall stopped by the Global Financial Crisis (GFC). Not only did staff retention rates improve after the GFC, but GSWA's baby boomers postponed their retirement. The EIS started in April 2009 and, with the additional funding, provided extra funds for operational-style project expenditure, but where employment under EIS was strictly capped at an additional eight FTE staff (who are not shown in Figure 22).

Recurrent-funded staffing recovered to a level of 135 in 2009–10 as EIS activities gathered momentum, but have stayed controlled since then and have overall gradually declined to an actual level of 125 in 2015–16 and a predicted 126 for 2016–17. This is despite the fact that the long-term trend reveals that the planned number usually slightly exceeds the final actual result for the year by one to five full-time staff. The government squeeze on salaries and recruitment since January 2015 means that although six staff were recruited during the prior five years, budget restraints will not permit any additional staff to be recruited to the sponsored Master's program during 2016–17. The strict Government controls on expenditure and staffing will continue in the short term, at least for 2016–17. Employment through short-term fee-for-service arrangements for specific project work remains the most flexible way to achieve operational objectives while balancing budget restraints.

**Figure 22. Long-term trends in GSWA's recurrent salary and non-salary expenditure, together with recurrent FTE staff (planned and actual)**

The proportion of geoscientists is slowly increasing relative to the other specialist groups, partly as a result of geoscientists taking on some of the cartographic/GIS and specialist geoscience data entry tasks, with geoscientists now representing about 58% of all full-time and part-time employees (Fig. 23; Table 11). Geoscientists and IT support staff are a high proportion of the fee-for-service staff (not included within the data of Table 11 and Figure 23).

Appendix C shows the organizational structure for GSWA at 30 June 2016.

Strategic allocation of CR funding 2016–17

Table 12 contains the result of allocating GSWA's CR funding to its two strategic objectives under the Geoscience Information service, viz. 'Encouraging exploration and discovery of resources' and 'Informed land-use planning'.

The analysis included in Table 12 reveals that 71% of GSWA's 2016–17 budget will be applied to the outcome of encouraging the exploration and discovery of mineral and energy resources and 29% will be directed towards informed land-use planning. The amounts are almost unchanged from the previous year, where the allocation was estimated at 70 and 30%, respectively. With the objective of encouraging exploration and discovery, the split between targeting minerals versus petroleum and coal is 45 basis points versus 23 basis points (totalling 68% of the GSWA budgetary resources) with both little changed relative to 2015–16.

Pre-competitive geoscience applied to greenfields areas targeting minerals, petroleum and coal (combined) consumes 47% of the budget compared to the 21% directed towards brownfields areas, a ratio of about 70:30. This ratio has been maintained for many years.

Recurrent budget work program 2016–17

The 2016–17 field mapping and map compilation program will continue to extend the 1:100 000 Geological Series maps (Fig. 24) for the Ashburton Basin and Bangemall Supergroup, and the Murchison Domain of the Yilgarn Craton. The Geological Information Series (GIS) products (Fig. 25) covering the Kimberley, west Musgrave, Murchison, and west Capricorn will be updated. Revised interpreted IBG layers at 1:100 000 and 1:500 000 scales will continue for an update of the East Yilgarn GIS product, together with the further extension of the Eastern Goldfields Superterrane stratigraphies. The revised 1:500 000 IBG map of the State will be updated. New field mapping and desktop studies will commence for the compilation of GIS products for the southeast Capricorn Orogen basins, the Fortescue and Hamersley basins, and the Southwest Yilgarn. There will be a release of WAROX, GSWA's field observation database, as a digital package. New 3D products will include Geophysical Modelling Records detailing the compilation and validation of published map-scale (4 km) to crustal-scale (up to 60 km) cross-sections against available geophysical data. A further new product initiative is the development of 'virtual tours' based on GSWA field guides, for viewing in Google Earth.

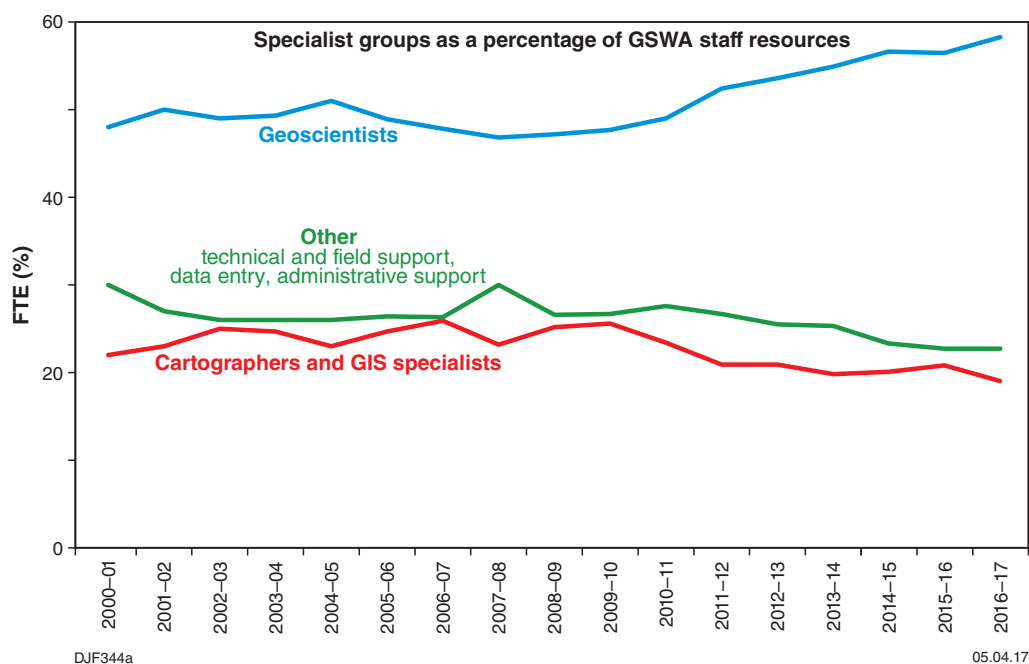


Figure 23. Specialist groups as a percentage of GSWA staff resources from recurrent funding

Table 12. Distribution of recurrent budget to high-level strategic objectives in 2016–17

GSWA 2016–17													
SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE													
Encouragement of exploration and discovery of mineral and energy resources and informed planning													
3103													
Regional Geoscience Mapping													
3102													
Basins and Energy Geoscience													
Mineral Resources													
3106													
Exploration Information and Core Libraries													
TOTAL													
Cost centres													
All figures as \$,000													
Percentage in 2016–17 budget													
Percentage in 2015–16 budget													
STATEGIC OBJECTIVES													
Project totals (as \$,000) include support budgets distributed pro rata by FTE levels													
Established and producing areas													
Precious metals													
Base metals													
Ferro-alloys													
Non-metals													
Green Fields													
Precious metals													
Base metals													
Ferro-alloys													
Non-metals													
Producing areas													
Petroleum, geothermal, CO ₂ and coal													
4285													
717													
3568													
PROSPECTIVITY ENHANCEMENT													
SUBTOTALS													
Informed land use planning													
Information on resource potential													
2592													
Policy advice on resource issues													
1838													
Information for R&D and the general public													
1023													
INFORMATION SERVICES													
SUBTOTALS													
TOTALS													

NOTE: some totals may contain rounding errors

KEY

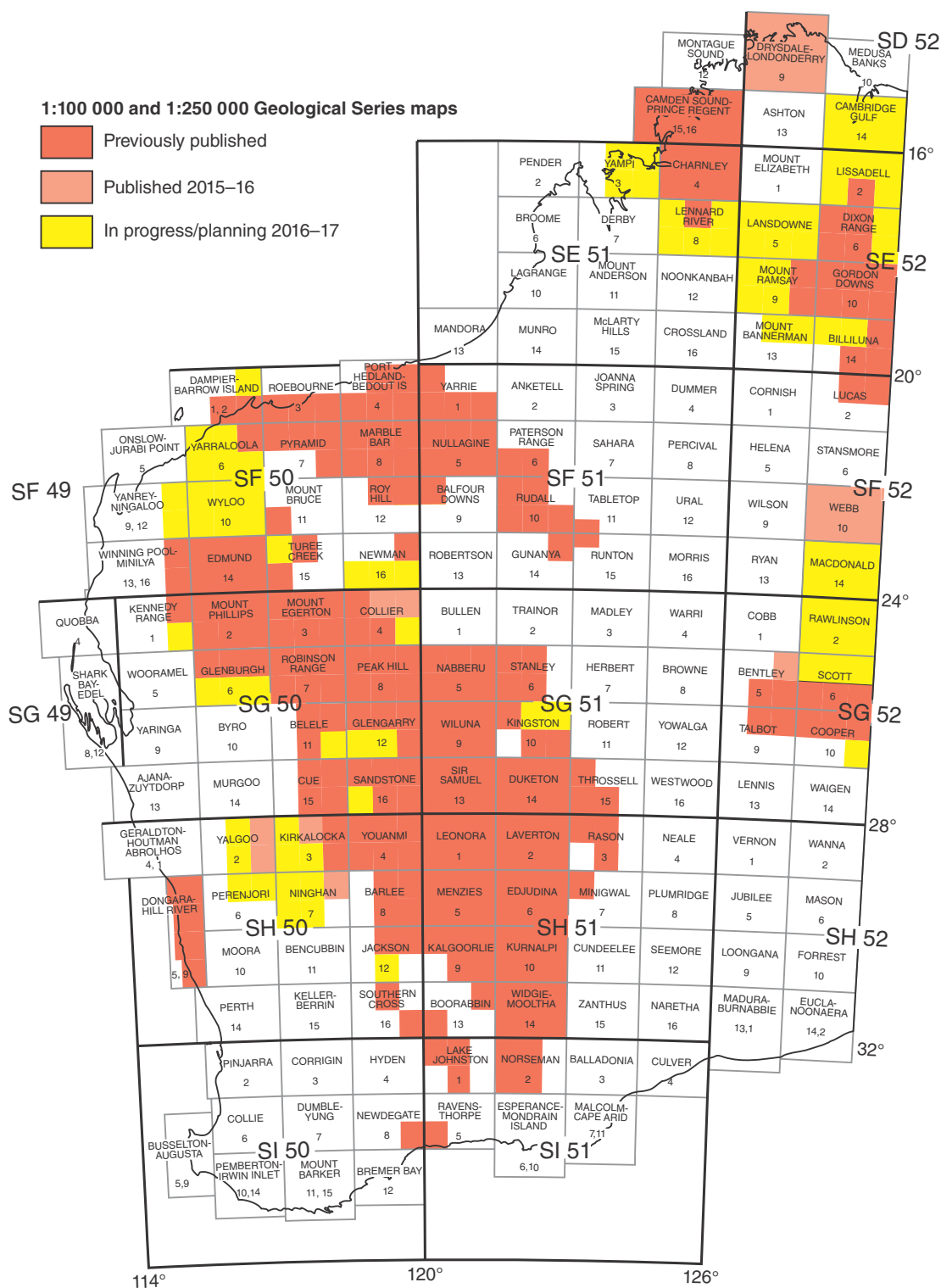
1. The budget of each project has been attributed in proportion to its perceived contribution to various strategic objectives.

2. The column to the right represents the aggregated weighted contribution of all Service 2 projects to various strategic objectives.

* CO₂; carbon dioxide geo-sequestration

Project titles

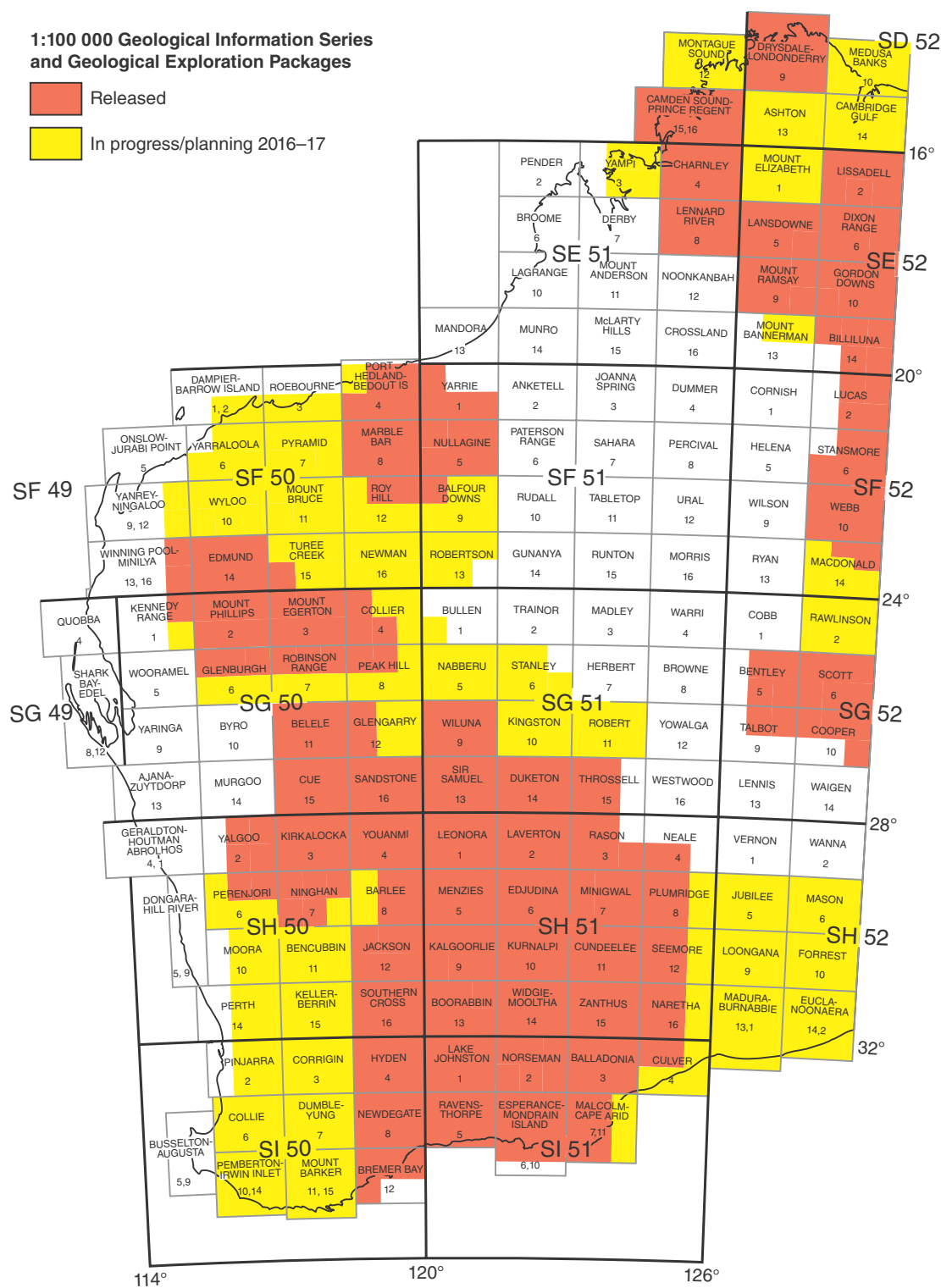
GS10 Basins and Energy Geoscience
GS11 Land Use Geoscience
GS12 Land Use Geoscience
GS13 Mineral Resource Analysis
GS14 Mineral Resource Analysis
GS15 Mineral Resource Analysis
GS16 Mineral Resource Analysis
GS17 Mineral Resource Analysis
GS18 Mineral Resource Analysis
GS19 Mineral Resource Analysis
GS20 Mineral Resource Analysis
GS21 Mineral Resource Analysis
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GS100 Mineral Resource Analysis



IMT175f

13/07/16

Figure 24. Index map showing 2016–17 planned achievements — 1:100 000 and 1:250 000 Geological Series maps



IMT176f

13/07/16

Figure 25. Index map showing 2016–17 planned achievements — 1:100 000 Geological Information Series (GIS) and Geological Exploration Packages (GEP)

Work of the Mineral Systems Studies section (including the HyLogger spectral scanner) is still being integrated with the mapping projects (above), as well as being involved as much as possible with the collaborative research projects funded by EIS. The proposed Mineral Systems Atlas is beginning to take shape and the team will be using komatiite-hosted nickel–copper as a mineralized system to test the concepts and the ability of GSWA databases to provide the necessary data layer products. Ongoing entry of mineral deposit information will continue into GSWA's mines and mineral deposits information database (MINEDEX), which is used throughout DMP for a number of policy and approvals purposes. An area of policy focus in 2015–16 and 2016–17 is on assessing the future viability of the numerous mines officially on 'care and maintenance' versus the potential environmental liability to the Mining Rehabilitation Fund if mining were not to resume. Improved online reporting of mineral production data into the royalties system and then automatically through to MINEDEX is planned for 2016–17, together with more information captured on ages of mineralization.

The Basins and Energy Geoscience section will continue its major investigations of the Canning, Perth and western Amadeus Basins using a mix of recurrent and EIS funding. This work involves the high-priority projects of interpreting the Canning Coastal seismic survey (700 line-km) and participating with industry in analysing core obtained from current petroleum wells in the Canning Basin, plus possibly also the Perth Basin. AWE Ltd's discovery of gas in the Waitsia/Senecio fields has renewed much interest in the northern Perth Basin.

The Land Use Geoscience section will continue responding to routine and ad hoc requests for prospectivity analyses from the Department of Planning and the Western Australian Planning Commission. Strategic projects for 2016–17 include:

- continuing the prospectivity assessments of parcels of Crown land in the southwest of the State that could potentially be returned to traditional owners as freehold land as part of the South West Native Title Settlement
- continuing strategic assessment of resources and parcels of land needed to be protected (or sequentially developed) from urban sprawl in the Perth–Peel region for an expanded population of 3.5 million people
- updating prospectivity assessments of pastoral leases purchased by the Department of Parks and Wildlife for conversion to conservation use as a basis for negotiating with that department on the type of reserve to be applied to areas within individual pastoral leases
- maintaining access for the mining and petroleum sectors to land impacted by conversion to freehold, leasehold or conservation estate — that is, where *Mining Act 1978* Section 16(3) clearance is required.

Cooperative projects

GSWA is currently involved in 37 cooperative projects with geoscience research organizations including universities, CSIRO, AMIRA, Cooperative Research Centres (CRC), Centres of Excellence, AuScope and GA. Nine of the current projects are with GA and operate under the National Collaboration Framework. A full list of the projects is included in Appendix D, which also includes many projects completed over the last decade. GSWA's process for tracking cooperative research projects improved greatly with the start of EIS in 2009. Cooperative projects are supported by both GSWA's recurrent funding and EIS, but some simply have GSWA 'in-kind' support and hence do not have a funding commitment. Further details of these current projects are contained in descriptions of individual recurrent and EIS project plans.

Recurrent budget — planned achievements 2016–17

Table 13 shows GSWA's planned achievements predominantly using 2016–17 recurrent budgetary resources, but with significant contribution also from EIS funding. Importantly, production of 1:100 000 Geological Series maps will see a drop this year to an anticipated six maps, rather than the longer term average of around 10 maps. This is due to a combination of several mapping teams moving to new project areas plus the greater trend towards online and gradual updating in the Explanatory Notes System instead of printing revised edition maps. Production of Reports, Records, non-series maps, and digital information packages should remain at around the long-term average production level for these products.

Other significant planned outputs of the 2016–17 recurrent budget include:

- obtaining government approval for the continuation of the EIS
- preparing a business case for expansion of the Joe Lord Core Library at Kalgoorlie
- releasing in full GSWA's field observations and rock database (WAROX). Although parts of it have been released for individual project areas in Geological Information Series packages, this will be the first ever release of the statewide data
- releasing the first of the innovative product in the series Digital Core Atlas — Olympic 1, which was drilled by Buru Energy Ltd in the Canning Basin and is an important stratigraphic well for GSWA
- releasing GSWA's concept and demo of the prototype of the Mineral Systems Atlas
- releasing GSWA's next suite of 3D products — Rocklea Dome and the Albany–Fraser Orogen

Table 13. Planned achievements for release in 2016–17

	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17 (planned)
Books (Reports, Records, non-series)	36	52	36	39	39	35	40	43
1:100 000 and 1:250 000 series maps	13	12	12	10	10	10	10	6
Maps — other (includes geophysical maps)	11	8	14	17	20	18	18	18
Digital information packages	21	17	18	11	20	18	16	18
Weighted Total Published product	170	188	174	173	187	124	140	150+

- creating web-based virtual geological tours for viewing through Google Earth — Marble Bar through the East Pilbara, Mafic–ultramafic intrusions of the Youanmi Terrane, and Meteorite impact structures of Western Australia
- interpreting the Eucla–Gawler deep seismic reflection survey
- releasing Explanatory Notes System — West Musgrave Province
- releasing Exploration targeting for BIF-hosted iron ore deposits (joint project with MRIWA)
- releasing Explorer’s guide for gold in the Yilgarn Craton (Part 3)
- releasing Western Australia unearthed (part 3): the Paleozoic of Western Australia
- revising Mineral Resources Bulletin on the Gemstones of Western Australia
- moving on to better systems for handling the core library assets, improved lodgement of mineral production data (lodged through the online royalties system but flowing through to MINEDEX), and enhancing the WAMEX online report-writing system
- creating TENGRAPH web, which will use the Geocortex software (that is, similar look and feel to GeoVIEW.WA)
- upgrading to GSWA’s Data and software Centre on the DMP website
- releasing an upgrade to the WA Geology mobile application, with new layers and new functionality
- releasing an upgrade to the free GeoMap.WA software.

PART 3

EXPLORATION INCENTIVE SCHEME BUDGET AND WORK PROGRAM FOR 2016–17 AND BEYOND

Outline of the Exploration Incentive Scheme

The Exploration Incentive Scheme (EIS) commenced in April 2009 as a Royalties for Regions (RfR) initiative with funding of \$80 million over four years. The objective of the EIS is to promote exploration in Western Australia, with a particular focus on greenfields areas and frontier petroleum basins, and maintain exploration activity at the levels needed for the long-term sustainability of the State's resources sector.

The original four-year life of the EIS was extended in the Western Australian State Budget in May 2012 with the re-allocation of funding that had originally been assigned to another RfR project. This additional \$20.6 million funded the activities of the EIS in 2013–14. The 2012 Western Australian State Budget papers showed that funding would be available for EIS out of consolidated revenue, with \$18 million allocated for 2014–15 and \$19.5 million for 2015–16. However, the 2013 Western Australian State Budget papers showed that this had changed, with a total \$30 million being allocated to the second phase of EIS (EIS2) over the three financial years 2014–15 through 2016–17 and at the rate of \$10 million per year (Fig. 26). The 2016 Western Australian State Budget papers flagged a further continuation of EIS funding with the forward estimates showing \$10 million per annum from July 2017 to June 2020 once again funded from RfR. The EIS also aims to signal that the Western Australian Government welcomes investment in the State's resources sector and is concerned about the sustainability of resource production if discovery rates in some commodities are not increased.

One of the measures of success of the EIS is the attractiveness of the State as an exploration destination. The ranking of Western Australia in the Fraser Institute's Survey of Mining Companies has improved since the commencement of the EIS from being the least attractive Australian destination for explorers in 2006–07 to being ranked first in the world in the Investment Attractiveness Index, sixth in the world in the Policy Perception Index and best in the world in terms of least uncertainty concerning existing regulations in the 2013 Survey (Fraser

Institute, 2013). In the 2015 survey, released in February 2016, Western Australia was ranked No. 1 globally in both the Investment Attractiveness Index and Best Practices Mineral Potential Index measures, and third in the world for its Geoscience Databases (Fig. 14, Table 3).

The long-term improvement in the perception of Western Australia for minerals investment is also seen in the Fraser Institute rankings of the Policy Perception Index for the Australian states relative to each other (Table 5).

Composition of EIS

The EIS was originally made up of six high-level programs, containing 24 subprograms. Completion or consolidation of a number of these subprograms, and changes in government priorities have led to a reduction in the number of high-level programs to five, containing a total of 13 subprograms.

The EIS2 programs, which started in July 2014, together with the proposed budgets to the end of June 2017, are listed in Table 14 which sets out the budgets of projects under each component. Projects are described in more detail in Part 5 Exploration Incentive Scheme — detailed work programs.

A flagship program of the EIS has been the geophysics program, which has completed the State's coverage by airborne magnetic and radiometric surveys at a line spacing of 400 m or less with a survey being undertaken in Yalgoo in 2015–16. Most of the airborne magnetic–radiometric survey program was completed in late 2012. Availability of medium-spaced, good-quality airborne geophysical data has already greatly contributed to reducing risk and aiding exploration targeting in underexplored areas of the State (Fig. 27). The program is also extending the reconnaissance airborne electromagnetic (EM) surveys, with the Capricorn EM survey undertaken in 2013–14.

The EIS also supports a major expansion of the area covered by gravity surveys with stations spaced at 2.5 km apart. Figure 28 is a composite map showing the EIS-funded gravity, seismic, magnetotelluric, airborne EM, passive seismic and 100 m spaced magnetic–radiometric coverage of the State.

Figure 29 sets out by tectonic unit the geoscience mapping and geophysical survey program carried out under the EIS over the period from 2008–09 to 2015–16, together with the program planned for 2016–17.

The other flagship program of the EIS is the Government–Industry Co-funded Drilling program, which is designed to stimulate geoscience exploration of underexplored areas of Western Australia and contribute to the economic development of these areas. On a competitive basis, it is funding high-quality, technically and economically sound projects that promote new exploration concepts and new exploration technologies. Core collected by companies that gain co-funding becomes available on open-file access in the relevant core library after a six-month confidentiality period. Reports of the drilling programs are also released online through the WAMEX database after a similar confidentiality period.

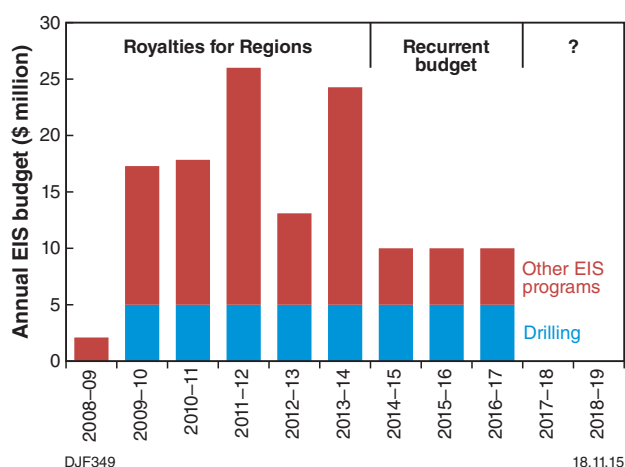


Figure 26. EIS budgets since 2008–09 and with forward estimates

Table 14. Detailed budgets for EIS programs in 2014–15 to 2016–17

Programs	FTE	2014–15 (\$,000)	2015–16 (\$,000)	2016–17 (\$,000)	Total (\$,000)
Exploration facilitation		350	300	80	730
ES01 Exploration and Environmental Coordination		350	300	80	730
Innovative drilling promotion	1	5 800	5 800	5 800	17 400
ES20 Government Co-funded Exploration Drilling		5 675	5 675	5 675	17 025
ES21 Mineral and Exploration Promotion		125	125	125	375
Geophysical and geochemical surveys		300	600	1 340	2 240
ES31 Deep Seismic Survey Program		300	300	0	600
ES32 Regional Gravity Surveys		0	300	880	1 180
ES33 Yilgarn Margin Geochemistry		0	0	460	460
3D prospectivity mapping	7	3 070	2 950	2 430	8 450
ES40 Geology Online		150	100	200	450
ES42 3D Geoscience		300	300	300	900
ES43 Mineral Systems Atlas		890	850	200	1 940
ES45 Geological Mapping and Interpretation		520	500	530	1 550
ES46 Enhanced Geochronology and Isotopic Fingerprinting		310	300	300	910
ES47 Petroleum, Coal and CO ₂ Geosequestration Program		900	900	900	2 700
Promoting strategic research with industry		480	350	350	1 180
ES50 Strategic Industry Research Program		480	350	350	1 180
TOTAL	8	\$10 000	\$10 000	\$10 000	\$30 000

The core submitted as a result of co-funding is analysed using GSWA's HyLogger, with the data and high-quality core photographs being released via the GeoVIEW.WA application on DMP's website.

The submission of recently drilled core from EIS-funded innovative mineral exploration programs has led to an increase in core library use for minerals core, an increase in the number of value-adding research projects, and a significant increase in the amount of EIS-funded drillcore that has been scanned using the HyLogger (Fig. 30).

Achievements 2015–16

Achievements during 2015–16, the seventh full year of operation of the EIS, are as follows:

- Drilling projects supported by the Co-funded Drilling program resulted in 20 391 m of diamond drilling and 23 611 m of non-cored drilling from 48 projects were completed during 2015–16.
- Forty-eight successful applicants were announced for Round 12 offers (for drilling during 2016) and 48 successful applicants for Round 13 offers (for drilling during 2016–17) under the Government–Industry Co-funded Drilling program.
- A Report was released on the geosequestration potential of the Carboniferous–Permian Grant Group and Permian Poole Sandstone, northwest Canning Basin, Western Australia.
- Gravity data which was acquired in the Ngururra lands was released between May and June 2015 (4964 stations), and the gravity data was acquired on a 28 700-station survey in the southwest Yilgarn.
- A collaborative study was completed on mineral exploration targeting in the Yilgarn Craton – Albany–Fraser margin.
- High-grade gold deposits: processes to prediction, CSIRO embedded researcher project was completed.
- Regional structural and stratigraphy study of the Canning Basin, Western Australia (The University of Western Australia [UWA]) was completed.
- Report on the mineral prospectivity of the King Leopold Orogen was released.
- The first two 3D models covering the Sandstone greenstone belt in the northern Yilgarn Craton and the Windimurra Igneous Complex in the Yilgarn Craton were released.

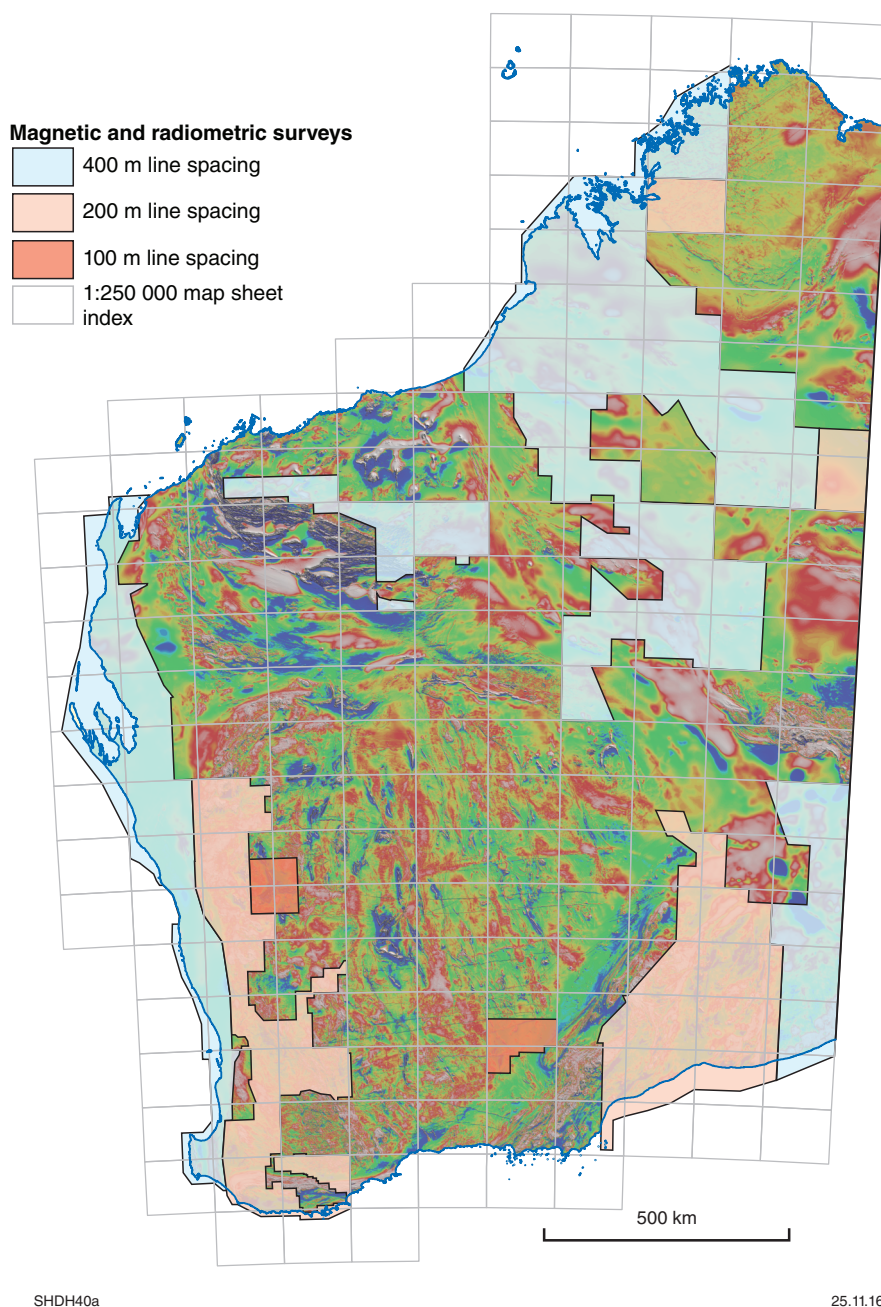


Figure 27. EIS-funded airborne magnetic and radiometric surveys

- Acquisition of 110 829 km of airborne electromagnetics (AEM), magnetics and digital elevation modelling (DEM) in the Yalgoo airborne survey was completed.
 - Two collaborative Reports were published on mineral prospectivity covering the King Leopold Orogen and Leonard Shelf, and the Halls Creek Orogen.
 - The results of the Eucla basement stratigraphic drilling program conducted by GSWA were released at a workshop.
 - A gravity and magnetic study of the Western Amadeus Basin was published.
- Full details of the achievements are included in the individual program plans — see Part 5.

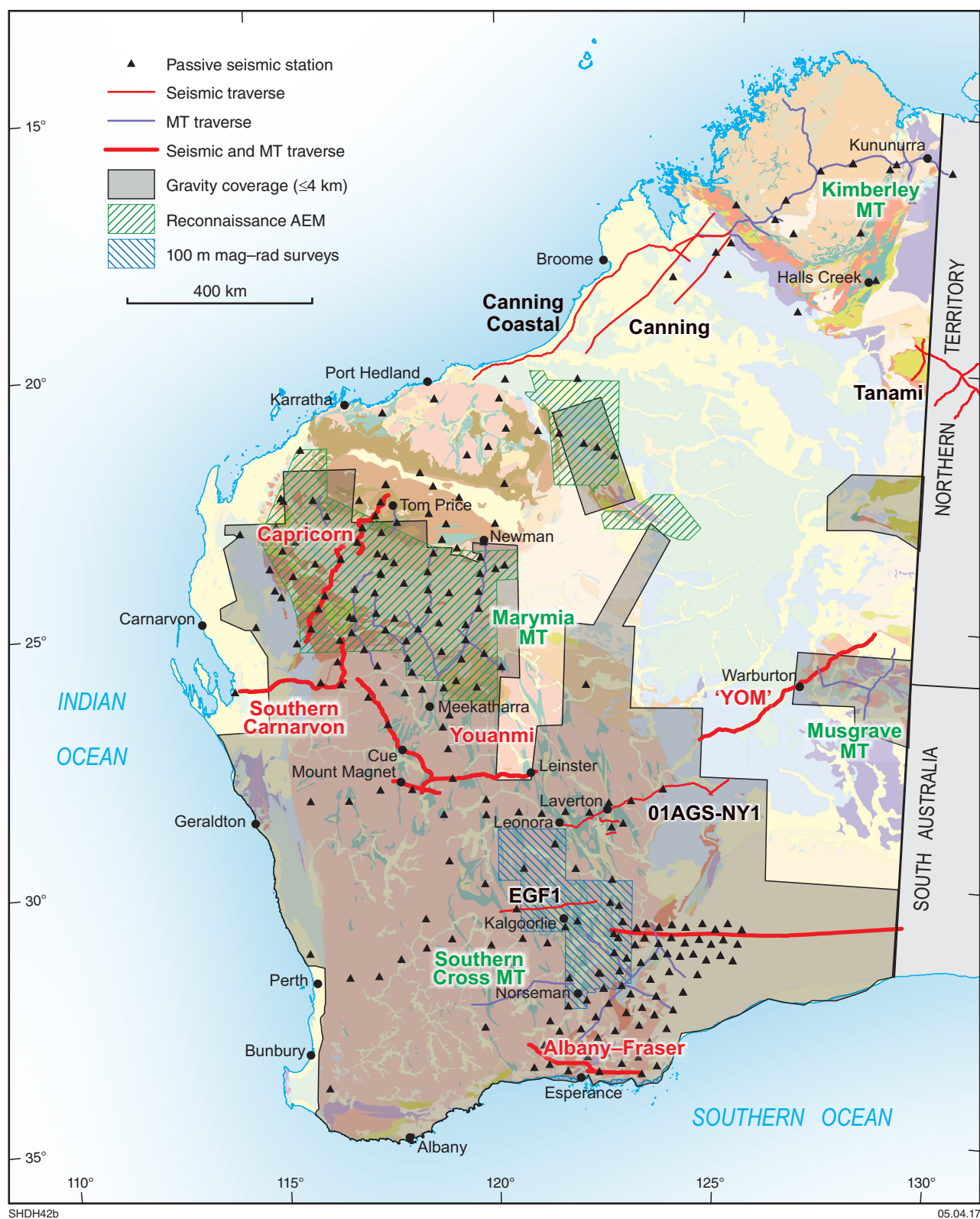


Figure 28. Composite map of EIS-funded gravity, seismic, magnetotelluric, airborne electromagnetic, and passive seismic coverage of Western Australia

EIS work program 2008–09 to 2016–17

Geological regions	Age	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
STATE		\$					M	M	M	M
KIMBERLEY										
Kimberley Basin	Prot				\$	\$	\$	M	M	\$
Halls Creek Orogen	Prot				\$	\$	M	M	M	\$
King Leopold Orogen	Prot		\$		\$	M	M	M	M	\$
PILBARA CRATON										
Granite–greenstone terranes	A									M
Hammersley Basin	A		\$		\$					
Paterson Orogen	Prot								\$	\$
Sylvania Inlier	A									
YILGARN CRATON										
Eastern Goldfields Superterrane — north	A				\$		\$	\$	\$	\$
Eastern Goldfields Superterrane — central	A		\$			\$	\$			
Eastern Goldfields Superterrane — south	A		\$			\$	\$			
Southern Cross Domain — north	A									
Southern Cross Domain — south	A		\$	M	M	M	M	M	M	\$ M
Murchison Domain	A		\$		\$	\$		\$	\$	M
Narryer Terrane	A		\$		\$					
South West Terrane	A	\$				\$		\$	\$	\$
CAPRICORN OROGEN										
Ashburton–Bresnahan Basins	Prot		\$				\$ M	M	M	\$ M
Gascoyne Complex — south	Prot			\$	M	M	\$ M	M	M	\$ M
Gascoyne Complex — north	Prot		\$	\$	M	M	\$ M	M	M	\$ M
Edmund–Collier (Bangemall) Basins	Prot						\$ M	M	M	\$ M
Earaheedy Basin	Prot						\$ M	M	M	
Bryah–Padbury–Yerrida Basins	Prot			\$			\$ M	M	M	\$
PINJARRA & ALBANY–FRASER OROGENS										
Albany–Fraser Orogen — east	Prot		\$ M	\$ M			\$	\$		
Albany–Fraser Orogen — west	Prot					\$			\$	\$
Northampton Complex	Prot				\$					
Leeuwin Complex	Prot					\$				
Mullingarra Complex	Prot				\$					
Nullarbor (basement)	Prot		\$			\$	\$	\$	\$	
CENTRAL AUSTRALIA										
West Granites–Tanami Complex	Prot					\$		\$	\$	
Birrindudu Basin	Prot			\$						
Arunta Orogen	Prot		M		M	M				\$
Amadeus–Murraba Basins	Prot									\$
Musgrave Province	Prot		\$	M	M	M				
BASIN STUDIES										
Southern and Northern Bonaparte Basins	Phan				\$	\$				
Canning Basin — Lower Paleozoic	Phan		\$	\$		\$	\$	\$	\$	\$
Canning Basin — Upper Paleozoic	Phan		\$	\$		\$	\$	\$	\$	\$
Canning Basin — Devonian	Phan		\$	\$		\$	\$	\$	\$	\$
Southern and Northern Carnarvon Basins	Phan				\$					
Officer Basin	Prot					\$				
Perth Basin — north	Phan				\$		\$			\$
Perth Basin — south	Phan			\$	\$		\$			\$
Eucla Basin	Phan		\$	\$	\$		\$			

RR110d

11/04/17

Phan Phanerozoic
 Prot Proterozoic
 A Archean

\$ Geophysical and geochemical surveys
 M Exploration targeting

Geological mapping (including 3D)
 Stratigraphic drilling

Figure 29. EIS-funded planned work program until 2016–17, by tectonic unit. Geological mapping includes some 3D products in 2015–16 and beyond

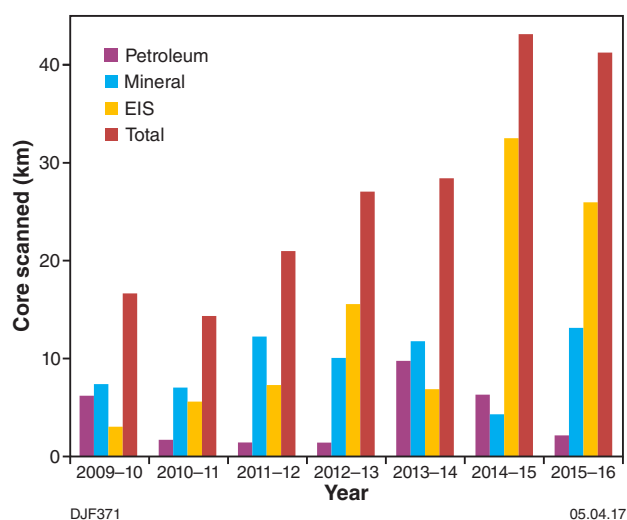


Figure 30. Spectral scanning of core through GSWA's HyLogger at Carlisle, highlighting the importance of new EIS-funded drilling

Cooperative projects

Several large collaborative projects are a major feature of the EIS, as these projects minimize public service appointments and fill critical gaps in GSWA's skill sets. Appendix D contains a detailed listing of collaborative projects involving GSWA (the full list contains both EIS-funded and recurrent-funded cooperative projects).

The EIS is providing an additional \$350 000 per annum to MRIWA* (formerly MERIWA) for four years, which in turn leverages funding from industry for minerals and energy research (Table 6).

* The Minerals and Energy Research Institute of Western Australia (MERIWA) was replaced by the Minerals Research Institute of Western Australia (MRIWA) on 1 February 2014, the starting date of the *Minerals Research Institute of Western Australia Act 2013*.

PART 4

RECURRENT BUDGET — DETAILED WORK PROGRAMS



GS10 Basins and Energy Geoscience

Manager: Deidre Brooks

Team members: Norman Alavi, Heidi Allen, Louisa Dent, Ameen Ghor, Peter Haines, Lorraine de Leuw, Alan Millar, Sarah Martin, Arthur Mory, Leon Normore, Suzanne Simons, Charmaine Thomas, Vijie (Alex) Zhan

The primary goal of this section is to develop consistent, basinwide stratigraphic and structural frameworks for Western Australia's onshore sedimentary basins. The aim is to encourage increased exploration for petroleum, coal and geothermal energy resources, and thus secure the State's energy future.

Historically, the team's focus has been on conventional oil and gas, although in recent years studies have broadened to include assessing the potential for petroleum resources from tight sand, shale, and coal seam reservoirs; geothermal resources from hot rocks and hot sedimentary aquifers; and potential for carbon capture and storage (CCS).

The team works in collaboration with the Petroleum Division of DMP and other organizations including CSIRO, the Western Australian Energy Research Alliance (WA: ERA), UWA, Curtin University, Northern Territory Geological Survey (NTGS) and GA.

Currently, the section's main focus is the onshore and nearshore Canning and Perth Basins. Both basins have proven petroleum systems and are underexplored, particularly in the case of the vast Canning Basin. The section is also contributing to geological mapping of the Western Australian portion of the Amadeus Basin, and interpreting results to better understand its petroleum potential.

During 2016–17 new areas of study will include: a review of new well data from the Officer Basin, which might yield improved understanding of the petroleum potential of the basin; investigation of the little-known Moora Basin, located adjacent to the eastern margin of the Perth Basin; and analysis of the source-rock potential of the Triassic and Permian within the onshore and nearshore Southern Carnarvon Basin.

Canning Basin

The main issues and uncertainties in the Canning Basin include:

- unreliable and poorly distributed geochemical data, creating uncertainties regarding the definition and distribution of petroleum systems
- inconsistent stratigraphic nomenclature across the basin, especially in the Paleozoic section, resulting in inconsistent picking of formation tops between wells

- lack of biostratigraphic data in many wells and intrinsic difficulties of biostratigraphically dating some stratigraphic intervals
- uncertain validity of the structural and tectonic framework
- lack of good-quality well and seismic data, and issues regarding the quality and distribution of the data, especially in the Kidson Sub-basin, where there is a lack of well and seismic data.

Southern Carnarvon Basin

The main issues and uncertainties in the onshore to nearshore Southern Carnarvon Basin include:

- questionable stratigraphic correlations due to the lack of biostratigraphic control in wells and poor-quality seismic ties
- paucity of well data to assess Triassic and Permian petroleum source-rock potential.

Perth Basin

The main issues and uncertainties in the Perth Basin include:

- patchy seismic coverage of variable quality
- questionable stratigraphic correlations due to the lack of biostratigraphic control in wells and poor-quality seismic ties
- paucity of well data to assess shale gas and carbon sequestration potential in the Northern Perth Basin, and tight gas in the Southern Perth Basin
- uncertainty about the tectonic and structural evolution, and depositional history of the basin.

Officer Basin

The main issues and uncertainties in the Officer Basin include:

- extensive surficial cover and deep weathering of outcrops mean that most information must come from sparse drillcores and limited seismic data

- stratigraphic control and correlation across Western Australia, and into South Australia, are in need of refinement
- new mineral cores are available in some areas but have not been assessed for their stratigraphic and biostratigraphic information, or sampled for source-rock evaluation
- the existence of Neoproterozoic source rocks in Western Australia remains problematic despite oil and gas shows in a number of wells in Western Australia and South Australia; a revised source-rock sampling strategy is required.

Moora Basin

The main issues and uncertainties in the Moora Basin include:

- age range is very poorly constrained (Mesoproterozoic or Neoproterozoic with possibility of early Paleozoic component)
- very limited biostratigraphic control, stromatolites previously reported as poorly preserved, a problematic fossil needs reassessment for biostratigraphic value
- origin of hydrocarbons (bitumen) reported in drillcore is uncertain, indigenous to Moora Group or migrated from Perth Basin?
- poor exposure and limited drilling.

Amadeus Basin

The main issues and uncertainties in the Amadeus Basin include:

- extensive surficial cover and deep weathering of outcrops; stratigraphic sections are incompletely exposed (particularly shaly successions) and source-rock properties cannot be determined
- lack of subsurface data
- stratigraphic control and correlation with the remainder of the basin; this problem is currently being addressed, although the details remain problematic
- limited biostratigraphic control, apart from stromatolites
- remoteness and difficulty of vehicular access due to the few roads and tracks, and extensive sand dunes.

Murraba Basin

The main issues and uncertainties in the Murraba Basin include:

- extensive surficial cover and deep weathering of outcrops; stratigraphic sections are incompletely exposed (particularly shaly, carbonate and glacial successions) and source-rock properties cannot be determined

- lack of subsurface data
- poorly understood correlation to prospective parts of the Centralian Superbasin (e.g. to Amadeus Basin)
- very poor age control
- remoteness and difficulty of vehicular access due to almost no roads and tracks, and extensive dune cover.

Outcomes of work program 2015–16

Canning Basin

Some of the main outcomes from studies in the Canning Basin 2015–16 are:

- reassessment of the palynology from the Grant Group and Reeves Formation indicates a significant break between these units, and the restriction of the Reeves Formation to the Fitzroy Trough – Gregory Sub-basin and Lennard Shelf. Much of the section previously incorporated into the Reeves Formation is now included in the Grant Group
- reliable and consistent seismic datasets as a result of basinwide systematic quality control
- ongoing interpretation of key horizons in the southern Canning Basin provides a series of maps to better understand its resources and structural framework
- review of the structural elements of the southwestern Canning Basin confirming the presence of thick sedimentary sections within the Wallal Embayment and Samphire Graben.

Perth Basin

Some of the main outcomes from studies in the Perth Basin 2015–16 are:

- sampling and palynological assessment of samples from DMP Harvey 2 and DMP Harvey 3A (in conjunction with the Carbon Strategy Group of DMP)
- reassessment of palynological slides from Lake Preston 1, and revision of palynological report data from other water bores in the Harvey area, as an aid to better constraining the biostratigraphy of this area
- improved definition of the structure and stratigraphy of the Southern Perth Basin through integration of revised biostratigraphy from petroleum, mineral and water wells and seismic interpretation, resulting in new regional depth maps of key horizons.

Amadeus Basin

Some of the main outcomes from studies in the Amadeus Basin 2015–16 are:

- improved correlations as a result of ongoing work on stromatolite biostratigraphy and now complete detrital zircon provenance studies

- refined cross-border correlations as a result of collaboration with NTGS
- improved understanding of the western Amadeus Basin and outliers of the basin to the north with the release of a second edition WEBB map sheet.

Murraba Basin

Some of the main outcomes from studies in the Murraba Basin 2015–16 are:

- reconnaissance helicopter-supported field examination in 2015 was permitted through collaboration with a regolith geochemistry survey being conducted in part over the southern Murraba Basin
- substantial revision of the age of much of the succession due to improved correlations to the rest of the Centralian Superbasin
- revised stratigraphic interpretation increases petroleum prospectivity of the basin (previously not considered to have any potential).

Regional studies

The main outcome from regional studies 2015–16 is:

- greater understanding of petroleum prospectivity of State acreage release areas.

Products released 2015–16

Report 149 Characterization and correlation of lower Permian strata, Canning Basin, Western Australia, and implications for CO₂ sequestration

Paleontology Report 2016/1 F52428: Early Cretaceous ammonite (Oppeliidae: Aconecerasinae), Muderong Shale, Barrow Island F45M core

Record 2015/8 Detrital zircon geochronology of upper Ediacaran to lower Cambrian deposits (Supersequence 4), western Amadeus Basin: testing revised stratigraphic correlations

WEBB, WA Sheet SF 52-10 (2nd edition) 1:250 000 Geological Series Map

Petroleum prospectivity of state acreage release area T15-1/L15-2, L15-3 and L15-4, Northern Carnarvon Basin, Western Australia

Data package Petroleum state acreage release, September 2015

External publications — see Appendix B

Planned work program and products 2016–17

Regional geological, geophysical and petroleum geochemical studies for the Canning, Perth and Amadeus Basins will continue during 2016–17 and beyond.

Canning Basin — continuation of studies on the Ordovician Goldwyer, Nambeet, and Willara Formations; Devonian–Carboniferous Fairfield Group; Permian Liveringa Group; regional seismic interpretation of the southern Canning Basin and incorporating results from the study of new cores from industry-drilled wells in the

Canning Basin into regional projects such as:

- Permian palynology of the mid-Carboniferous – Permian
- field study of the Permian Liveringa Group and division of subsurface sections
- compilation of the Play Types and location of Play Fairways present in the Canning Basin
- completion of the Record on interpretation of the Canning Basin deep crustal seismic survey
- mid-Carboniferous – Permian palynostratigraphy, Canning Basin
- Devonian–Carboniferous Fairfield Group and Anderson Formation
- seismic interpretation of the Paleozoic in the southern Canning Basin
- structural interpretation for the northern Canning Basin.

Perth Basin — continuation of studies on biostratigraphy and tight petroleum systems, with an emphasis on hydrocarbon source potential including:

- completion of palynological data review for the Harvey region and expand to encompass all of the southern Perth Basin
- completion of seismic interpretation Record for the southern Perth Basin.

Carnarvon Basin — commencement of studies in the Southern Carnarvon Basin including:

- source-rock potential of the Triassic and Permian of the onshore and nearshore Carnarvon Basin
- stratigraphy and biostratigraphy of the Permian Byro Group.

Officer Basin — commencement of studies on the petroleum potential of the basin including:

- review of new well data with an emphasis on the petroleum potential of the Officer Basin.

Moora Basin — commencement of investigations into bitumen in cores, and biostratigraphy of the Moora Basin including:

- review of cores from Goonderoo 1 and 1A to investigate origin of bitumen described in fractures within the core
- obtaining new insights into the age of the very poorly dated Moora Basin.

Amadeus Basin — studies on stratigraphy, biostratigraphy, structure, and petroleum potential of the Amadeus Basin continue in collaboration with NTGS including:

- completion of documentation of field, drillcore and office-based studies of Neoproterozoic basins in Western Australia including stratigraphy, regional correlation and petroleum potential
- revised stratigraphy of the western Amadeus Basin
- cross-border collaboration with NTGS (including joint fieldwork) to facilitate better understanding of the evolution and resource potential of the Amadeus Basin will be completed.

Regional studies — studies include:

- increased information of petroleum prospectivity of State acreage release areas
- review of tight petroleum systems within the basins of Western Australia
- collaborative project with Curtin University to document the Mesozoic of Western Australia (book in Western Australia unearthed series)
- release of external publications related to many of the above topics — see Appendix B.

Products planned for release 2015–16

The Wallal Rift System: geology and petroleum potential (Record)

Stratigraphic field study of the Liveringa Group, Canning Basin (Record)

Regional structure and seismic interpretation of the early Paleozoic of the southern Canning Basin (Record)

Carranya Formation, Canning Basin (Record)

Revised geology of the Cobb Embayment, Canning Basin (Record)

Seismic interpretation of the southern Perth Basin (Record)

A review of palynology from the Harvey region, southern Perth Basin, Western Australia (Record)

Complete expanded extent and improved correlation of the Aralka Formation, Amadeus Basin (joint NTGS/GSWA Record)

Geological reconnaissance of the southern Murraba Basin, Western Australia: revised correlation to the Centralian Superbasin and petroleum prospectivity. Reconnaissance observations and new interpretation of Murraba Basin (Amadeus correlative) (Record)

Petroleum prospectivity of State Acreage Release Areas L16-1 and L16-2, Canning Basin, Western Australia

Paleozoic of Western Australia (book in Western Australia unearthed series)

Mesozoic of Western Australia (book in Western Australia unearthed series)

Paleontology Reports (ad hoc, as required)

GS12 Land Use Geoscience

Manager: Warren Ormsby

*Team members: Bob Gozzard, Charlotte Hall, Glennis Hall, Lisa Kirby,
Elias Peiris, Kevin Ridge, Colin Strickland*

Land Use Geoscience plays a key role in providing geological information, advice and approval to assist in government decision making related to the most appropriate use of land. The provision of relevant geological information to State and local government authorities, planners and the community contributes to Western Australia's economic sustainability and helps to ensure that the interests and rights of all parties are recognized.

Proposals for land subdivisions and other land use changes are routinely received from State and local government authorities. Each proposal is examined; its implications for access to mineral and energy resources are assessed, and recommendations or advice are made accordingly. The section has also played key roles in:

- undertaking assessments associated with the South West Native Title Settlement
- undertaking strategic assessment for the Perth–Peel region
- clarifying and streamlining administrative arrangements with other government agencies in consultation with other divisions within DMP.

The number of proposals received from other government agencies generally decreased in 2015–16, although there was a marked increase in those associated with the South West Native Title Settlement.

The Strategic Assessment project is a whole-of-government approach to avoiding and minimizing the impact on significant Commonwealth and State environmental matters balanced against the need for planning for future urban, industrial, infrastructure development and basic raw materials (BRM) extraction. The section has played a key role in ensuring that sufficient low-cost BRM will be available to facilitate the future growth of the Perth–Peel region in close collaboration with other government agencies, industry and other divisions within DMP. The draft Strategic Assessment document was published for public comment (as the Perth and Peel Green Growth Plan for 3.5 million people) on 17 December 2015. The comment period closed on 13 May 2016.

The proposed creation of new conservation reserves throughout Western Australia and the proposed upgrading of existing reserves continue to be significant land use issues affecting the resources industry. The section works

with government to minimize the impacts on access to strategic mineral and petroleum resources and associated (mining and petroleum) interests in the selection of proposed conservation initiatives associated with the Strategic Assessment project. The section also plays a key role within DMP.

Other roles for the Land Use Geoscience section include:

- providing geological input to other government activities such as mapping, and advice to support planning policies, strategies and schemes
- publishing resource potential for land use planning, mapping and developing associated land use planning policy to help inform other government agencies and the public of potential land use conflicts
- administering the Western Australian Register of Geoheritage Sites and Geoheritage Reserves.

Outcomes of work program 2015–16

The section produced the following outcomes:

- Additional funding continued to be provided for the South West Native Title Settlement project (Fig. 31). Further development was undertaken on a new computer-based system for improving the efficiency of the assessment process. The focus for this year was the extension of the 'screening' assessment process to a 'full' assessment system. The new 'full' assessment system integrates with a new land identification and referral system that has been developed by Landgate for the Department of Lands specifically for the South West Native Title Settlement project. One additional fee-for-service staff was contracted to facilitate the section's role in this project. Five 'full' assessments and 1537 'screening' assessments for potential land tenure changes were completed specifically for this project. These assessments are additional to the 858 referrals listed below in the 'products released' table.
- Regionally significant BRM mapping was completed and published for Albany and Esperance. This completes the base mapping for the high-growth coastal regions to assist in protecting significant BRM resources from being inadvertently developed for



Figure 31. South West Settlement project — location map

incompatible land uses. Much of the previous BRM mapping in the Mid West region was incorporated into the Sea to Scarp publication covering the northern Swan Coastal Plain. Work continued this year, in collaboration with the Department of Planning, on defining zones requiring BRM protection in high-growth areas throughout the State.

Products released 2015–16

Provision of information, advice and assessments in response to requests from other government agencies — 858 referrals dealt with

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2016 (map)

Albany, regionally significant BRM, resource potential for land use planning (map)

Esperance, regionally significant BRM, resource potential for land use planning (map)

Sea to scarp — geology for land use planning in the northern Swan Coastal Plain, Lancelin to Geraldton

Planned work program and products 2016–17

The section will continue to provide information, advice, and assessment in response to requests from other government agencies. The estimated number of referrals is expected to continue at similar levels to those experienced in 2015–16 (Fig. 32).

Additional funding will continue for the South West Native Title Settlement project to complete the development of the new computer-based system for improving the efficiency of the assessment process. One additional fee-for-service geologist will continue to be contracted to facilitate the section's role in this project. Other specialist contractors will be involved in associated software development. It is anticipated that there will be substantial land assessment 'screening' and approvals associated with the South West Native Title Settlement.

Further development of computer-based systems will take place to improve the efficiency of the assessment process for other aspects of the section.

The section will continue to contribute to the Strategic Assessment of the Perth–Peel region. Documentation for this project, which is being led by the Department of Premier and Cabinet, should be finalized.

A potential project is being scoped with Main Roads and local governments with the aim of assisting these agencies with the identification of suitable gravel resources for use in long-term road maintenance and construction.

Products planned for release 2016–17

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2017 (map)

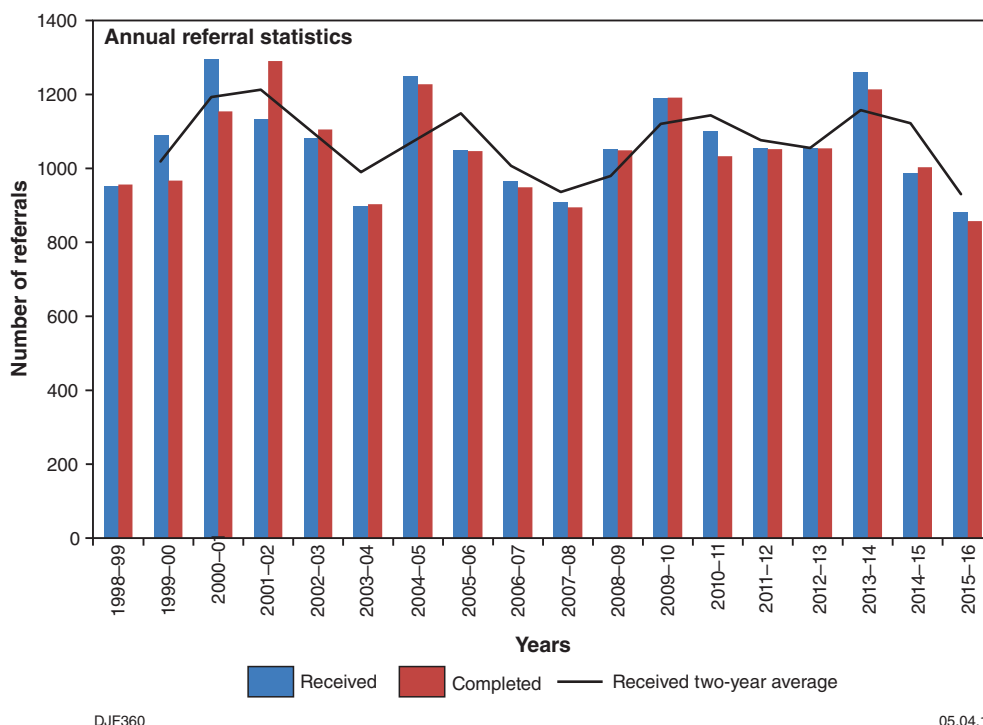


Figure 32. Land Use Geoscience section — annual referral statistics

GS14 Commodity and Industry Analysis

Manager: Lee Hassan

*Team members: Roger Cooper, Lyn Day, Mike Fetherston, Glennis Hall,
Amanda Jones, Jutta Pagel, Caroline Strong, Nicole Wyche*

The Commodity and Industry Analysis section provides statistics and expert analysis on all commodities in the areas of mineral exploration activity, mineral resources and reserves, and mining. Users of the section's outputs are other DMP groups, other government agencies, universities, industry, and the community at large. 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 DMP's website. The MINEDEX data, and products derived from it, are regarded as the point of truth for information on mines and deposits, their location, compilation of mineral resource estimates, and historical production data in Western Australia. The database is also used to produce annual or biannual updates of a number of maps and publications. MINEDEX data are spatially displayed in the TENGGRAPH and GeoVIEW.WA online systems, and on most maps produced by GSWA.

This section also has a regulatory role and is responsible for the assessment of Mineralization and Resource Reports submitted in support of Mining Lease applications. The section is also responsible for providing Mining Act advice on expenditure exemptions/extensions of term, retention licences/retention status, combined reporting, and reports on Special Prospecting Licences (SPL) for the Warden's Court.

Outcomes of work program 2015–16

Significant routine work during 2015–16 included maintenance of systems and content comprising the MINEDEX database, including auditing of all mines, deposits, and prospects shown on four 1:100 000-scale Geological Series maps, three 1:250 000-scale Geological Series maps and the non-series Youanmi Layered Intrusions map. This audit work removed duplicate sites, revised coordinates, and updated mineralization styles. Data from 336 Mining Proposals, 159 Annual Environmental Reviews, 44 Extractive Industry Licence applications and 97 Resources Safety notifications of

commencement/suspension of mining or changes of operator were entered into MINEDEX during the year. In addition, 1998 new mineral resource estimates and 1115 site production records (both confidential and public) were entered into the database. New versions of MINEDEX featuring expanded search functionality were released on 28 October 2015 and 4 May 2016.

Regulatory duties included assessment of 75 Mineralisation and Resource Reports during the year, which were lodged under Sections 74 and 74A of the *Mining Act 1978* in support of Mining Lease applications, assessment of 802 applications for expenditure exemptions/extensions of term, 105 applications for retention licences or retention status, 91 applications for combined reporting, and 35 applications for Special Prospecting Licences. In addition, 28 Sterilisation Reports for in-pit waste/tailings disposal proposals were assessed.

The section also updated a number of standard map and digital products throughout the year including:

- Mines — operating and under development, Western Australia — 2016 (map)
- Major resource projects, Western Australia — 2016 (map)
- Iron ore deposits of the Yilgarn Craton 2016 (map)
- significant exploration activity in Western Australia ('hotspots' map)
- investment opportunity flyers — Au, Cu, U (updates) and new lithium and phosphate flyers.

A new map of 'Manganese deposits of the Pilbara and Capricorn regions — 2016' was released and a related digital product will be released early in the next financial year.

The second edition of the *Gemstones of Western Australia*, Mineral Resources Bulletin 25 is in the final stages of editing and will be released early in the next financial year.

Products planned for release 2015–16	Current status
Major resource projects, Western Australia — 2016 (map)	Released
Mines — operating and under development, Western Australia — 2016 (map)	Released
Iron ore deposits of the Yilgarn Craton, 2016 (map)	Released
Significant exploration activity in Western Australia ('hotspots' map update)	Released
Manganese deposits of the Pilbara and Capricorn regions — 2016 (map and digital product)	Map released; digital product in final stages of editing
Investment opportunity flyers — potash and phosphorous	New Li* and Phosphate flyers released; also updates for Au, Cu, U and Fe flyers; potash flyer in progress
Mineral Resources Bulletin 25 Gemstones of Western Australia second edition	In final stages of editing

* This item was not listed as a planned product in the 2015–16 work program as the need for this product was not foreseen at the time the 2015–16 work program was prepared

Planned work program and products 2016–17

Recurrent MINEDEX maintenance and regulatory activities will continue throughout 2016–17. MINEDEX-related work will include entry of new sites from Mining Proposals, Mineralisation and Resource Reports, and published announcements as well as auditing of mines, deposits, and prospects for those 1:100 000-scale Geological Series maps and other maps being prepared for publication during the year.

Regular map products will be updated (Mines — operating and under development, Western Australia; Major resource projects, Western Australia; Iron ore deposits of the Pilbara Craton; and Western Australian mineral deposits and petroleum fields), as will existing commodity investment flyers — on an ad hoc basis. A new commodity flyer for potash is also planned.

Ongoing regulatory activities will include the assessment of Mineralisation and Resource Reports submitted in support of Mining Lease applications, assessment of 'sterilisation reports' connected with Mining Proposals for in-pit disposal of mine tailings, providing Mining Act advice on expenditure exemptions/extensions of term, Retention Licences, retention status and combined reporting, and reports to the Warden on SPL applications.

Products planned for release 2016–17

Major resource projects, Western Australia — 2017 (map)
Mines — operating and under development, Western Australia — 2017 (map)
Iron ore deposits of the Yilgarn Craton, 2017 (map)
Significant exploration activity in Western Australia ('hotspots' map update)
Mineral Resources Bulletin 25 Gemstones of Western Australia second edition
Investment opportunity flyer — potash; updates to other flyers if warranted
Western Australia atlas of mineral deposits and petroleum fields 2017
Western Australia mineral deposits and petroleum fields — 2017 (map)

Planned work program, products 2017–18 and beyond

Routine updating of databases and regulatory work will continue, as will updates of many of the core products.

The section will work with the Minerals Systems Studies section to capture geological information and mineralization attributes for significant mineral deposits in Western Australia.

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

Team members: Lauren Burley, Paul Duuring, Joshua Guillianse, Lena Hancock, Lee Hassan (GSWA Affiliate), Sidy Morin-Ka, Franco Pirajno (Emeritus), Lisa Roche

The Mineral Systems Studies section focuses on mineral systems in Western Australia, with the objectives of building metallogenic models and improving our understanding of the geodynamic environment of ore formation, thereby assisting with making exploration targeting in greenfields areas more predictive. Such work typically involves both fieldwork (mapping, core logging, sampling) and laboratory studies (petrology, geochronology, isotope chemistry), and is supported by and supplements existing databases. The section makes extensive use of the GSWA HyLogger (Project GS95) to assist with detailed studies of alteration assemblages in diamond drillcore and other specimens from mineral deposits. The work of this section is complemented by projects funded by the EIS, and reported herein under ES43 Mineral Systems Atlas.

All mineral systems knowledge is ultimately made available for the benefit of resource companies, research groups, other government agencies, and the wider community. This knowledge is disseminated via GIS packages, and internal and external publications.

Four young, talented geologists were recruited to the Mineral Systems Section between 2011 and 2014 to carry out research on mineral systems in Western Australia under the auspices of the GSWA Geology Masters (GeM) program. This program provides Geology Honours graduates early professional development via completion of a Master's degree through the Centre for Exploration Targeting (CET) at UWA. All four have now successfully completed their Master's degrees. Dr Paul Duuring was recruited as Senior Geologist to the section in early 2016, to expand the capacity for, and scope of, individual and team-based mineral systems studies, and to assist with the continuing professional development of less-experienced team members.

Dr Franco Pirajno (now retired from GSWA) is retained by the Mineral Systems Studies section on a casual, fee-for-service basis to provide technical expertise and coaching to the section.

Outcomes of work program 2015–16

The Mineral Systems Studies section continued its studies of volcanogenic massive sulphide (VMS), rare

earth element (REE), gold, nickel and iron ore deposits. These studies focus on determining characteristics of the geological setting, mineralization and associated alteration that inform metallogenetic interpretations, and also provide useful tools for targeting mineral deposits at all scales, thereby reducing for resource companies the technical risk of discovery.

VMS systems

Studies continued of variably deformed and metamorphosed VMS deposits at Wheatley and Manindi, in the South West Terrane and Murchison Province, respectively. A particular aim of the current work is to test exploration tools developed in previously completed projects.

The EIS-funded study of the VMS fertility of Yilgarn volcano-sedimentary successions was completed in late 2015. The GSWA Report on Phase 1 of an analysis by a CSIRO-embedded researcher has been peer reviewed and will be published in early 2016–17. These results have also been published in the journal, *Precambrian Research*. The final Report and several journal papers are also being prepared for Phase 2 studies on the lithogeochemistry and geochronology of a number of under-represented terranes (see the work program for Project ES43).

Past and present GSWA staff also co-authored several journal articles published in 2015–16, on aspects of now-completed studies of VMS mineralization at the Quinns deposit in Youanmi Terrane (Yilgarn Craton), and the Abra and DeGrussa deposits in the Capricorn Orogen.

REE systems

Geological and metallogenic studies continued on several Western Australian rare earth element (REE) systems. Sidy Morin-Ka is preparing a GSWA Report based on his Master of Economic Geology dissertation, which describes development of a technique for directly detecting and distinguishing REE using hyperspectral technologies, using Mt Weld, Gifford Creek, and Browns Range as case studies. The section is investigating the poorly understood hydrothermal, vein-and-breccia-hosted heavy REE mineralization in the East Kimberley and north Tanami regions. An industry collaborative study of the age and alteration of the hydrothermal, heavy REE-dominated Browns Range deposits has been completed, and the first

results were released in an extended abstract at GSWA's 2016 Open Day. A GSWA Report is being prepared describing the full details of the study. The section is studying the hydrothermal heavy REE mineralization in the East Kimberley region. The age of mineralization event at John Galt deposit has been determined, and some other physical and chemical constraints are being obtained from fluid inclusions and alteration studies.

Gold systems

Lisa Roche published GSWA Report 155 describing the results of her Master of Economic Geology study of the Glenburgh deposit in the Gascoyne Province, and is co-authoring several external publications incorporating this work. She has turned her attention to examining the metallogeny of the Paterson Orogen, using material available in the GSWA sample archive, obtained by collaborations with companies active in the region. Samples have been collected from core obtained by the EIS Co-funded Exploration Drilling program, for geochronological and petrochemical analyses of buried basement rocks in the northern part of the Orogen, that are associated with significant newly discovered copper-gold mineralization.

Lena Hancock and CSIRO staff completed the predominantly EIS-funded collaborative study of the 3D architecture of the mantle-tapping Nanjilgardy Fault, and the gold mineralization and associated alteration spatially related to it (including at Paulsens and Mount Olympus, both of which are close to splays from the fault). The final Report was released in early 2016 as GSWA Report 156, and an extended abstract and presentation were delivered at GSWA's Open Day 2016.

Lena Hancock, with GSWA and resource company colleagues, also completed a government–industry collaborative research project to constrain the physical and chemical conditions during mineralization at the mesothermal, orogenic-lode style Paulsens gold deposit, using geochronology, and mineralogy, composition and distribution of gold, and associated alteration. The final report was confidential until late 2015, but will be released to the public as a GSWA Report in early 2016–17.

The Mineral Systems Studies section initiated a government–industry collaborative project to determine the prospectivity of regions for primary hypogene gold mineralization using the morphological and geochemical features of 'alluvial' gold nuggets, and their 'regolith-stratigraphic' settings. The initial pilot study of the Kurnalpi goldfield includes collaboration with the gold forensic group at TSW Analytical to develop an analytical technique for obtaining quantitative geochemical data using laser-ablation inductively coupled mass spectrometers (LA-ICP-MS). This is the first systematic study of its type in Western Australia; results will eventually inform gold prospectivity assessments for other Western Australian metallogenic terranes.

Josh Guiliamse commenced a systematic study of gold deposits in the Ashburton Basin, beginning at Mt Clement with a review of historical exploration data, geological

logging and sampling of drillcore archived by GSWA, and petrographic and geochemical analysis of those samples. This work will contribute to a much larger, ongoing collaborative investigation of the architecture and metallogeny of the Capricorn Orogen being done under the banner of the National 'UNCOVER' initiative.

Nickel systems

Lauren Burley successfully completed her Master of Economic Geology study of the Fisher East komatiite-hosted nickel mineralization, in the northeastern Yilgarn Craton. She is preparing her dissertation for publication as a GSWA Report, but delivered significant results in an extended abstract and presentation at GSWA's Open Day in February 2016.

Lauren is now developing collaborative projects with CSIRO to understand (i) the tectono-stratigraphic evolution and nickel prospectivity of the Kurnalpi and Burtville Terranes of the eastern Yilgarn; and (ii) the geochemical fertility of mafic volcano-plutonic rocks of the Warakurna Large Igneous Province for Ni–Cu–PGE mineralization.

Iron systems

Government–industry collaborative metallogenic studies of BIF-hosted iron ore systems in the Yilgarn and Pilbara Cratons were recently completed by CET at UWA, as part of Project ES43. Project leader Paul Duuring subsequently joined GSWA's Mineral Systems Studies section in early 2016 as Senior Geologist, and is preparing for publication a series of GSWA Reports and Records, and journal papers documenting the work (listed in the ES43 work program). Paul is now extending this work with a program to obtain independent verification of previously obtained c. 2700 Ma ages for hydrothermal iron mineralization at selected deposits in the Yilgarn Craton. He has prepared separates of hydrothermal iron oxide minerals from iron deposits in the Weld Range, for geochronological analysis at the John de Laeter Centre, Curtin University.

Other activities

The Mineral Systems Studies section continued with the compilation of published mineral deposit age data for Western Australia. Such data will be included in an improved MINEDEX database, which itself will inform a future Mineral Systems Explanatory Notes System, and the development of a Mineral Systems Atlas.

The section continued to manage or monitor a number of other minerals-oriented research initiatives funded by GSWA's EIS (refer to the work programs for Projects ES43 and ES50).

Several members of the section are co-authoring papers on the Fisher East nickel deposits (Burley), Waroonga (Agnew) gold deposit (Beardsmore), Yilgarn and Pilbara iron deposits (Duuring), and the metallogeny of the Paterson Orogen (Beardsmore), that will be included in the 'Australian Ore Deposits' monograph to be published by the Australasian Institute of Mining and Metallurgy.

In a significant new initiative, the section has commenced a systematic program to validate and supplement analyses of significant mineral systems in Western Australia, with the aim of defining ‘mappable proxies’ for critical metallogenic processes, then creating statewide, digital ‘proxy layers’ derived from existing and enhanced or newly created datasets, that can then underpin GIS-based mineral prospectivity studies. The ‘proxy layers’ would be delivered via an interactive, digital Mineral Systems Atlas developed by GSWA.

Products released 2015–16	Current status
Report 155 Geological setting and nature of gold mineralization and associated alteration at the Glenburgh deposit, Gascoyne Province (based on MEconGeol dissertation)	Published
Report 156 Integrated spectral mapping of precious and base metal-related mineral footprints, Nanjilgardy Fault, Western Australia (jointly published with CSIRO; significantly funded via EIS Project ES43)	Published
Record 2016/1, p. 8–11, Extended Abstract The geology of the Fisher East komatiite-hosted nickel sulfide prospects	Published
Record 2016/2, p. 21–25, Extended Abstract Alteration and age of the Browns Range heavy rare earth elements deposits	Published
Record 2016/2, p. 26–30, Extended Abstract Integrated spectral mapping of precious and base metal-related mineral footprints, Nanjilgardy Fault, Western Australia	Published
Geological setting and nature of nickel mineralization at Fisher East, NE Yilgarn Craton (provisional title; based on MEconGeol dissertation) (Report)	In peer review
Detection and distinction of rare earth elements using hyperspectral technologies (based on MEconGeol dissertation) (Report)	In preparation
Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (funded via EIS Project ES43) (Report and series of external publications)	In preparation
The geology, tectonic evolution and gold mineralization of the Lawlers region: A synopsis of present knowledge (authorized release of Company Technical Report) (Report)	In preparation
External publications — see Appendix B	

Planned work program and products 2016–17

The Mineral Systems Studies section will continue its studies of selected mineral systems and deposits. Outstanding reports from recent projects will be completed and published, including those describing:

- detection and distinction of rare earth elements using hyperspectral technologies
- age and alteration at the Browns Range hydrothermal vein-and-breccia-hosted heavy REE deposits
- the age of heavy REE mineralization at John Galt, East Kimberley

- nickel sulfide mineralization at Fisher East, northeastern Yilgarn
- metallogeny of Archean BIF-hosted iron ore in the Yilgarn Craton (several Reports, Records and external publications)
- age and mineralogical characteristics of gold mineralization and alteration at the Paulsens deposit.

Work in 2016–17 on VMS systems will involve further field and laboratory studies of the geological settings and metallogeny of deposits at Wheatley and the Manindi camp. In particular, representative diamond drillcore is being acquired from a deposit in the Manindi camp, for logging, sampling, and hyperspectral scanning using the GSWA’s HyLogger-3, to test mineral vectors developed in studies of VMS mineralization at Golden Grove and Weld Range (see GSWA Report 141).

Ongoing studies of REE systems will include fluid inclusion and alteration studies for the John Galt deposit, to place constraints on the physical and chemical condition of mineralization. New government–industry collaborative projects are to be developed for other REE deposit types in Western Australia.

The collaborative pilot study of gold prospectivity for the Kurnalpi region using gold nugget morphology, geochemistry and regolith setting will be completed during 2016–17, and a GSWA Report prepared. Some results from this and similar, previously completed, studies will be presented in August at the 35th International Geological Convention in Cape Town, South Africa. Mineral Systems Studies staff will co-author a publication describing the newly developed methodology for quantitative trace-element analysis of gold grains. This type of study will be expanded to other districts and terranes, pending negotiation of projects and sourcing of suitable sample material.

Studies of gold metallogeny in the Ashburton Basin will continue in the first instance with targeted field mapping and selective logging and sampling of extra drillcore from the Mt Clement deposit, reconnaissance sampling from other deposits in the region, and further laboratory analyses of samples.

Continuing metallogenic analysis of the Paterson Orogen will include targeted, field-based logging and sampling of drillcore from significant domains, arranged where necessary via newly developed government–industry collaborative projects.

The Mineral Systems Studies section will extend the study of nickel prospectivity of the eastern Yilgarn Craton by prosecuting a program of systematic, regional-scale sampling of lithostratigraphy and selected komatiite-hosted nickel sulfide systems adjacent to the boundaries between Kurnalpi and Burtville — and perhaps the Yamarna — Terranes, as an integral part of a larger collaborative project with CSIRO and UWA research staff. The study of Cu–Ni–PGE prospectivity of mafic large igneous provinces (LIP) in the Capricorn Orogen will, in

2016–17, comprise a short program of targeted mapping and sampling of mafic intrusive rocks in the Edmund and Collier Basins, then petrological and lithogeochemical analyses.

The section will obtain the first independently verified ages for hydrothermal iron ore mineralization in the Weld Range by direct dating of iron-oxide minerals, and concurrently initiate a collaborative, GSWA–MRIWA–Industry-funded project to develop matrix-matched standards for geochronological analyses of hydrothermal iron oxides.

‘Big picture’ projects will also continue, with the methodical analysis of significant mineral systems in Western Australia. The Mineral Systems Studies section will define and create ‘mappable proxies’ for critical metallogenic processes that can underpin GIS-based mineral prospectivity studies, and will take the lead in developing an interactive, digital Mineral Systems Atlas for delivery of the ‘proxy’ datasets.

During this coming year, GSWA will begin developing the in-house knowledge and technological capacity to undertake multiscale prospectivity studies. Staff from the Mineral Systems Studies section, the Mapping section, and the GIS section will initially attend a series of training workshops provided by UWA–CET staff that have been undertaking such studies.

The Mineral Systems Studies section will continue to manage or monitor — and where relevant be involved with — minerals-oriented research initiatives being funded by GSWA’s EIS (Project ES43).

Preliminary development work will begin on a Mineral Deposit Explanatory Notes System.

Products planned for release 2016–17

Detection and distinction of rare earth elements using hyperspectral technologies (based on MEconGeol dissertation) (Report)

Exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia (co-branded publication of final report for MRIWA Project M426; jointly with EIS Project ES43) (Report)

Geological setting and nature of nickel mineralization at Fisher East, NE Yilgarn Craton (provisional title; based on MEconGeol dissertation) (Report)

Products planned for release 2016–17

Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (funded via EIS Project ES43) (Report and series of external publications)

Alteration and age of the Browns Range heavy rare earth elements deposits (provisional title) (Report)

The geology, tectonic evolution and gold mineralization of the Lawlers region: A synopsis of present knowledge (authorized release of Company Technical Report) (Report)

Provenance fingerprinting of gold from the Kurnalpi Goldfield (provisional title) (Report)

Mineralogy and chemistry of lode and alluvial gold from the Paulsens and Mount Olympus gold deposits, northern Capricorn Orogen, Western Australia (Record)

The age of rare earth element mineralization at the John Galt prospect, East Kimberley (provisional title) (Record)

Results of fluid inclusion analysis of samples from the John Galt REE prospect, East Kimberley (provisional title) (Record)

GSWA Open Day 2017 extended abstract(s) (to be determined)

Nine external publications — see Appendix B

Planned work program, products 2017–18 and beyond

The Mineral Systems Studies section will continue its studies of significant Western Australian mineral systems. This work will be done in close collaboration with GSWA’s regional mapping sections, and as appropriate with CSIRO, UWA, Curtin University, University of Tasmania, GA and other academic institutions, and an expanding network of affiliated exploration and mining companies. The section will continue to engage with collaborative Mineral Systems-oriented research projects funded by the EIS.

The section will continue to lead the development of mappable Mineral System ‘proxies’, and a digital Mineral Systems Atlas to deliver these products, drawing upon other in-house and external expertise where required. Future products may include targeted prospectivity studies.

GS43 Geochemistry and Regolith

Manager: Paul Morris

Team member: Nadir de Souza Kovacs

Geochemical data and regolith mapping are found in the majority of GSWA's regional mapping products, as well as contributing to geoscience programs in Mineral Systems and Basins and Energy Geoscience. In addition, both make up GSWA's regional regolith geochemistry programs, where regolith geochemistry is interpreted in terms of bedrock composition and regolith–landform mapping. Factors that have emphasized the increasing importance of both disciplines include a national approach to better understand the composition, nature and thickness of cover, and how lithogeochemistry contributes to mineral systems analysis.

In order to ensure that GSWA's geochemistry and regolith mapping is widely applicable, standardized approaches have been adopted. Thus, regolith mapping is carried out using a single regolith–landform classification scheme, which is scale independent and applicable throughout the diverse geological terrains that characterize the State. Interpretative regolith mapping follows a process of integrating geophysical and remotely sensed data, orthophotos, existing geological mapping, and point observations from GSWA's WAROX database. Similarly, the acquisition of geochemical data follows common procedures, although flexibility exists to tailor acquisition according to sample media and program needs. Data are acquired with sufficient quality control samples and metadata for stakeholders to determine whether data are fit for purpose, thus ensuring a high level of transparency. All chemical analyses of GSWA samples are stored in the WACHEM corporate database, and following linking to metadata in WAROX, are made available in GSWA's GeoVIEW.WA mapping application, or through the web-enabled download application GeoChemExtract.

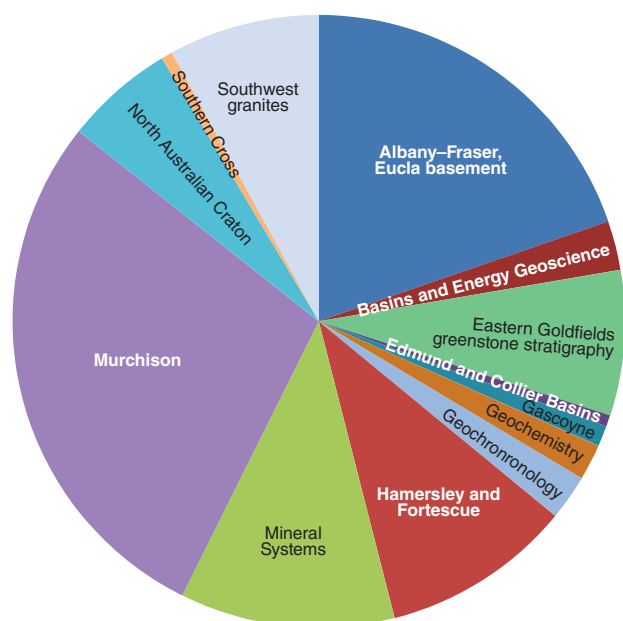
Lithogeochemical data are commonly acquired using X-ray fluorescence (XRF) and solution-based inductively coupled plasma (ICP) analysis, although capabilities can extend to partial digestion approaches for specific studies. In 2016–17, more use has been made of coupled XRF and laser ablation ICP analysis, which is capable of producing lower levels of detection for a wide range of trace elements, and avoids issues with digestion of resistant mineral phases that can occur for solution-based ICP. An addition provided by this approach is the generation of Pb isotope data, which has potential as a regional mapping tool. A standard part of GSWA geochemical programs is the routine analysis of sample duplicates, reference materials and blanks. In 2015–16, 1004 rock samples were processed and analysed, an increase of

40% on the previous financial year. The breakdown according to groups or projects (Fig. 33) shows that the majority of analyses were generated from the Albany–Fraser – Eucla Basin program (approximately 20% of all analyses) and the Murchison program (almost 30% of analyses). The inception of three new programs this financial year (Hamersley – Fortescue, eastern Goldfields stratigraphy, and southwest granite assessment) is reflected in 25% of data acquired. This growth in lithogeochemical data reflects several factors: the demonstration that comprehensive, high-quality geochemical data can provide valuable insight into evaluation of tectonic setting, stratigraphy, and mineralization potential; the improving quality of geochemical data in terms of the increased levels of precision and accuracy especially at low concentration levels; the shortening of turnaround times; and the affordability of geochemical analysis.

Storing and making data available in a controlled format, as well as ensuring that data quality can be independently assessed is arguably as important as data acquisition itself. The WACHEM database stores not only analyses of rocks and regolith, but also associated QAQC data, available in formats that allow assessment of analytical batches and include information on techniques and method of sample preparation. In the 2015–16 financial year to May, the WACHEM database contained in excess of 53 600 analyses (an increase of 6% on the previous financial year), which included almost 5800 analyses of reference materials and approximately 1700 analyses of sample duplicates.

Geochemical data can benefit from improvements and developments in analytical technology, and these are monitored to ensure that GSWA's geochemical relevance continues to grow in a fiscally responsible and accountable manner. The introduction of field-portable X-ray fluorescence (pXRF) analysers into GSWA in 2009 has seen them integrated into several programs, with in excess of 40 staff trained in their use and capabilities. Advances made in the use of hand-held laser-induced breakdown spectroscopy (LIBS) will offer wider access to the periodic table than pXRF, at enhanced levels of detection. It has potential for application in a wide variety of GSWA projects.

Technological improvements have advanced the dating of regolith, and can provide insight into the absolute timing of regolith-forming events and the formation rates of mineralization-related alteration. The dating



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Figure 33. Breakdown of geochemical analyses according to groups or projects

On some map sheets, regolith can make up more than 90% by area. An ongoing component of work within the Geochemistry and Regolith section is the advice given and mentoring of geoscientists on the compilation of interpretive regolith–landform maps, and the assessment of final compilations. The diversity of geological terranes that the State embraces means revisions to the regolith classification scheme are made where necessary.

Planned work program and products 2016–17

Work program planning includes ongoing evaluation of new analytical techniques, including both laboratory-based and portable techniques.

of regolith can also provide a better understanding of landscape evolution. As part of the relationship with Curtin University, GSWA is investigating the dating of ferruginous and aluminous duricrust using such techniques as (U–Th)/He, and opportunities for establishing facilities for the dating of regolith using optically stimulated luminescence (OSL).

GS45 Pilbara Craton

Manager: Arthur Hickman

Team: GSWA staff as required

Formed between 3800 and 2830 Ma, the Pilbara Craton provides Australia's best preserved geological record of Eoarchean to Mesoarchean crustal evolution, and contains several of the world's oldest mineral deposits. Paleoarchean rocks of the east Pilbara Craton preserve the oldest fossilized remains of life on Earth, and also some of the oldest evidence of asteroid impacts.

Underlying approximately 400 000 km² of northwestern Australia, the Pilbara Craton is composed of metamorphosed volcanic, sedimentary, and igneous rocks containing important gold, iron ore, and copper mineralization. Additionally, the Pilbara is well known for its economically important pegmatite mineralization, most of which is concentrated around the margins of 2850 to 2830 Ma monzogranites. Tin and tantalum have been mined from these pegmatites for more than 50 years but currently they are being more actively explored for lithium. Iron ore, gold, manganese, lead, silver, and uranium mineralization is contained in Neoarchean–Proterozoic volcanic and sedimentary successions (Fortescue, Hamersley, Turee Creek, and younger basins) that unconformably overlie the craton.

The Pilbara mapping project was successful in providing information on the processes involved in the geological evolution of the exposed northern half of the craton. Shortly before the project commenced in 1995, there was no consensus within the geoscientific community on how the craton had been formed. To resolve this issue, the entire northern half of the craton was remapped with the aid of new airborne magnetic and radiometric surveys. Additionally, the geological events governing its crustal evolution were dated using zircon U–Pb and Lu–Hf geochronology. Results of the mapping provided the basis for the release of a revised interpretation of the stratigraphy, structure, crustal evolution, and mineralization of the northern half of the craton.

Evidence from the project confirmed a previous interpretation by several geoscientists that the oldest volcanic and sedimentary rocks of the east Pilbara ('greenstone' succession), now known to be 3530 to 3235 Ma in age, were deposited on older continental crust. A previous conflicting interpretation had been that the succession was deposited in oceanic settings. This clarification is significant for understanding the mineralization of the eastern part of the Pilbara Craton. A second important finding was that the crustal evolution of the craton changed at c. 3200 Ma, when long-term

continental volcanism was abruptly replaced by rifting, continental breakup, and the beginning of plate-tectonic processes. This fundamental change had a profound effect on mineralization processes, and is now important for mineral exploration targeting. Only the northwest Pilbara, which is largely post-3200 Ma, contains mineralization formed by plate-tectonic processes, and it is these processes that have produced the area's largest mineral deposits.

Work is currently focused on completion of a detailed geological Report on the east Pilbara and on completing the ENS database for the Pilbara.

Outcomes of work program 2015–16

The section expects to release a new 1:250 000 interpreted bedrock geology (IBG) map followed by an update of the 1:100 000 geological mapping across the east Pilbara. This new east Pilbara 1:250 000 IBG layer was combined with a previously released west Pilbara 1:250 000 IBG interpretation to generate complete digital 1:500 000 IBG coverage for the northern half of the craton. A geological Report on the Paleoarchean–Mesoarchean geology of the northwest Pilbara was released and a similar Report on the east Pilbara was commenced. Many additions were made to the ENS database and a number of journal and conference publications were released.

Products released 2015–16

East Pilbara 1:250 000 IBG (map and reference on three plates)

Report 160 Northwestern Pilbara Craton

Three external publications — see Appendix B

Planned work program and products 2016–17

A GSWA Report on the Eoarchean–Mesoarchean geology of the east Pilbara Craton will be completed and released. Further contributions will be made, as required, to the special volume 'Archean, building the core of a continent' (Western Australia unearthed series). A GSWA Record based on GSWA Hf data from the Mount Edgar Dome will be released. Additional entries will be made to the

ENS database, and journal papers based on Pilbara data will result from collaboration with a number of external workers.

Products planned for release 2016–17

East Pilbara Craton: 900 million years in the growth of an Archean supercontinent (Report 143)

Contribution to the GSWA Archean special volume in the 'Western Australia unearthed' series

Hf insights from the Mount Edgar Dome (Record)

Two external publications — see Appendix B

Planned work program and products beyond 2017

Work beyond 2016–17 will involve completion of the Pilbara component of the ENS database and release of the digitally generated Explanatory Notes.

GS47 Gascoyne Province

Manager: Simon Johnson

The Paleoproterozoic to Neoproterozoic Gascoyne Province is the deformed, medium- to high-grade metamorphic core of the Capricorn Orogen. It contains subeconomic deposits of gold, lead, copper, barite, uranium, rare earth elements, muscovite, beryl, tantalum, tungsten, graphite and semiprecious gemstones. The Gascoyne Province has been affected by at least five tectono-thermal events, and displays an extended, episodic history of intracontinental reworking and reactivation until the end of the Neoproterozoic. Reactivation of major structures during the Mesoproterozoic and Neoproterozoic has controlled the formation and deformation of the overlying Edmund and Collier Basins, and might also have provided pathways for mineralizing fluids. An understanding of the province is essential for interpreting the evolution of the Capricorn Orogen, and the formation of large-scale structures that have controlled mineralization along the northern margin of the Yilgarn Craton and the southern margin of the Pilbara Craton.

The Gascoyne Province was first systematically mapped by GSWA in the 1970s. Products from this program include 1:250 000-scale maps and Explanatory Notes, along with two Reports, one on the geology of the province, and another on the Rb–Sr geochronology of the province. Modern aeromagnetic and radiometric data at 400 or 500 m line spacing cover the whole province, and SHRIMP U–Pb zircon geochronology is available for much of the province. Recent orthophotography is now available for much of the province. An MT survey across the Gascoyne Province was conducted in 2007, and a deep crustal seismic survey and accompanying MT survey were completed in 2010–11.

Important advances have been made in our understanding of the Gascoyne Province in the last few years, but there are some major questions yet to be resolved. First, the Gascoyne Province records a protracted (more than 1 Ga) and complicated history of intracontinental reworking and reactivation, but the precise extent of individual events and their causes remains enigmatic. Second, the aerial extent, depositional age and tectonic setting for the precursors to the Leake Spring Metamorphics (formerly Morrissey Metamorphics), which were deposited before the Capricorn Orogeny, are yet to be firmly established. Third, there are virtually no direct ages on any of the mineralization styles in the province, so the relationship

between mineralization and the various orogenic events is uncertain. Finally, the nature of the boundary between the Gascoyne Province and the upper Wyloo Group to the north (in particular, the Ashburton Formation) is not well established.

Outcomes of work program 2015–16

Personnel issues have affected the work program during 2015–16, with the manager having spent more than six months acting in the Chief Geoscientist position (GS53). However, a limited amount of time has been spent mapping Gascoyne Province rocks on the UAROO 1:100 000 Geological Series map sheet, mostly in conjunction with members of the Edmund and Collier Basins mapping section (GS49). An external publication outlining the role of crustal differentiation and heat production across the province was released in *Earth and Planetary Science Letters*.

Collaboration with Professor Birger Rasmussen at Curtin University has continued, both under the EIS and an ARC Linkage grant culminating in a publication called ‘Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: Constructing a geological framework for understanding mineral systems’. This work has already resulted in defining the timing of gold mineralization at the high-grade Glenburgh deposit in the southern part of the Gascoyne Province as well as the timing of gold mineralization at the Paulsens mine in the northern Capricorn Orogen. Results of both these studies have been submitted to international journals for publication.

A significant proportion of time was spent supervising and liaising with PhD students on the ARC Linkage grant as well as providing advice and working closely with various researchers in the UNCOVER Australia: Capricorn Distal Footprints project.

Products released 2015–16

One external publication — see Appendix B

Planned work program and products 2016–17

Most of 2016–17 will be focused on the collaborative ARC Linkage project work with Professor Birger Rasmussen. Although ARC funding will cease midway through the financial year, the PhD projects are not scheduled for completion until the end of the 2017–18 financial year. Work will focus on defining the timing of sediment deposition across the southern Pilbara region and the timing of low-grade deformation and gold and base metal mineralization. An external publication outlining the timing of gold mineralization at the Paulsens mine has been submitted to an international journal.

Work during 2016–17 will also concentrate on completing and publishing the UAROO 1:100 000 Geological Series map sheet and associated Explanatory Notes. This map will be the last series map to be published under the Gascoyne Province project. Several Reports are proposed for publication.

Products planned for release 2016–17

UAROO 1:100 000 Geological Series map

Update of the Western Capricorn Geological Information Series 2016 (including ILGARARI* and LOFTY RANGE* 1:100 000 Geological Series maps; digital product), including updated digital Explanatory Notes for the Gascoyne Province, and new units consisting of the Wyloo*, Shingle Creek* and Turee Creek Groups*

Western Capricorn Explanatory Notes update: UAROO (for inclusion in digital product)

The oxygen and hafnium isotopic evolution of the Moorarie and Durlacher Supersuites: contrasts in magma source and emplacement styles (Report)

Modelling the thermal history of the Gascoyne Province through the Mangaroon Orogeny and Mutherbukin Tectonic Event (Report)

* EIS product

Planned work program, products 2017–18 and beyond

Work in the 2017–18 financial year will be related to the finalization of PhD projects associated with the ARC Linkage project with Professor Birger Rasmussen at Curtin University. This will result in the publication of at least two Reports and associated external publications. A final update of the Western Capricorn Geological Information Series will be released in late 2017.

Products planned for release 2017–18

Update of the Western Capricorn Geological Information Series 2017 (including UAROO and WONYULGUNNA 1:100 000 Geological Series map; digital product)

Constraining the timing of deformation in the Ashburton Basin and deposition in the Blair Basin* (Report)

The timing and setting of mineral deposits in the southern Pilbara region* (Report)

* EIS product

GS49 Edmund and Collier Basins and Eastern Capricorn Basins

Manager: Huntly Cutten

Team member: Olga Blay

From July 2016, with the completion of 1:100 000-scale mapping of the Edmund and Collier Basins, the GS49 project will begin transition into the Eastern Capricorn Basins which include the Bryah, Earahedy, Padbury and Yerrida Basins. The tectonic settings of these basins are still poorly understood but are thought to have developed in a variety of settings associated with rifting, accretion, and passive-margin tectonism along the northern margin of the Yilgarn Craton. The age of the basins is very poorly constrained; the basins appear to have developed between c. 2200 and 1800 Ma and were deformed and metamorphosed at low metamorphic grade during the 1820–1770 Ma Capricorn Orogeny. Based on the known stratigraphy, stacking of all the Proterozoic supracrustal units present in the eastern Capricorn Orogen, gives a maximum cumulative thickness of about 20 km. These basins contain a significant endowment of VMS-hosted and epithermal base metal deposits, forming one of the largest copper provinces of Australia, including world-class Besshi-type VHMS-base metal mineralization at the DeGrussa Cu–Au–Ag deposit in the Bryah Basin. Most of the Eastern Capricorn Basins were mapped and published as printed maps just over a decade ago at 1:100 000 scale, preceding the current development of seamless digital coverage. The project will produce seamless geological digital layers of bedrock and regolith geology, based on new geophysical, remote sensing, geochemistry, geochronology, and stratigraphic data. The digital layers will be published as the Eastern Capricorn Basins Geological Information Series including accompanying Explanatory Notes.

The Edmund and Collier Basins have been systematically mapped at 1:100 000 scale by GSWA over the last 15 years updating earlier work from the 1960s to 1980s. The region is covered by State 400 m line spaced aeromagnetic and radiometric data, and aerial orthophotography. Landsat and DEM-derived imagery is available for much of the outcrop area. All of these data, including comprehensive Explanatory Notes, are published in the Western Capricorn Orogen Geological Information Series 2015. The Edmund Basin hosts Western Australia's largest stratabound Pb–Ag–Cu–Au deposit. This, combined with the age and geological setting of the basins make the region one of the most prospective areas in Australia for large, blind, sediment-hosted base-metal ore bodies. The Edmund and Collier Basins also have a history of minor gold and phosphate production. Six depositional packages defined for the Edmund and Collier

Groups are bounded by hiatuses that record important stages in the evolution of the architecture of the basins. Despite the relatively poor age constraints for the timing of sediment deposition, recent zircon, baddeleyite and xenotime geochronology has produced age constraints for the deposition of the Edmund Group to between c. 1679 and 1455 Ma, and the overlying Collier Group to between c. 1171 and 1067 Ma.

Outcomes of work program 2015–16

The 2015–16 work program has focused on mapping Edmund and Collier Group rocks on UAROO and the compilation of the ILGARARI and LOFTY RANGE 1:100 000 Geological Series maps, partly under the EIS.

Geochemistry and geochronology studies have identified a new dolerite suite, the Waldburg Dolerite dated at 1517–1505 Ma. These dolerites intrude the Irregully and Yilgatherra Formations (Depositional package 1) of the Edmund Group and provide a younger age limit for this package. These results will be released as a GSWA Report in late 2016.

A study of the structural history of the Edmund and Collier Basins has described the movement history of major faults involved in the opening, and later inversion of the basins. The Report includes Lu–Hf isotopic analysis of detrital zircons in the basins and the source history of the sedimentary material, which although were originally derived from the Gascoyne Province were recycled through older sedimentary basins in the southern Pilbara region. These results were released as a GSWA Report in mid-2016.

K–Ar dating of illite from fault gouge material and slickensides recovered from exposed faults, which has been carried out in collaboration with Horst Zwingman of CSIRO, has confirmed dates ranging from c. 1506 to 586 Ma. The dating method records only the youngest fault movement. However, these dates include fault movement from individual fault strands within a single fault system that are attributed to either successive events from the basin-forming extensional phase, to basin inversion and deformation during the Mutherbukin Tectonic Event, and to the Edmundian Orogeny and Mulka Tectonic Event. Material from EIS drillcore crosscutting

the Six Mile Fault and the Abra Cross Fault near the major Pb–Ag–Cu–Au deposit at Abra has identified 800–900 Ma fault movements, previously not defined in the basement rocks of the Gascoyne Province. These results will be released in a GSWA Report in mid-2016.

Update of the Explanatory Notes for the Edmund and Collier Basins was completed and included in the West Capricorn Geological Information Series 2015 (digital package).

Products released 2015–16

LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps*

West Capricorn Explanatory Notes update for MOUNT AUGUSTUS, MOUNT PHILLIPS, PEEDAWARRA, CANDOLLE, ERRABIDY, MARQUIS, CALYIE, TANGADEE, MOUNT EGERTON, MULGUL, MILGUN, TEANO, ELLIOTT CREEK, ULLAWARRA, CAPRICORN, EDMUND, MANGAROON, MAROONAH, MOUNT VERNON, JAMINDI, THREE RIVERS, TOWERA, LYNDON, CARDAWAN, LOFTY RANGE and ILGARARI, 1:100 000 Geological Series maps

Report 127 Deposition, provenance, inversion history and mineralization of the Proterozoic Edmund and Collier Basins, Capricorn Orogen

* EIS product

Planned work program and products 2016–17

Work during 2016–17 will focus mainly on final mapping, field checking, and compiling the geology of Edmund and Collier Group and basement rocks on UAROO and the compilation of the WONYULGUNNA 1:100 000 Geological Series maps. A new seamless compilation of 1:100 000-scale digital geology layers will commence for the GS49 East Capricorn Basins project. The first year of the project will be focused on the compilation of legacy data and limited field checking.

Products planned for release 2016–17

UAROO and WONYULGUNNA* 1:100 000 GEOLOGICAL SERIES MAPS

West Capricorn Geological Information Series update 2016 (including LOFTY RANGE* and ILGARARI* 1:100 000 Geological Series maps; digital product)

West Capricorn Explanatory Notes update for MOUNT AUGUSTUS, MOUNT PHILLIPS, PEEDAWARRA, CANDOLLE, ERRABIDY, MARQUIS, CALYIE, TANGADEE, MOUNT EGERTON, MULGUL, MILGUN, TEANO, ELLIOTT CREEK, ULLAWARRA, CAPRICORN, EDMUND, MANGAROON, MAROONAH, MOUNT VERNON, JAMINDI, THREE RIVERS, CARDAWAN, UAROO, TOWERA, LYNDON, LOFTY RANGE, and ILGARARI 1:100 000 Geological Series maps

The geochemical evolution of Mesoproterozoic mafic dykes that intrude the Edmund and Collier Groups* (Report)

K–Ar dating of fault rocks in the Edmund and Collier Basins (Report)

Two external publications — see Appendix B

* EIS product

Planned work program, products 2017–18 and beyond

Work during 2017–18 and beyond will continue on the compilation of legacy data (aerial photographs, field notebooks and samples) of the Eastern Capricorn Basins, and the progressive release of two or more 1:100 000-scale mapping tiles (WONGAWOL, GRANITE PEAK and NABBERU) as digital layers on the East Capricorn Geological Information Series digital product. A Report, continuing the study of the geochemical evolution of Proterozoic mafic dykes and sills, will focus on the Paulsens Mine area in the Wyloo Inlier of the northern Capricorn Orogen. The K–Ar geochronology of fault gouges, in collaboration with Professor Zwingmann of Kyoto University and Andrew Todd of CSIRO, will continue in the Eastern Capricorn Basins, and potential correlation with abundant mineralization will be investigated.

Products planned for release 2017–18

West Capricorn Geological Information Series update 2017 (including UAROO and WONYULGUNNA* 1:100 000 Geological Series maps; digital product)

Compilation of legacy data (aerial photographs, field notebooks, and samples) for the Padbury, Bryah, Yerrida and Earahedy Basins*

East Capricorn Geological Information Series 2017 (including a digital compilation of the 100 000 IBG and associated digital layers, and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earahedy Basins)*

Geochemical evolution of Proterozoic mafic dykes that intrude the Ashburton Basin* (Report)

* EIS product

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Stephen Wyche

Team members: Matt de Paoli, Cat Newman, Jyotindra Sapkota

The Eastern Goldfields Superterrane occupies approximately the eastern third of the Archean Yilgarn Craton. This highly mineralized region contains world-class gold and nickel deposits, and significant deposits of other commodities including base metals, rare earth elements, uranium, gemstones and industrial minerals. An understanding of the tectonic evolution of the Eastern Goldfields, including the structure and stratigraphy, is essential to the understanding of the controls on formation and distribution of mineralization in the region.

The published 1:100 000-scale mapping that covers the entire Eastern Goldfields Superterrane is available in the East Yilgarn Geological Information Series in GIS form. This product is being upgraded to implement formal stratigraphic concepts, which include recent new data and concepts arising from various research projects, particularly the large body of new geophysical, geochronological, geochemical and isotope data.

Outcomes of work program 2015–16

New mapping and integration of data and stratigraphic information have been applied to the East Yilgarn GIS in the area northwest of Kalgoorlie–Boulder in the Ora Banda – Siberia region. Explanatory Notes (ENS database) have been completed and published for the Melita and Leonora areas. New interpretation has been completed for the area between Kalgoorlie and Menzies and will be released in the 2016–17 financial year.

A large suite of whole-rock geochemistry analyses has been undertaken on diamond drillcore from the western part of the Eastern Goldfields in conjunction with HyLogger scans of sampled cores. These data, much of which have been obtained from core collected through the EIS Co-funded Drilling program, will be used to characterize stratigraphy in conjunction with the new mapping interpretations that are being undertaken by staff from the GSWA Kalgoorlie office.

The GSWA Kalgoorlie office hosted visits from various industry and government delegations, and school and university groups, and continued to provide geological information to visitors to the Goldfields region.

Products released 2015–16

East Yilgarn Geological Information Series 2016 update

Planned work program and products 2016–17

The ongoing revision of the East Yilgarn GIS to incorporate the new structural and stratigraphic framework will continue. In 2016–17, new geological interpretation will focus on the region between Kalgoorlie and Norseman, and the greenstones west of Menzies between Davyhurst and Mount Ida, linking the areas in the current release. Explanatory Notes coverage will include parts of the local Kalgoorlie stratigraphy.

An ongoing program of systematic geochemical sampling, from both outcrop and drillcore, will fill gaps in the existing dataset and provide detailed coverage of greenstone successions in the region.

Products planned for release 2016–17

East Yilgarn Geological Information Series update including Eastern Goldfields Superterrane stratigraphy and updated Explanatory Notes database entries

Eastern Goldfields komatiite geology and nickel deposits excursion guide

Planned work program, products 2017–18 and beyond

Beyond 2016–17, the incorporation of regional stratigraphy into the East Yilgarn GIS will continue with releases as appropriate. Explanatory Notes will be prepared to cover the whole of the East Yilgarn GIS and will be delivered in the ENS database. Future stratigraphic interpretation will focus on completing the western part of the Eastern Goldfields Superterrane (Kalgoorlie Terrane) and then extend to the east.

Ongoing collection of granite–greenstone geochemical and geochronological data will be used to assist in describing stratigraphy and geodynamic setting for the Eastern Goldfields Superterrane.

Products planned for release 2017–18

East Yilgarn Geological Information Series update including Eastern Goldfields Superterrane stratigraphy

ENS database update

Publications detailing the new regional stratigraphy for the Eastern Goldfields Superterrane

Application of mafic geochemistry to stratigraphic interpretation in the Eastern Goldfields

GS53 Chief Geoscientist and Terrane Custodians

Manager: Simon Johnson

Team members: Terry Farrell, Sarah Goss, Kath Grey, Roger Hocking, Fawna Korhonen, David Martin, Angela Riganti

Terrane Custodians: Peter Haines (basins), Simon Johnson (Proterozoic), Paul Morris (regolith), Stephen Wyche (Archean)

The Chief Geoscientist and Terrane Custodians section is responsible for maintaining a coherent geological framework for Western Australia and ensuring geoscience information delivered by GSWA is relevant, appropriate, and of a high standard. This includes delivering GSWA geoscience as multi-themed products developed and extracted from information stored in GSWA databases, with single-layer datasets, documents, and static, printed, or downloadable maps only part of the total product. The Chief Geoscientist and his section's part in achieving this are twofold. They work with project teams and groups as appropriate, guiding and overseeing development and population of GSWA databases, coordinating capture of spatial and textual legacy data, contributing to products as appropriate, validating database content, reviewing and approving manuscripts and spatial products, and coordinating work that spans more than one project. They work independently on geological problems not part of current GSWA project work and on statewide geological issues and datasets. The work of the team is thus partly process, with definable standards but no clearly defined outcomes, and partly program, for which there are outcomes. ENS content management and monitoring, legacy data capture, and management of quality control and product relevance are the processes, whereas outcomes and products arise from delivery of State-level datasets.

Outcomes of work program 2015–16

The completion and release of 1:2 500 000 seamless geoscience data layers was a high priority during 2015–16. The 1:2 500 000 dataset, as the 1:500 000 layers, comprises a set of intelligent spatial layers rather than a single map or digital layer.

These layers include:

- Interpreted Bedrock Geology (polygons) derived from 1:500 000 layers
- Cenozoic geology (polygons) for areas of significant Cenozoic deposits
- linear structures, e.g. faults and folds

- dyke suites of Western Australia
- bespoke 1:2 500 000 surface geology specifically for Geological map of Western Australia 1:2 500 000, 2015 (printed version).

Also released were the 1:10 000 000 Large Igneous Provinces and Tectonic Units spatial layers. The 14th edition of the Geological map of Western Australia (the first in over 15 years) was accompanied by a GSWA Record that provided details on the novel approach used in the map and digital data compilation, as well as an accompanying set of comprehensive Explanatory Notes. An additional publication (Mapping Western Australia: State geological maps 1894–2015) highlighted the evolution of the State geological map from its first incarnation in 1894 through to the present-day edition.

The online version of ENS was launched in February 2016. This system has a graphical interface allowing textual and spatial interrogation of lithostratigraphic and tectonic units, and events. The following activities continued throughout the year:

- populating ENS and WAROX (GSWA's field observation database)
- monitoring the style and quality of GSWA geoscience
- overseeing GSWA database capture and validation.

A smartphone app (Everythere) for discovering geologically significant sites around Rottnest Island was released as a beta product under a one-year trial. If successful, other tours, such as the content of the Stepping Stones walk in Perth, will be released.

The section continued populating the data entry module of ENS in 2015–16, and expanded content within provinces already covered (extending to the Turee Creek, Wyloo and Blair Basins, and parts of the South and East Yilgarn Craton). This brings the total number of published lithostratigraphic units to over 650.

The section coordinated the revision of all GSWA pages for the DMP website. Several new pages were prepared, greatly expanding the content for deep seismic and magnetotelluric surveys, 3D geoscience, mineral geoscience, and educational pages.

Products released 2015–16

1:500 000-scale spatial geoscience layers (geology, structure, tectonic units, linear features)

1:2.5 million spatial geoscience layers, derived from 1:500 000 spatial layers

1:2.5 million geological map of Western Australia, derived from 1:2.5 million spatial layers

1:10 million tectonic units layer

ENS online delivery system

Record Geological map of Western Australia 14th edition: Explanatory Notes

Non-series book Mapping Western Australia: State geological maps 1894–2015

Smartphone App (Everywhere) highlighting the geological sites on Rottnest Island (beta version)

Planned work program and products 2016–17

Work during 2016–17 will focus on the update of our online data delivery systems and on progress towards the addition of key data layers such as project-specific seamless 1:100 000-scale geology, regolith–landform and linear structure layers, as well as the WAROX field observation data. Updates of the 1:500 000 geology and tectonic units layers, based primarily on outcomes from 2015 GSWA mapping projects and spatially compatible with 1:2 500 000 layers, will be released early in the 2016–17 financial year. Work will then commence on updating these layers based on 2016 mapping. Work will begin on the implementation and progressive attribution (dip, age, reactivation events) of the current State 1:500 000 and 1: 2 500 000 Linear Structure layers.

A priority task for 2016–17 will be to design and begin compilation of a bespoke, seamless 1:500 000 State regolith–landform map and accompanying digital layer, with delivery expected in late 2017–18. Work will also begin on developing a State metamorphic map (at various scales) also due for delivery in late 2017–18.

Population of ENS and WAROX, monitoring of the style and quality of GSWA geoscience, and overseeing GSWA database capture and validation will continue. Design and testing of additional modules (geochronology and regolith) to ENS will commence during 2016–17, with an expected deployment late in the financial year, or early in 2017–18.

The third part in the concise Geology of Western Australia (Western Australia Unearthed) series ‘A Paleozoic perspective of Western Australia’ will be published, while the writing and editing of the Archean part is expected to be complete by the end of 2017. Several geotourism products are planned including a book, digital data layer and accompanying virtual tour of the State’s meteorite impact structures, as well as a brochure on the geology of the Albany region of Western Australia.

Products planned for release 2016–17

1:100 000 spatial geoscience layers (interpreted bedrock geology, regolith–landform, and structural data) where available

WAROX field observation and rock database spatial geoscience layer

Update attribution table (dip, age, reactivation events) of State 1:500 000 and 1: 2 500 000 Linear Structures spatial layers and begin data population

Updates of 1:500 000 spatial geoscience layers (IBG, Tectonic Units)

Extended ENS content over existing and new geological provinces

Geology of Western Australia (WA Unearthed) part 3 – the Paleozoic

1: 500 000 impact structures spatial geoscience layer and accompanying Explanatory Notes

Geotourism book and accompanying virtual tour of State meteorite impact structures

Geotourism brochure on the geology of the Albany region

Planned work program, products 2017–18 and beyond

Work will continue to focus on the maintenance, upgrade, and population of spatial and textual datasets, extension of the Western Australia unearthed products to layperson’s guides and region-by-region guides, and quality assessment of GSWA products and data. Legacy capture of geoscience for ENS remains a long-term goal, and may be undertaken by senior geoscientists as transition-to-retirement projects.

GS54 Geochronology and Isotope Geology

Manager: Michael Wingate

*Team members: Frances James, Yongjun Lu, Ed Mikucki,
Marlene Pappicio, Tom Scillieri, John Williams*

The Geochronology and Isotope Geology section determines precise and accurate ages of rocks and geological events, and is an integral part of GSWA's mapping programs and mineralization studies. A range of isotope systems (including U–Pb, Ar–Ar, and Re–Os) and a variety of minerals (zircon, baddeleyite, monazite, titanite, hornblende, feldspars, and micas) is used to constrain the timing of magmatism, metamorphism, deformation, and mineralization. The ages of detrital zircons are used for provenance analysis and to provide maximum ages of deposition for sedimentary rocks. The timing of tectono-thermal events is constrained by dating of pre-tectonic, syntectonic, and post-tectonic intrusive rocks. Geochronology results and materials are used extensively in isotope geology studies (see ES46 Enhanced Geochronology and Acquisition of Isotope Data). Geochronology and isotope geology are important for understanding Western Australia's geological history and contributing to the prospectivity of the State.

The sensitive high-resolution ion microprobe instrument (SHRIMP) in the John de Laeter Centre at Curtin University is used extensively by GSWA for U–Pb dating. GSWA also dates detrital zircons using LA-ICP-MS in the John de Laeter Centre, which allows rapid analysis of a large number of crystals. The ages of cooling, deformation, and crystallization of rocks containing potassium-bearing minerals are determined in collaboration with Ar–Ar geochronology specialists in the Centre. The section also provides specialized isotope geochemistry services to GSWA mapping and mineralization projects.

The varied aspects of the geochronology and isotope geology program, as well as GSWA's geochemistry program, are supported by world-class sample preparation services provided in-house by the GSWA laboratory at Carlisle. The laboratory manages archiving and retrieval of sample materials in GSWA's extensive collection, to support numerous in-house and external research projects, and coordinates petrographic services for geologists.

Outcomes of work program 2015–16

About 100 rock samples were processed for U–Pb geochronology by GSWA's laboratory; 86 were analysed by GSWA geochronologists using the SHRIMP facilities

at Curtin University. Figure 34 shows the distribution of analysed samples both geographically and by tectonic unit. These samples were dated in support of GSWA geoscience programs in the west Musgrave and Gascoyne Provinces, the Yilgarn Craton (Youanmi and South West Terranes, and Eastern Goldfields region), the Albany–Fraser, Capricorn, and Granites–Tanami Orogens, the Kimberley region, the Amadeus Basin, and in basement rocks beneath the Eucla Basin. Results are published as Geochronology Records, a total of 81 of which were published during 2015–16. Some of the achievements for 2015–16 are outlined below.

The U–Pb geochronology of basement rocks from EIS-funded drillholes through the Eucla Basin has been interpreted and integrated with isotopic, geochemical, petrographic, and geophysical information. Several new Paleo–Mesoproterozoic supersuites have been defined and characterized, and comparisons made between the Madura, Coompana, and Musgrave Provinces and the Albany–Fraser Orogen. A synthesis of results was presented at a workshop in 2015 (GSWA Record 2015/10).

The section provides sample materials and analytical and laboratory support to several PhD and MSc projects at Curtin University and UWA, that are conducted in areas of interest to GSWA. These projects include:

- geological evolution of the northern Capricorn Orogen
- geological evolution of the northern Gascoyne Province
- relationships between zircon grain shape, chemistry, and detrital provenance
- facies characterization and provenance of the Yarragadee aquifer
- precise timing of Cu–Mo–Ag–Au mineralization in the South West Terrane.

Geochronology of zircons from felsic volcanic and clastic sedimentary rocks in the northern Capricorn Orogen provides rigorous age constraints for deposition in the Ashburton and Blair Basins and for D1 deformation during the Capricorn Orogeny. Felsic volcanism was contemporaneous with intrusion of Moorarie Supersuite granites in the Gascoyne Province, and sedimentation, volcanism, and deformation occurred within a few million years at c. 1800 Ma, probably in a foreland basin setting.

Unexpected results have been obtained from a collaborative project with the John de Laeter Centre to use (U–Th)/He thermochronology of zircon and apatite to constrain the evolution of thrust systems in the Petermann Nappe Complex of the western Musgrave Province. Although most samples indicate uplift ages of 600–500 Ma, a sample from footwall rocks south of the main fold-and-thrust belt suggests that rapid basement uplift occurred during the late Triassic, at c. 220 Ma. Additional samples will be analysed to verify this result. Interestingly, numerous earthquakes, including a significant event of magnitude 6.1, were recorded in the same area during May 2016. This region might have been tectonically active for at least the last 600 million years!

Products released 2015–16

Compilation of geochronology information, 2016

Record 2015/6 GSWA Kimberley workshop 2014: extended abstracts include:

- Characterization and timing of events in the richly mineralized Speewah area of the East Kimberley, Western Australia: Paleoproterozoic sedimentation, intrusion of the Hart Dolerite and fault-hosted alteration and vein systems

Record 2015/8 Detrital zircon geochronology of upper Ediacaran to lower Cambrian deposits (Supersequence 4), western Amadeus Basin: testing revised stratigraphic correlations

Record 2015/10 Eucla basement stratigraphic drilling results release workshop: extended abstracts include:

- U–Pb geochronology of the Madura Province
- Madura Province: geochemistry and petrogenesis
- Madura Province: isotopes and crustal evolution
- U–Pb geochronology of the Forrest Zone, Coompana Province
- Forrest Zone: geochemistry and petrogenesis
- Forrest Zone: isotopes and crustal evolution
- Eucla basement results: implications for geodynamics and mineral prospectivity

Record 2016/4 Geology and U–Pb geochronology of the Warlawurru Supersuite and MacDougall Formation in the Mitika and Wanarn areas, west Musgrave Province

Niujuanzi, northwest China, 1:50 000 geological map

81 Geochronology Records and U–Pb datasets released to online applications (GeoVIEW.WA) and published maps and digital products

12 external publications — see Appendix B

Planned work program and products 2016–17

GSWA's geochronology program will continue to generate U–Pb zircon, baddeleyite, and monazite ages in support of regional mapping programs in the Yilgarn Craton (Eastern

Goldfields Superterrane and the Youanmi and South West Terranes), the Capricorn Orogen (Gascoyne Province, and Edmund and Collier Basins), the western Musgrave Province, the Albany–Fraser Orogen, and the Kimberley and Amadeus Basins. The results of Sm–Nd, Lu–Hf, Re–Os, and oxygen isotope studies (see ES46 Enhanced Geochronology and Acquisition of Isotope Data), together with new results from in situ phosphate dating, will be integrated with SHRIMP U–Pb and geological information by geochronologists and mapping program staff. The timely release of geochronology results will be maintained, through both rapid in-house brief reports and the Geochronology Record Series, published online via GeoVIEW.WA, eBookshop, and the Data and Software Centre.

Products planned for release 2016–17

Compilation of geochronology information, 2017

External publications and contributions to GSWA publications — see Appendix B

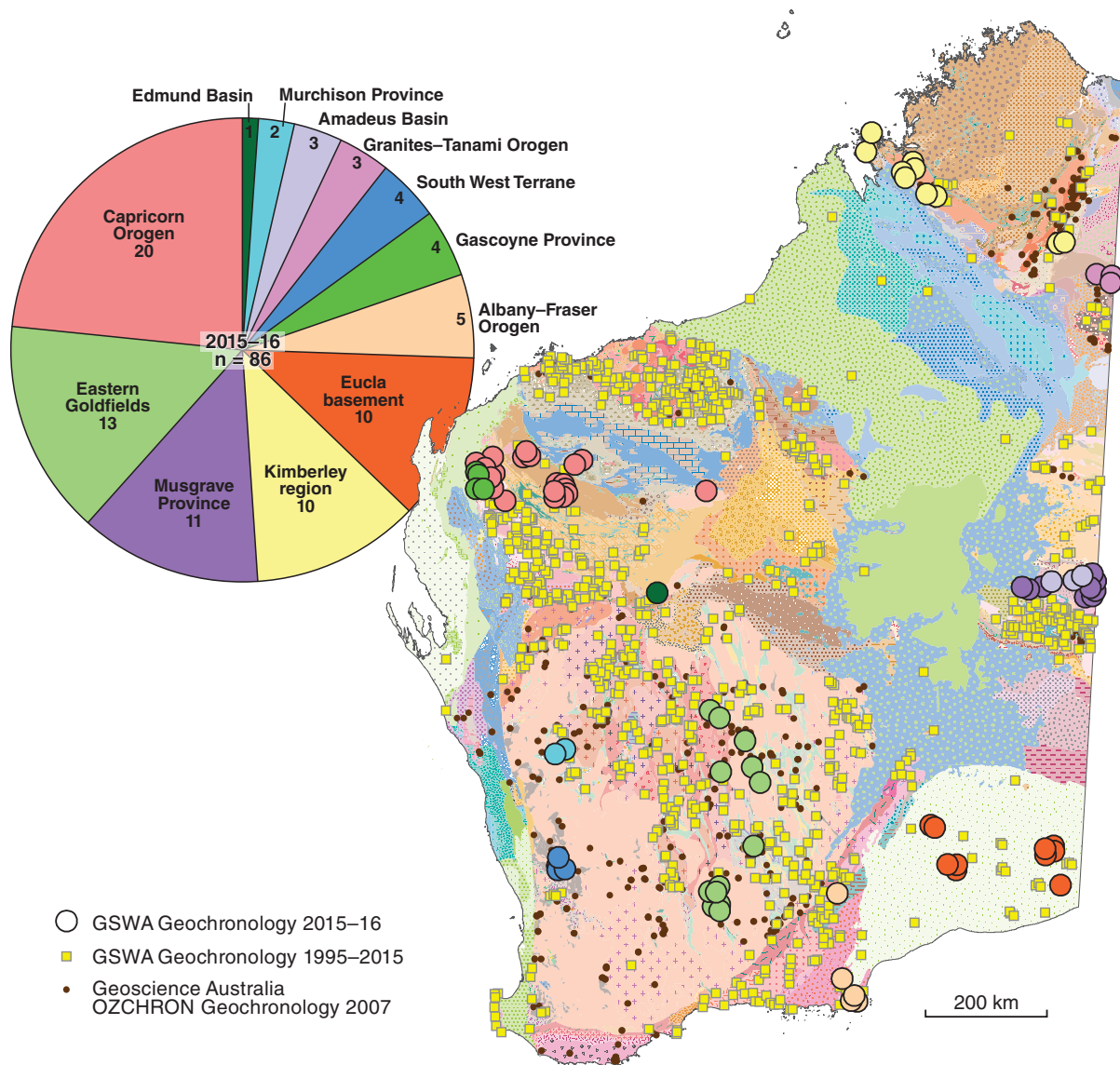
Planned work program, products 2017–18 and beyond

Future geochronology work will continue to support GSWA's regional mapping programs. Geochronology results and publications will be informed by a range of additional data, including the results of Sm–Nd, Lu–Hf, and oxygen isotope studies (see ES46 Enhanced Geochronology and Acquisition of Isotope Data). The Geochronology and Isotope Geology section will continue to expand its range of geochronological and isotopic techniques through in-house research and external scientific collaborations.

Products planned for release 2017–18

Compilation of geochronology information, 2018

External publications and contributions to GSWA publications — see Appendix B



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Figure 34. Geographical and tectonic distribution of GSWA samples analysed by SHRIMP

GS55 Geophysics and Remote Sensing

Manager: David Howard

Team member: John Brett

The acquisition, processing, synthesis and interpretation of geophysical and remotely sensed spectral information are integral parts of GSWA's regional regolith and bedrock geology mapping process. The role of the Geophysics and Remote Sensing section is to plan and manage the various regional geophysical data acquisition projects, to deliver the datasets to the public and internal users, and to provide processing, interpretation services and advice as required.

Outcomes of work program 2015–16

Regional survey data acquisition activities are reported under the EIS programs — ES30 Airborne Geophysical Surveys and ES32 Regional Gravity Surveys.

Updates of the now standard statewide compilations of magnetic, radiometric and gravity grids and images were published and a new 40 m first vertical derivative magnetic grid of Western Australia was also compiled and published.

The MAGIX data repository of company airborne survey data continued to grow. During 2015–16, 80 new company airborne survey datasets containing about 302 000 line-km of data were received for inclusion in the repository. At 30 June 2016, the MAGIX repository contained about 9.5 million line-km of company data from 2218 surveys. Open-file datasets are available for download via DMP's GeoVIEW.WA online system.

Planned work program, products 2016–17 and beyond

The planned work program for 2016–17 and beyond — dependent on the then prevailing GSWA budget — is described separately under programs ES30 (Airborne Surveys) and ES32 (Gravity Surveys). The work will be managed by the Geophysics and Remote Sensing section.

All new data acquired will be included in updates to the statewide compilation magnetic, radiometric and gravity grids and images.

The section will continue to manage the MAGIX data repository and the submission, archive and release of airborne and some ground survey datasets supplied by the exploration industry.

GS56 North Australian Craton

Manager: David Maidment

Team members: Graham Eacott, Christopher Phillips

The North Australian Craton mainly comprises Neoarchean to Mesoproterozoic rocks forming the basement throughout the northern and central parts of the Australian continent. The craton is host to extensive mineral deposits and major mines, including Pb–Zn–Ag (–Cu) (Mount Isa, McArthur River), U (Ranger, Rum Jungle), iron oxide–Cu–Au (Tennant Creek), Au (The Granites, Callie), diamonds (Argyle), Ni (Sally Malay), and Fe (Koolan Island). In Western Australia, the craton crops out in the Kimberley, west Tanami, and west Arunta regions, and is overlain by the sedimentary rocks of the Neoproterozoic Centralian Superbasin and the Phanerozoic Canning, Ord and southern Bonaparte Basins (with potential for oil, gas and Pb–Zn deposits).

In the Kimberley region, which forms a focus area for the project, the Halls Creek and King Leopold Orogens affect igneous and low- to high-grade metamorphic rocks of the Paleoproterozoic Lamboo Province. The Lamboo Province is overlain by sedimentary and volcanic rocks of the Paleoproterozoic Speewah and Kimberley Basins and correlatives, the Paleoproterozoic to Mesoproterozoic Birrindudu, Crowhurst and Bastion Basins and the Mesoproterozoic lower Victoria River, Glidden and Carr Boyd Basins. The Speewah and Kimberley Basins were intruded by the Hart Dolerite – Carson Volcanics large igneous province.

First edition 1:250 000-scale mapping covers the North Australian Craton in Western Australia. GSWA carried out second edition 1:250 000-scale remapping of the King Leopold Orogen between 1986 and 1989. Together with the then Bureau of Mineral Resources, Geology and Geophysics (BMR), later Australian Geological Survey Organisation (AGSO), now GA, 1:100 000- and 1:250 000-scale mapping in the Halls Creek Orogen took place from 1990 to 1995 as part of the National Geoscience Mapping Accord. SHRIMP U–Pb zircon geochronology and extensive whole-rock geochemistry were carried out. GA published reconnaissance SHRIMP U–Pb zircon geochronology and whole-rock geochemistry from the west Arunta in 1998, and has undertaken geochronology in the west Tanami as part of the GA–NTGS–GSWA North Australia Project. The 2005 Tanami Seismic Collaborative Research project acquired 719 km of deep seismic reflection data across the Western Australia/Northern Territory border. Aerial magnetic and radiometric data at 400 m-line spacing is available from government or commercial sources over most of

the craton in Western Australia. A detailed gravity survey (2.5 km-station spacing) covers part of the West Arunta region. The area is covered by recent Landsat satellite imagery and recent orthophotography.

Further interpretation of geophysical, geochemical and geochronological data will assist in understanding the evolution of the crust and underlying mantle across the North Australian Craton. The nature of crustal-scale fault structures and their history of reactivation will be examined; this has implications for the location of mineral deposits. Tectono-stratigraphic, geochronological and provenance studies on the Paleoproterozoic and Mesoproterozoic basins will help establish tectonic and possible mineral system links with the mineralized Pine Creek Orogen, McArthur Basin and Mount Isa Inlier.

Outcomes of work program 2015–16

Results of the work program include:

- release of the Second edition DRYSDALE–LONDONDERRY 1:250 000-scale Geological Series map
- update of ENS with units included in published maps
- release of Kimberley 2016 GIS update, including new 1:250 000-scale mapping, regolith geochemical data and regolith–landform maps
- collection of new geochronological, geochemical and Sm–Nd isotopic data for metasedimentary and igneous rocks in the east Kimberley
- undertaking fieldwork in the east Kimberley, involving collection of samples of sedimentary and metamorphic rocks to constrain basin correlations and geodynamic history of region
- publication of a Report on interpretation of geophysical data for the east Kimberley, in conjunction with CET at UWA
- publication of a Report on mineral prospectivity analysis of the east Kimberley, including GIS dataset, in conjunction with CET at UWA
- publication of an abstract volume for 2014 Kimberley Workshop.

Some of the important geological outcomes from the North Australian Craton group in 2015–16 include:

- a new interpretation of geophysical data for the east Kimberley has proposed the existence of three cryptic, cross-orogen structures which might have influenced the Paleoproterozoic development of the region, including fluid flow and mineralization
- a mineral prospectivity study of the Halls Creek Orogen for Au, Cu, Ni, PGE, V, Ti, Pb, Zn and diamonds has highlighted different areas of higher prospectivity that warrant more detailed investigation
- initial field examination of fault-bound sedimentary basins in the east Kimberley suggests correlations with parts of the Kimberley and Speewah Basins, and possibly also with the Birrindudu Basin. Samples have been collected to test potential correlations of these previously undated units
- Sm–Nd isotopic data collected for granitic rocks of the Sally Downs Supersuite show distinct spatial and temporal variations that constrain the development of the Halls Creek Orogen. These data are being combined with new detrital zircon data for basement units to assess and develop the geodynamic model for the region.

Planned work program and products 2016–17

The work program for 2016–17 is dominated by work in the Kimberley region. Fieldwork will include helicopter-supported sampling and characterization of a series of undated Paleo- to Neoproterozoic basin remnants in the Kimberley region (Moola Bulla, Red Rock, Texas Downs and Revolver Creek Basins). Detrital zircon from samples collected during this program and sampling in 2015–16 will be dated using LA-ICP-MS and SHRIMP techniques. Fieldwork will also target the Western and Central Zones of the Halls Creek Orogen to collect samples for geochronology, geochemistry and Sm–Nd isotopic analysis to better understand the Paleoproterozoic geodynamic setting of the region. Samples collected in a transect across the orogen will be submitted for ^{40}Ar – ^{39}Ar thermochronology to provide timing constraints on post-Paleoproterozoic deformation in the region. ENS will be updated with additional information based on recent fieldwork and dating.

The metamorphic history of the King Leopold and Halls Creek Orogens will be studied using existing thin-section and hand-specimen samples, with a view to producing a Report on the P–T–t evolution of parts of the Lamboo Province in 2017–18. Geochronological, isotopic and geochemical data will also be compiled and synthesized in order to produce a Report in 2017–18 on the geodynamic evolution of the Halls Creek Orogen.

Four Reports will be released in 2016–17: one on the geology, geochronology and geochemistry of the Eastern Zone of the Halls Creek Orogen; one on the volcanology and geochemistry of the Carson–Hart Large Igneous Province; one on the geochronology and geochemistry of the Rudall Province; and one on the sedimentology of the Speewah and Kimberley Basins.

Products planned for release 2016–17

The sedimentology, geochronology and geochemistry of the Eastern Zone of the Halls Creek Orogen (Report)

The physical volcanology and geochemistry of the Carson–Hart Large Igneous Province (Report)

Geochronology and geodynamic development of the Rudall Province (Report)

Sedimentology of the Speewah and Kimberley Basins (Report)

Kimberley 2017 GIS update, including new units published in ENS

Planned work program, products 2017–18 and beyond

The work program for 2017–18 and beyond will depend in large part on the result of ongoing land access negotiations and the results of the current work program. One 1:250 000-scale geological series map (LANSDOWNE) is planned for production. The geochronological and isotopic data collected across the Western, Central and Eastern Zones of the Lamboo Province will be synthesized in a Report on the Paleoproterozoic geodynamic evolution of the region. Reports are also planned to document the sedimentology, geochronology and geodynamic setting of basin outliers in the region, the results of ^{40}Ar – ^{39}Ar dating in the Lamboo Province, and the metamorphic evolution of parts of the Lamboo Province. New mapping and analytical data will be incorporated in a Kimberley 2018 GIS update.

Products planned for release 2017–18

LANSDOWNE and CAMBRIDGE GULF 1:250 000 Geological Series maps

Kimberley GIS 2018 update, including new units published in ENS

Geodynamic evolution of the Lamboo Province (Report)

Detrital zircon dating of basin outliers in the Kimberley region (Report)

^{40}Ar / ^{39}Ar dating from the Halls Creek Orogen (Report)

The metamorphic evolution of the Lamboo Province (Report)

GS57 West Musgrave Province

Manager: Heather Howard

Team members: Raphael Quentin de Gromard, Hugh Smithies

The West Musgrave Province is the Western Australian portion of the Mesoproterozoic to Neoproterozoic Musgrave Province that straddles the borders between Western Australia, South Australia, and the Northern Territory. The extremely varied geology encompasses structurally complex low- to high-grade metamorphic terrains that record a history involving up to six magmatic and deformational events including the Mesoproterozoic Musgrave Orogeny and the Neoproterozoic–Cambrian Petermann Orogeny. Forming the junction of Proterozoic orogenic trends in central and southern Western Australia, the Musgrave Province is critical to an understanding of the Proterozoic crustal evolution of Australia. The province includes the voluminous layered mafic–ultramafic Giles intrusions and associated smaller mafic intrusions. These intrusions have been the site of significant nickel, copper and platinum group element discoveries. The economic potential of extensive felsic volcanic sequences has not been fully explored; however, recent exploration in these rocks has also uncovered significant gold mineralization.

Despite its importance in understanding the Proterozoic evolution of Australia, and its economic potential, the Musgrave Province remains one of the most understudied parts of Proterozoic Australia. Some of the main impediments in this regard have been land access issues and the geographical isolation of the region. Very few detailed geoscientific research projects have been carried out in the west Musgrave Province, with focused PhD studies completed in 1971 by CM Gray and in 1997 by RW White being perhaps the most notable. Regional 1:250 000-scale geological mapping of the west Musgrave Province in the late 1960s culminated in the publication of Bulletin 123 (Daniels, 1972) which documented the regional geology of the area between Warburton and Wingelinna. A subsequent survey was undertaken in the 1990s by GA (then AGSO) which focused primarily on the mafic–ultramafic Giles intrusions, but also considered some more regional geological issues. This survey culminated in the publication of AGSO Bulletin 239 in 1996. In 2004, GSWA released the west Musgrave Geological Exploration Package (Record 2004/9). This package combined pre-existing and newly acquired digital datasets, including Landsat TM and ASTER satellite image data, 1:25 000 colour orthophotography, and aeromagnetic and radiometric data (at 400 m line-spacing) for six 1:100 000 Geological Series map sheets covering

the central eastern part of the west Musgrave Province project area (BATES, BELL ROCK, BLACKSTONE, HOLT, COOPER, and FINLAYSON). Since then, GSWA has acquired similar datasets covering the entire project area (including DEERING, GUNBARREL, DICKENSON, DIORITE, TABLE POINT, BENTLEY, GOLDEN POINT, MOUNT EVELINE, Warburton Range, and AGNES).

It has become clear that there are major geological differences between the northeastern and southwestern parts of the project area, but it is unclear how significant the boundary between these two regions truly is, and whether that boundary is the Mann Fault, a major east-trending regional structure, or the Tjuni Purlka Zone, a recently defined zone of extensive northwest faulting. The later structural zone was clearly the site of extensive felsic magmatism and deformation during the Mesoproterozoic Musgravian Orogeny. It seems most likely that this zone was the main control on the structural architecture of the region, perhaps modified to a large degree by east-trending faults like the Mann Fault, during the Neoproterozoic Petermann Orogeny. One of the main geological differences across this zone is the absence, in the northeast, of the c. 1300 to 1330 Ma calc-alkaline crust that forms a significant component of the area to the southwest.

The economically important mafic intrusions emplaced during the 1090–1040 Ma Giles Event primarily occupy the tectonic contacts bounding either side of the Tjuni Purlka Tectonic Zone. The Giles Event has now been shown to be much more magmatically and structurally complicated and long-lived than previously thought. This hampers exploration models for orthomagmatic deposits. Our dating of copper-mineralized gabbros shows that at least some of the orthomagmatic mineralization relates to intrusions that are late (c. 1067 Ma) in the geological history of the larger mafic intrusions, small with respect to the main mafic intrusions, and most likely peripheral to those larger intrusions.

Outcomes of work program 2015–16

Some of the main geological outcomes from the west Musgrave Province mapping program to arise from the 2015–16 financial year include:

- geological mapping and geochronology on AGNES have helped identify the presence of a c. 1540 Ma basement component in the southern part of the west Musgrave Province. These gneissic granites have subduction-like geochemical signatures similar to contemporaneous gneissic granites previously identified in the northern part of the eastern Musgrave Province. This strengthens the suggestion that the c. 1600 to 1300 Ma subduction history of the Musgrave Province basement youngs from east to west
- recent mapping and geochronology on REBECCA have identified the presence of migmatitic granites previously interpreted on the Northern Territory side of the border to belong to the 1190–1140 Ma Pottoyu Granite Suite. This granite reveals an igneous crystallization age of c. 1030 Ma, extending the age range of the Giles Event and Warakurna Supersuite to 1090–1030 Ma
- new geochronology data suggest the Petermann Orogeny started as early as 630 Ma rather than 580 Ma
- the completion of geological mapping in the Mitika, Wanarn and Rawlinson areas, combined with exhumation ages from Ar–Ar data, resulted in a reinterpretation of the Youanmi–Officer–Musgrave (YOM) seismic section in the west Musgrave Province, presented at the 2015 conference of the Specialist Group in Tectonics and Structural Geology (SGTSG).
- a new collaborative project with the John de Laeter Centre yielded a highly unexpected result in central Australia. Low temperature (U–Th)/He thermochronology was applied to structurally controlled samples to constrain the evolution of the Petermann Fold and thrust belt. While most samples dated exhumation related to the c. 550 Ma Petermann Orogeny, one date suggested that kilometres of uplift occurred in the Late Triassic at c. 220 Ma. This new date suggests a previously unrecognized tectonic event in Australia. Additional samples will be analysed to verify this result. Interestingly, the neighbouring Woodroffe Thrust showed active seismicity with a magnitude 6 earthquake in the Northern Territory on 20 May 2016. This suggests interspersed reactivation of these structures during the last 550 Ma.

Products released 2015–16	Current status
Geological interpretation of the West Musgrave Province 1:250 000 Geological Series map	Released
DIORITE 1:100 000 Geological Series map	Released
West Musgrave GIS (including GUNBARREL, DICKENSON and TABLE POINT)	Released
Record 2016/4 Geology and U–Pb geochronology of the Warlawurru Supersuite and MacDougall Formation in the Mitika and Wanarn areas, west Musgrave Province	Released
ENS update (DIORITE and GOLDEN POINT)	Submitted

Planned work program and products 2016–17

The fieldwork component for the project has been completed and compilation of the remaining mapping and Reports will continue. New digital maps of AGNES, DEERING, REBECCA, MOUNT BUTTFIELD, and RAWLINSON at 1:250 000 scale, will be released in the West Musgrave GIS update.

Products planned for release 2016–17
West Musgrave GIS (with complete 1:250 000 layer for project area (includes AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON))
Geochemistry of mafic magmatism in the West Musgrave (Report)
Neoproterozoic structural evolution of the west Musgrave Province (Record)

Products planned for release 2017–18 and beyond
West Musgrave GIS with ENS update (for AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON)
Geology of Rawlinson (Record)

GS58 Youanmi Terrane

Manager: Stephen Wyche

Team members: Tim Ivanic, Ivan Zibra, Sandra Romano

The Youanmi Terrane in the western part of the Archean Yilgarn Craton contains significant deposits of gold, iron ore, copper, lead, zinc, tungsten, molybdenum, bismuth, vanadium, titanium, beryllium, lithium, tin, tantalum and uranium, and has the potential for more discoveries of these commodities. It has a long and complex geological history. An understanding of the tectonic evolution of the Youanmi Terrane, including its structure and stratigraphy, is essential to understanding the controls on formation and distribution of mineralization in the region.

GSAW has recently suspended mapping in the southeastern part of the Youanmi Terrane in the southern part of the Southern Cross Domain. Geological data and mapping derived from this program are available in the South Yilgarn Geological Information Series (GIS) 2016 release. Mapping in the Murchison Domain in the northwestern Youanmi Terrane is ongoing with annual releases of new mapping and analytical results.

Cooperative projects include:

- a geochemistry and isotopes project in the Narryer Terrane with Dr Tony Kemp from UWA and Professor Cees Passchier from the Gutenberg University in Mainz
- structural studies in the Murchison Domain with various external collaborators
- an ARC Linkage project with Sydney University to study the geochemistry and tectonic setting of the Murchison region.

Outcomes of work program 2015–16

New mapping in the Yalgoo–Singleton greenstone belt has established stratigraphic relationships, which are being tested with geochronology and geochemistry. Field mapping has been completed over most of the greenstones around the Yalgoo Dome. Ongoing structural studies in the Yalgoo Dome are aimed at determining the relationship between granite emplacement and the greenstone stratigraphy.

Field mapping has been completed on the Meekatharra 1:100 000 map sheet, resulting in some modifications to the published Murchison stratigraphy.

A map compilation covering the Windimurra, Narndee and Youanmi igneous complexes has been prepared and will be published during 2016–17. A 3D model of the Windimurra Igneous Complex was prepared using mapping, gravity, aeromagnetic, drilling and seismic data.

Products released 2015–16

MOUNT MAGNET 1:100 000 Geological Series map

YALGOO 1:100 000 Geological Series map

BADJA 1:100 000 Geological Series map

BUNGAR 1:100 000 Geological Series map

South Yilgarn GIS 2016

Murchison GIS 2016

Record 2015/12 and 3D Geomodel Series digital release The Windimurra Igneous Complex, Yilgarn Craton: an Archean layered intrusion revealed by seismic data and 3D modelling

Record 2016/6 A field guide to the mafic–ultramafic intrusions of the northern Youanmi Terrane

Record 2016/5 Microstructural evolution of the Yalgoo Dome, Western Australia

Planned work program and products 2016–17

Field mapping and compilation will be completed on the THUNDELARRA and NINGHAN 1:100 000 map sheets in the Yalgoo–Singleton greenstone belt. The MEEKATHARRA 1:100 000 map sheet will be compiled. Field mapping will be completed on GABANINTHA 1:100 000 map and the map compiled, but further field checking may be required.

Cooperative projects will continue including structural and isotope studies in the Narryer Terrane, and geochemistry and structural studies in the Murchison Domain.

Products planned for release 2016–17

NINGHAN 1:100 000 Geological Series map

THUNDELARRA 1:100 000 Geological Series map

MEEKATHARRA 1:100 000 Geological Series Map

Murchison GIS 2017

Murchison stratigraphy and Explanatory Notes update

Interpretative geological map of the major mafic–ultramafic igneous complexes in the Youanmi Terrane (map)

Planned work program, products 2017–18 and beyond

Field mapping in the Murchison Domain of the Youanmi Terrane will continue in 2017–18. Data will be compiled for release in future versions of the Murchison GIS. A Report and map providing a comprehensive overview of the Windimurra and Narndee Igneous Complexes will be prepared and published. Reports and external publications, including 3D models of various aspects of Murchison geology, will be prepared. A metamorphic map and accompanying database for the Yilgarn Craton will be published.

Products planned for release 2017–18

Murchison GIS update

Explanatory Notes update

GABANINTHA, ROTHSAY and WOODLEY 1:100 000 Geological Series maps

Windimurra Narndee Igneous Complexes Report

West Yilgarn metamorphic project: Yilgarn metamorphism map and GIS

Structural setting of the Narryer Terrane in the Youanmi Terrane

Youanmi Terrane structural studies

GS61 Albany–Fraser Orogen and Eucla Basement Project

Manager: Catherine Spaggiari

Team members: Hugh Smithies, Raphael Quentin de Gromard

The Albany–Fraser Orogen flanks the southern and southeastern margin of the Archean Yilgarn Craton over a distance of at least 1200 km, and is part of the West Australian Craton (WAC). The orogen is dominated by Paleoproterozoic and Mesoproterozoic rocks formed during reworking of the southern Yilgarn Craton from at least 1815 Ma through to 1140 Ma. Fragments of Archean crust, interpreted to be remnants of the Yilgarn Craton, are also preserved within the orogen. The eastern part of the orogen and adjoining Proterozoic Madura and Coompana Provinces collectively comprise the Eucla basement, being entirely covered by younger basin rocks. The Coompana Province extends across the border into South Australia, and links to the Gawler Craton. New data from these hidden basement provinces is providing information enabling a better understanding of the development of the southern WAC margin over time, on the prospectivity of the region, and informing models of Proterozoic Australia assembly.

Several mineral systems are now recognized in the Albany–Fraser Orogen. They are:

- Neoproterozoic (c. 2500 Ma) thrust-related shear zone Au hosted in retrogressed amphibolite to granulite facies ortho and paragneisses (Tropicana, Tropicana east)
- Paleoproterozoic (c. 1760 Ma) intrusion-related Au–Ag (Voodoo Child)
- Paleoproterozoic stratabound sedimentary clastic-hosted Pb–Zn–Ag–Cu–Au (Trilogy)
- Paleoproterozoic (1800–1600 Ma) magnetite iron ore (Southdown)
- Mesoproterozoic (c. 1300 Ma) orthomagmatic mafic and ultramafic intrusion-related Ni–Cu–Co (Nova–Bollinger).

The Tropicana–Havana deposit in the Tropicana Zone in the northeastern part of the orogen is currently being mined, and an underground mine for the Nova–Bollinger Ni–Cu sulfide deposit in the Fraser Zone is under construction. These recent discoveries are significant because they demonstrate that regions previously thought as unprospective, often because they were perceived to be ‘the wrong age’, were simply poorly understood. The provinces of the Eucla basement have potential for Cu–Au (including nonsubduction-related porphyry, subduction or

arc related, and exhalative or VMS style), IOCG, Ni–Cu–PGE, and Ni-sulfide deposits, although it is conceivable that other types of deposits could occur. Both the Albany–Fraser Orogen and the adjoining Eucla basement are major greenfields exploration regions.

Previous work and modern datasets available

Previous work in the Albany–Fraser Orogen consists of first-edition 1:250 000-scale geological mapping, limited university research studies focused mainly on the central and western parts of the orogen, and reconnaissance mapping and sampling by GSWA (John Myers) in 1985 and the early 1990s. Since that time, GSWA has acquired geophysical datasets for both the Albany–Fraser Orogen and Eucla basement including 400–200 m line-spaced aeromagnetic data and 2.5 km grid-spaced gravity data. These are combined with numerous, higher resolution company datasets that are continually becoming available due to new exploration interest in the region. These datasets are critical because much of the region is covered by either extensive regolith or younger basin rocks. Four deep crustal seismic lines (west Esperance [12GA-AF2], east Esperance [12GA-AF1], Trans-Australian Railway [12GA-AF3], and Tropicana region [12GA-T1]) and three MT lines have been acquired and interpreted. In 2013 seismic line 12GA-AF3 and MT acquisition were continued from Haig to the South Australian border (Western Australian component), and through to Tarcoola (South Australian component; the 13GA-EG1 Eucla–Gawler line). The interpretations of the full line and accompanying geophysical data were released in June 2016 at the Australian Earth Sciences Convention. The success of this release was dependent on effective collaboration between GSWA, the Geological Survey of South Australia, and GA.

The increasing availability of exploration diamond drillcores (most of which is through the EIS co-funding initiative) and the EIS stratigraphic drilling program in the Eucla basement, have provided essential material for ongoing analytical work such as geochemistry, isotope analysis, geochronology, structural analysis, and mineral systems studies. Combined with the geophysical data, these drillcores provide a valuable means of mapping under cover.

Major uncertainties relating to the geological framework and mineral deposits

Significant progress has been made in recent years, and there is now a good understanding of the architecture and geodynamic evolution of the Albany–Fraser Orogen. The eastern extent of the Albany–Fraser Orogen, and adjoining Eucla basement, remain the most challenging regions largely because of the extensive cover. The Eucla basement contains the Madura and Coompana Provinces, which are separated from the Albany–Fraser Orogen by the Rodona Shear Zone. Although recognized as a major structure and suture zone, the kinematic history of the Rodona Shear Zone can only be determined through geophysical analysis, aided by data from the few available drillcores. Drillcores, particularly diamond cores, are of utmost importance in regions that are entirely unexposed because they permit the use of current project mapping methods of integrating geophysical interpretation with geochronology, geochemistry, isotope geochemistry, and structural and metamorphic analysis to be used under cover. These methods are necessary to constrain the evolution of the various tectonic units and their prospectivity.

While a handful of diamond drillholes exists in the Madura Province, no basement mineral exploration holes have been drilled in the Western Coompana Province. The EIS Eucla basement stratigraphic drilling program has partly addressed this deficiency, with five stratigraphic holes now drilled in the Western Coompana Province, and three in the Madura Province.

One of the aims of this project is to open up new frontiers in mineral exploration in these greenfields regions by understanding the magmatic, sedimentary, and tectonic environments. This allows exploration teams to better evaluate prospectivity and potential targets. This is exemplified by the discovery of the Ni–Cu sulfide deposit at Nova in the Fraser Zone, and the ongoing exploration to find similar deposits in this region. Previously, the Fraser Zone was interpreted to be a remnant of one or more oceanic arcs, but analysis of whole-rock geochemical data and isotope data has shown that this is not the case, and that the Fraser Zone gabbros were intruded into a deep basin through Yilgarn–Biranup continental basement, in the presence of a high geothermal gradient.

The Madura and Western Coompana Provinces are virtually unexplored, although there is some indication of Ni and PGE mineralization in the c. 1410 Ma Loongana intrusion, now interpreted as an oceanic arc. There is also the potential for Cu in much of the region, as indicated by its presence in most of the stratigraphic cores. The presence of Macquarie Arc-like shoshonites in the Western Coompana Province is encouraging for Cu–Au. The Coompana Province presents an entirely new region that is linked tectonically to the Gawler Craton in South Australia. The new drillcores from the EIS Eucla basement stratigraphic drilling program, and the 13GA-EG1 Eucla–Gawler seismic line, have been of enormous value in constraining these relationships.

Outcomes of work program 2015–16

Significant advances have been made in our understanding of the evolution of the Albany–Fraser Orogen and Eucla basement. The main advances are:

- the Eucla basement stratigraphic drillcores have revolutionized understanding of the Madura and Coompana Provinces by providing detailed information about the rock types present, their petrogenetic evolution and age, and structural history
- interpretation of seismic line 13GA-EG1, combined with 12GA-AF3, has provided a crustal-scale cross-section from the Yilgarn Craton to the Gawler Craton in South Australia. The section shows significant differences in crustal architecture along the two craton edges, relating to differences in their evolution, and the effects of the Maralinga Event
- results from the ARC Linkage project passive seismic ‘ALFREX’ array have shown 3D crustal features including a linear section of thicker crust between the Yilgarn Craton and the Fraser Zone. This highlights the difference between crustal rheology and its effect on controlling magmatism
- deep crustal geophysical data analysis and modelling allows full integration of the increasing array of geophysical datasets available, which, in conjunction with geological information, are providing insight into the crustal architecture in 3D, and the role of major structures.

In the Fraser Zone, ongoing collaborative work with Curtin University includes sulfur isotope, mineral, and geochemical studies to assess the mineralization potential for the region, P–T analysis of gabbroic rocks to determine magmatic and metamorphic conditions of emplacement and deformation, and detailed geophysical interpretation and structural mapping. All of these are helping determine the tectonic environment of mineralization and prospectivity of the region.

Products released 2015–16

Plates 1–4, final versions accompanying Record 2014/6 Albany–Fraser Orogen seismic and magnetotelluric (MT) workshop 2014

Record 2015/10 Eucla basement stratigraphic drilling results release workshop: extended abstracts volume

Extended abstract Interpretation of the western Gawler Craton section of seismic line 13GA-EG1, Report Book 2015/00029, Department of State Development, Adelaide, South Australia

Record 2016/2 Extended abstract Exposing the Eucla basement — what separates the Albany–Fraser Orogen and the Gawler Craton?

Record 2016/8 The evolution of mafic and ultramafic rocks of the Mesoproterozoic Fraser Zone, Albany–Fraser Orogen, and implications for Ni–Cu sulfide potential of the region

1: 250 000-scale pre-Mesozoic interpreted bedrock geology of the East Albany–Fraser Orogen

East Albany–Fraser Orogen Geological Exploration Package (GEP)

Posters for GSWA 2016

Products released 2015–16

Ten abstracts and presentations for the Australian Earth Science Convention (AESC), including the release of the interpretation of 13GA-EG1

Three external publications — see Appendix B

Planned work program and products 2016–17

Key targets are to:

- consolidate and publish the results from several geophysics projects
- publish a detailed comprehensive Report on the Eucla basement
- update and expand the contributions in the Explanatory Notes online database
- continue 1:100 000-scale series mapping that has recently commenced and which is focused on the Fraser Zone and adjoining regions (map sheets FRASER RANGE and MOUNT ANDREW).

The field mapping work is integrated with detailed structural analysis to determine the kinematic evolution of the southern Fraser Zone and adjoining Biranup Zone (the ‘S-bend’ area), a new Minerals Research Institute of Western Australia (MRIWA) project in collaboration with industry and Curtin University, and with GS61 regional work, particularly in the eastern Nornalup Zone.

Because of extensive cover, these studies all utilize available drillcores, including donated core and EIS co-funded cores, and interpretation of high-resolution magnetic data flown by exploration companies. The new MRIWA project is a collaboration between exploration industry sponsors and Curtin University (Associate Professor Chris Kirkland and Dr Katy Evans) titled ‘Mineral systems on the margin of cratons: Albany–Fraser Orogen — Eucla basement case study’. It has three modules looking at: 1) isotopic monitors of crustal evolution, 2) petrochronology, (3) sulfides sources and budgets. Pilot work has included sulfur isotope analysis (Dr Katy Evans) and metamorphic work on the Fraser Zone (Dr Tim Johnson, Curtin University). The latter is designed to determine the crustal depth and temperature of magmatism and metamorphism of these rocks (the P–T path), and compare them to the P–T conditions already determined for the metasedimentary rocks they intrude. The Fraser Zone work leads on from collaborative work with Professor Wolfgang Maier (Cardiff University) looking at the petrogenesis, metamorphism and economic prospectivity of mafic and ultramafic rocks of the Fraser Zone. The petrochronology module in the new MRIWA project will add to GSWA’s existing zircon geochronology program by coupling U–Pb geochronology (on a wide range of different mineral phases) to the grain-scale mineral chemistry as a proxy for the conditions of the crust during specific periods in time.

The ARC Linkage grant with the Australian National University (ANU) is nearing completion. This was set

up to examine the 3D structure of the lithosphere of the Albany–Fraser Orogen and adjacent Yilgarn Craton through passive seismic data acquisition and analysis. Both deployments have finished successfully, and the data are being analysed and interpreted. In conjunction with external publications, these results and interpretations will be published in a GSWA Record, and the data will be made available online.

Following the release of the interpretation of 13GA-EG1, the Eucla–Gawler seismic line, MT data, and potential field data modelling at a dedicated session at AESC in June 2016, these results will be published in a co-branded GSWA–Geological Survey of South Australia–GA Record. This work also links GS61 with GSWA’s 3D section, and includes further interpretations of the Albany–Fraser seismic and MT lines, potential field data modelling, and construction of 3D models.

Products planned for release 2016–17

Proterozoic basement geology under the Nullarbor Plain (Report)

Results from hylogger data from the Eucla (CSIRO report) (Record)

A magnetotelluric survey across the Albany–Fraser Orogen and adjacent Yilgarn Craton (Record)

Constraints on the 3D structure of the Albany–Fraser Orogen from passive seismic data (Record)

Eucla–Gawler seismic line and MT data interpretation (Record)

Eucla–Gawler seismic line and MT interpretation (Plate)

Geological framework and events of the Albany–Fraser Orogen, Madura and Western Coompana Provinces (Record)

Five external publications — see Appendix B

Planned work program, products 2017–18 and beyond

The focus for 2017–18 will be production of the first IBG map at 1:250 000 scale of the Eucla basement, as part of a Geological Exploration Package (GEP). The IBG will use the results of the Eucla basement stratigraphic drilling and interpretation of the Western Australian component of the Eucla–Gawler deep crustal seismic line and MT data.

Structural mapping of key areas and large-scale shear zones in the Albany–Fraser Orogen will continue in conjunction with 1:100 000-scale mapping. This will provide an understanding of the kinematic and magmatic history of crustal-scale features, and potential links to mineralization.

Results from the MRIWA project will be published as GSWA Records when available.

Work will commence on linking the western Albany–Fraser Orogen.

Products planned for release 2017–18

1:250 000 IBG and GEP of the Eucla basement

Record Eucla–Gawler seismic line and MT data interpretation

FRASER RANGE 1:100 000 Geological Series map

MOUNT ANDREW 1:100 000 Geological Series map

Structural evolution of the east Albany–Fraser Orogen (Report)

GS62 3D Geoscience

Manager: Klaus Gessner

Team Members: Ruth Murdie, Lucy Brisbout, Huaiyu Yuan (Macquarie University)

The emergence of 3D structural modelling and numerical simulation techniques allow the extension of knowledge from exposed and well-understood areas to inaccessible or data-poor parts of the solid Earth. These techniques also test the validity of conceptual models and interpretations. The aim of the 3D Geoscience section is to increase the knowledge of Western Australia's subsurface through the integration of geophysical, geological and geochemical data in 3D structural models.

The objectives of the 3D Geoscience section are to:

- develop the capability to build, manage, analyse and store 3D models according to GSWA quality standards and stakeholder needs
- engage with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling.

The 3D Geoscience section focuses on solid Earth models of the composition and structure of the Earth's crust and mantle at the tens to hundreds of kilometres scale. Input data include active and passive source seismic data, and measurements of mineral spectra, radiation, magnetization, density, and electrical properties. The workflow to generate 3D models involves data acquisition, processing, visualization, interpretation, publication and archiving. 3D Geoscience is committed to producing models and developing modelling workflows that satisfy the requirements of GSWA and its stakeholders, and that integrates with existing databases and products.

Outcomes of work program 2015–16

Contributions have been made to regional mapping teams, including work on the seismic interpretation of the Albany–Fraser Orogen, and forward modelling of cross-sections of 1:100 000 series map sheets in production. Please see work program ES42 for progress on EIS-funded projects, which represent the bulk of 3D Geoscience activities.

Products released 2015–16

3D Geomodel Series: Sandstone

3D Geomodel Series: Windimurra

Record 2015/11 The Sandstone greenstone belt, northern central Yilgarn Craton: 3D modelling using geological and geophysical constraints

Products released 2015–16

Record 2015/13 Saying goodbye to a 2D Earth

Record 2015/16 2nd Lithosphere Workshop Abstracts

Record 2016/3 Integrated Exploration Platform v2.5

13 external publications — see Appendix B

Planned work program, products 2016–17 and beyond

The 3D Geoscience section will continue to contribute to regional mapping project teams. The focus for 2016–17 is to contribute to the interpretation of the Eucla–Gawler seismic survey, but the team will work on a number of regional 3D modelling studies, potential field interpretations accompanying the seismic interpretation of the Eucla–Gawler seismic survey, and on fieldwork in the Murchison Domain, Capricorn and Albany–Fraser Orogen areas.

More 3D models and accompanying GSWA Records are planned for the Albany–Fraser Orogen and a 3D fault network model for the northwest and central Yilgarn Craton. Further 3D modelling work will be carried out by external collaborators on the Capricorn Orogen and the Kimberley region. Geophysical validation of cross-sections will continue for production of the 1:100 000 Geological Series maps, with an accompanying short explanatory Record.

Products planned for release 2016–17

Alteration and geochemical footprint of VMS-style mineralization, Quinns district, Murchison Domain, Western Australia (Report)

Imaging the structure of Archean fault rocks with synchrotron X-ray microtomography (Record)

The Precious Earth – Understanding Hydrothermal Ore Forming Systems (Book)

West Gawler 3D model

3D models from the Eucla Gawler seismic line (extended abstract)

Rocklea Dome 3D Model

Albany–Fraser Orogen 3D Model

Seismic Surveys 10GA-YU1, 10GA-YU2, 10GA-YU3, 11GA-SC1 (Geophysical Modelling Reports)

GSWA map sheets ATLEY, BADJA, BUNGAR, DIORITE, GOLDEN POINT, LAKE PERCY, RICHENDA, SANDSTONE/GUM CREEK, WARBURTON RANGE, YALGOO, YOUANMI (Geophysical Modelling Reports)

Specifications for submission of 3D Models to GSWA (Record)

Eight external publications — see Appendix B

GS63 Tectonic Evolution of the Fortescue and Hamersley Groups

Manager: Heather Howard

Team members: David Martin, Paul Morris

The 2775–2630 Ma volcano-sedimentary Fortescue Group and the conformably overlying 2630–2445 Ma Hamersley Group belong to the Mount Bruce Supergroup, which unconformably overlies the granite–greenstones of the Pilbara Craton in Western Australia. Not only does this supergroup incorporate the world's best preserved sequence of Archean ultramafic to felsic volcanic deposits and arguably the world's most continuous transect across the Archean–Proterozoic boundary, it remains the most economically important stratigraphic unit on the Australian continent.

The stratigraphy of the Fortescue Group has been previously described in detail by GSWA. It has an estimated thickness of 6.5 km. In most areas it is subdivided into seven formations, which are grouped into four major tectono-stratigraphic units, including several basaltic units with volumes and aerial extents similar to Phanerozoic flood basalt provinces. At the base is the Mount Roe Basalt, which consists of subaerial basaltic lavas, subaqueous basaltic (pillow) lavas and water-lain volcanoclastic rocks. This is overlain by sedimentary, mafic and felsic volcanic rocks of the Hardey Formation, subaerial basaltic flows (Kylena and Maddina Formations), sedimentary and volcanoclastic rocks (Tumbiana Formation) in the north Pilbara, and subaqueous basaltic to komatiitic lavas and volcanoclastic rocks in the south (Boongal, Pyradie, Bunjinah Formations). The uppermost unit (Jeerinah Formation) is mostly argillaceous in the north but contains abundant basaltic lava and volcanoclastic rocks in the south.

The Hamersley Group is a dominantly low-grade metasedimentary succession that includes chert, banded iron-formation (BIF), jaspilite, dolomite, mudstone, siltstone, felsic volcanic rocks and numerous dolerite sills. It is subdivided (in ascending order) into the Marra Mamba Iron Formation, Wittenoom Formation, Mount Sylvia Formation, Mount McRae Shale, Brockman Iron Formation, Weeli Wolli Formation, Woongarra Rhyolite and Boolgeeda Iron Formation.

Mantle plumes have been proposed to explain the evolution of many Phanerozoic flood basalt provinces in general; however, the three main basaltic units of the Fortescue Group were interrupted by sedimentary deposition (Hardey and Tumbiana Formations) and therefore, a single plume model is inadequate. The lower part of the Fortescue Group has been interpreted in terms of a two-phase continental breakup model, but

an alternative explanation argued that discrete periods of lithospheric extension alone, related to continental breakup, could account for this flood basalt volcanism.

GSWA suggested the Fortescue Group is part of a rift sequence where west-northwesterly trending faults controlled the margins of the rift and were buried beneath a breakup unconformity. This was overlain by a passive margin sequence, comprising the uppermost unit of the Fortescue Group and overlying Hamersley Group. A collisional setting for the BIF and mafic and felsic rocks in the upper part of the Hamersley Group has been proposed. The debate on stratigraphic definition, tectonic setting and evolution of the Mount Bruce Supergroup remains largely unresolved.

Second-edition 1:250 000-scale mapping of the Fortescue and Hamersley Basins region was completed between 1980 and 1992, and several areas, mainly overlying the northern part of the Pilbara Craton, were also covered by 1:100 000-scale mapping during the 1990s and 2000s. In 2011, 581 km of deep seismic reflection data was acquired along several traverses from the Pilbara Craton, across the Capricorn Orogen to the Yilgarn Craton. One of these lines (10GA-CP1) imaged the Fortescue and Hamersley Basins. Aerial magnetic and radiometric data at 400 m line spacing is available from government or commercial sources over the area. Recent LANDSAT satellite imagery and orthophotography are also available.

Since GSWA mapping in the region, there have been significant advances in the understanding of the tectonic history of the Capricorn Orogen, the northern margin of which includes Fortescue and Hamersley Group rocks within the Ophthalmia Fold Belt. No regional synthesis of the structural history and tectonic setting of the Ophthalmia Orogeny has ever been undertaken.

SHRIMP U–Pb zircon geochronology carried out on the succession by GSWA was limited and whole-rock geochemical data was mainly acquired before the widespread use of modern LA-ICP-MS techniques. In terms of both high-quality geochemical and isotopic data, the Fortescue and Hamersley Basins remain distinctly underpopulated compared with the geological regions to the north and south.

Importantly, the well-preserved felsic, mafic and ultramafic units within the Fortescue Group are also partial age equivalents of volcano-sedimentary sequences

accumulating in the Yilgarn Craton. As such, they not only provide an ideal opportunity to understand the petrogenesis of Archean greenstone-related sequences but also to understand the tectonic setting that led to economically important Proterozoic deposits of the Hamersley Group. Despite this, a detailed, systematic, regional synthesis of the geochemical variation of magmatic units throughout the entire Mount Bruce Supergroup has not been undertaken.

Planned work program, products 2016–17 and beyond

The main objective of the project is to increase the geological knowledge of the Fortescue and Hamersley Groups in terms of their context within the wider Mount Bruce Supergroup and Capricorn Orogen. This will mainly involve using spatially and stratigraphically controlled, detailed, high-precision geochemical, isotopic and geochronological data, obtained from outcrop and diamond drillhole sampling. Limited remapping of significant stratigraphic and structural relationships will be carried out where appropriate.

Initial objectives are to:

- establish datasets that will allow the construction of a ‘magmatic-stratigraphy’ of the Mount Bruce Supergroup in key areas and extend this to a regional scale. This will also include (for example):
 - o establish which of the mafic intrusive rocks of the region are related to the Fortescue and Hamersley Groups
 - o establish the geochemical relationship between felsic igneous rocks of the Fortescue and Hamersley Groups and the associated mafic and ultramafic rocks
 - o investigate the geochemical relationship between felsic igneous rocks of the Fortescue and Hamersley Groups and the associated mafic and ultramafic rocks
 - o use lithogeochemistry to characterize associated sedimentary rocks, and determine the relative contribution of terrigenous vs volcanic sources
- re-evaluate the definition of the Mount Bruce Supergroup and revise where necessary
- understand the relationships between the volcanic and sedimentary units and integrate this with petrogenetic constraints on magmatism to better constrain the tectonic evolution of the Mount Bruce Supergroup.

The work program has initially focused on a literature review and the collation of available legacy data from the Fortescue and Hamersley Groups. HyLogger scanning of drillcore from the Hamersley Basin has also commenced. These data will form a component of a digital package to be released in 2017–18. The first year of the project has involved limited fieldwork, aimed primarily at validating existing mapping and identifying areas for detailed future work. Systematic sampling of mafic and felsic igneous units that belong to the Mount Bruce Supergroup has begun and will form part of the larger geochemical sampling program.

Products planned for release 2017–18 and beyond

Compilation of legacy data (aerial photographs, field notebooks, and samples), existing mapping and imagery for the project area

Reinterpretation of the bedrock geology of the southwestern Hamersley Province at 1:250 000 scale

HyLogger study of hydrothermal alteration in the Fortescue Group, Hamersley Basin

Stratigraphy, structure and tectonic evolution of the Ophthalmia Orogeny (Report)

WYLOO 1:250 000 map sheet (third edition)

YARRALLOOLA 1:250 000 map sheet (second edition)

GS80 Editing and Publishing

GS81 Mapping

GS82 Graphics

GS83 GIS Services

GS84 Spatial Systems

GS85 Geoscience Promotions

General Manager: Stephen Bandy

Team members: Ryan Aston, Paul Backhouse, Robin Bower (Manager GS80), Cameron Brien, Derek Canham, Shaun Coldicutt (Manager GS81), Joel D'Antoine, Neville D'Antoine (Manager GS84), Ibrahim El-Fayoumi, Bhumita Fadadu, Marie Ferland, Annick Francois, Kiran Gavni, Kay Greenberg, Bill Hanrahan, Gary Hartley, Bec Hitchings, Arthur Hoffman (Manager GS85), Joe Hogen-Esch, Dave Horrocks, Stewart Jefferys, Jean Johnston, Murray Jones, John Kirk, David Ladbrook, Tom Lenane, Irena Lesiak, Frank Matera, Tuyen McDonald, Sue Mulligan, Margie Nash, Mittal Patel, Joyce Peng, Michael Prause (Manager GS82), Chris Schroder, Bernd Striewski, Adam Symonds, Daniel Then (Manager GS83), Brad Tapping, Darren Wallace, Stephen White

Experienced and qualified staff are critical to the quality and delivery of geoscience information produced by GSWA. These staff members include:

- geoscience editors
- cartographers
- graphic designers
- product designers
- desktop publishers
- database managers
- GIS specialists.

These program areas reside in the Geoscience Information Branch (GIB). This branch is responsible for the production of all GSWA products including geoscientific maps, manuscripts and digital datasets for delivery as hardcopy, digital media and via the internet. In addition, the team creates high-quality artwork for display and promotion, and prepares pamphlets, catalogues, flyers and other exhibition materials. The branch also manages development and maintenance of quality assurance processes that align with national and international standards. In cooperation with internal and external geoscience groups, GIB develops the data models and standards required for spatial geoscience information

management. GIB's data specialists manage GSWA spatial geoscience databases and develop web-based applications to deliver these data.

Outcomes of work program 2015–16

There was continued focus on improving access to geoscience data. Enhanced management and delivery of the data was also achieved. Major outcomes of the work program included:

- promotion of Western Australia's prospectivity at international and national conferences, and trade shows
- release of Explanatory Notes System (ENS) that provides detailed unit descriptions integrating stratigraphic relationships with links to all tectonic units and events recognized in Western Australia. It replaces the previously published Explanatory Notes manuscripts that accompanied individual 1:100 000 and 1:250 000 geological maps series
- release of WAPIMS, a petroleum exploration database containing data on wells, geophysical surveys, titles, and other related exploration and production data.

Products released in 2015–16

40 manuscripts

10 Geological Series maps (1:100 000 and 1:250 000 scale)

18 geological maps at other scales, including one printed State Geology of Western Australia 2015

16 digital products

completed Stage 1 Section 16(3) referrals assessment system tool across the Department of Lands and DMP

first 3D products – Sandstone greenstone belt and Windimurra.

Planned work program and products 2016–17

The team will continue to produce geoscientific maps, manuscripts, digital datasets and promotional materials as follows:

- 43 manuscripts
- 6 Geological Series maps (1:100 000 and 1:250 000 scale)
- 18 geological maps at other scales
- 18 digital products
- completed Stage 2 Section 16(3) referrals assessment system tool across the Department of Lands and DMP
- develop a spatial tool for MRIWA website
- redevelopment of DMP's Data and Software Centre
- further develop ENS to include regolith, geochronology and mineral systems.

Other headline deliverables for 2016–17 are outlined in the Executive Summary.

GS91 Mineral Exploration Information Management

Acting Manager: Ann Fitton

Team members: Monique Brouxhon, Subashni De Biran, Joyce Edmonds, Fiona MacCorquodale, Robert Pizzi, Christine Suchodolski, Julia Thom

GSWA has a statutory obligation to manage the collection, storage, and release of company exploration reports containing geoscience information on mining tenements in Western Australia. The archive of statutory exploration information is a valuable resource, providing a means whereby companies can assess the potential of an area and develop exploration strategies using previous data that minimizes duplication of effort and enables more efficient exploration.

The reports and information also provide valuable input to a number of GSWA mapping and resource assessment projects.

Outcomes of work program 2015–16

The updated version of the Guidelines for Mineral Exploration Reports on Mining Tenements was gazetted and published on DMP's website in February 2016. The guidelines incorporate reporting of data from new exploration techniques — the data required and data formats.

The new online report-writing application for mineral exploration reports was launched in February 2015 and has generally been well received. It has been available for 15 months during which time companies have had an

opportunity to use it for the compilation of at least one annual report. Its use is still optional and at end June 2016, more than 1200 reports had been submitted online. Current plans are for use of the online report-writing application to be mandatory from late 2016, but refinement of the application is required before then.

The ninth annual release of 950 exploration reports, after an advertising and objection period on the website in early 2016, was completed in May 2016. This consisted of reports submitted to DMP in 2010 and released under the provisions of the Mining Regulation 96(4), commonly known as the 'sunset clause'. In addition, 3086 reports were released to open file as part of the normal cancellation process of dead tenements. At the end of June 2016 more than 83 200 reports were accessible to the public on the DMP website.

The mineral drillhole and surface geochemistry database was maintained. It now contains around 2.7 million drillholes and 8.9 million surface samples, the data from which are available to the public. Updates of the whole database, including the database schema, are released bi-annually and were released in August 2015 and March 2016. Charts illustrating the annual number of drillholes, amount of metres drilled, and number of surface geochemistry samples analysed (all by sample type) are included as Figures 35–37, respectively.

Outcomes 2015–16	Current status
The updated version of the Guidelines for Mineral Exploration Reports on Mining Tenements was gazetted and published on DMP's website in February 2016	The guidelines are now enforceable
The online report-writing application for mineral exploration reports has been available for 15 months	It has generally been well received. At the end of June 2016 more than 1200 reports had been submitted via the system
Bi-annual updates of mineral drillhole and surface geochemistry database	Updates were released in August 2015 and March 2016
Annual release of reports under the 'sunset clause' legislation	The ninth annual release of 950 exploration reports under the 'sunset clause' was successfully completed in May 2016
Release of reports on dead tenements	A total of 3086 reports was released under the normal cancellation process. At end of June 2016, more than 83 200 mineral exploration reports were available on the web
Review of mineral exploration reports for compliance with the Guidelines for Mineral Exploration Reports on Mining Tenements	Reports are reviewed in the three months after receipt to ensure that companies comply with the most recent guidelines
Training in the use of the WAMEX and mineral drillhole database in both Perth and Kalgoorlie	Three training sessions per year held in Perth and Kalgoorlie (November 2015, March 2016, and June 2016)
Identification of mineral exploration core suitable for inclusion in the Perth and Kalgoorlie core libraries	Donations of mineral core continued in 2015–16 with the extended downturn in the industry. Under the circumstances, company geologists were very keen to find a good home for their valuable core

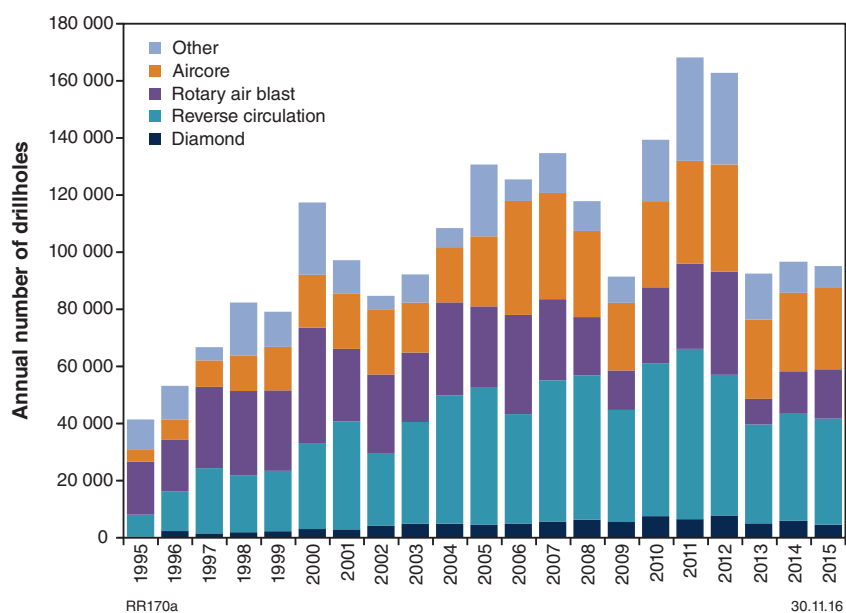


Figure 35. Drillhole database: number of drillholes recorded, by year of drilling and drilling type

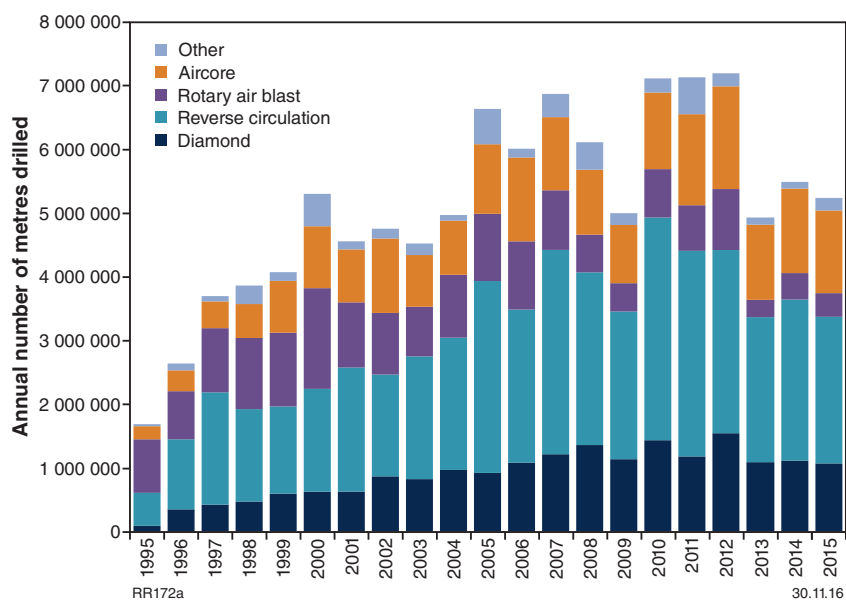


Figure 36. Drillhole database: amount of metres drilled, by year of drilling and drilling type

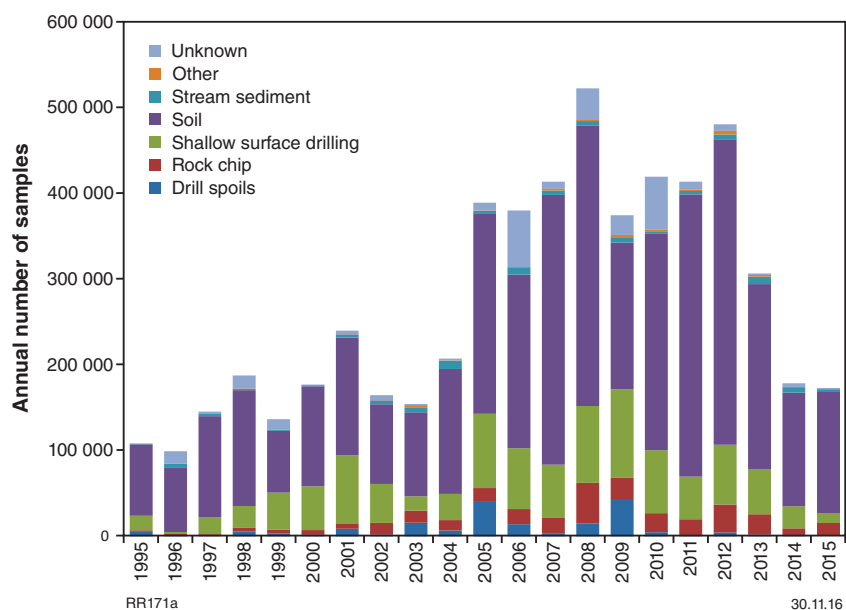


Figure 37. Drillhole database: number of surface geochemistry samples recorded, by year of sampling and sample type

Outcomes planned 2016–17

Planned activities and outcomes are to:

- formalize the online report-writing application for mineral exploration reports to become mandatory late in 2016 or early in 2017
- review and release surrender reports and their associated annual reports as they are received, together with the 10th annual release of reports under the ‘sunset clause’ legislation. This will ensure that access to this historical data increases
- release of reports that relate to exploration on dead tenements will continue, although many of these relate to tenements under the *Mining Act 1904* to which the ‘sunset clause’ does not apply
- continue review of the mineral exploration reports for compliance with the Guidelines for Mineral Exploration Reports on Mining Tenements to ensure all data is included in the report prior to archiving, and it is then ready for release via the ‘sunset clause’ or normal cancellation process
- continue bi-annual updates of mineral drillhole and surface geochemistry database
- continue training in the use of the WAMEX and mineral drillhole and surface geochemistry databases in both Perth and Kalgoorlie
- redevelop the core library database for mineral core with links to the mineral drillhole and WAMEX databases
- continue to identify and collect historical drillcore suitable for the Perth and Kalgoorlie core libraries. It was successful in 2015–16 and, under the continued industry downturn, is likely to continue to be successful during 2016–17
- continue the capture of attribute information for legacy mineral exploration core submitted to the core libraries in Perth and Kalgoorlie.

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

Team members: Alan Bloore, Brian Bradshaw, Fiona Dodd, George Karniewicz, Yanrong Li, Janine Malligan, Richard O'Brien, Yasinta Situmorang

The Statutory Petroleum Exploration Information section (SEIG) is involved with the monitoring, administration and release of petroleum and geothermal data submitted under the State Petroleum Act covering onshore and territorial sea.

From 1 January 2012, the National Offshore Petroleum Titles Administrator (NOPTA) assumed responsibility for a range of regulatory and administrative functions for Commonwealth Waters that had previously been the responsibility of the designated authorities. This includes the regulation of documentary information and petroleum mining samples (petroleum data), in accordance with Part 7 and Part 8 of the Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011 (RMA Regulations).

Under the State–Commonwealth National Collaboration Framework, DMP will continue to provide services to the Commonwealth in the handling of core, cuttings and thin sections that relate to petroleum exploration in offshore Commonwealth-controlled waters and will continue to make those samples available for viewing, further sampling and loan.

The section adds quality-assured geoscience information to the WAPIMS database, undertakes transcription and scanning programs related to State activities, and ensures data submitted are complete and in a format easily used by explorers. It also manages the release of data online through WAPIMS, including documents related to offshore activities occurring before 1 January 2012.

Priorities for transcribing and scanning legacy data are set in part by the future activities of GS10 Basins and Energy Geoscience and the Specific Area Gazettes conducted twice yearly by the Petroleum Group.

Outcomes of work program 2015–16

Outcomes 2015–16

WAPIMS redevelopment

Stage 1. Business priority to replace the external web screens and migrate WAPIMS Oracle to WAPIMS SQL. Develop online sample requests

Outcomes 2015–16

Stage 2. Develop administration component, compliance and monitoring modules to manage reports and data

Continue creating comprehensive data packages and acreage release data packages for petroleum and geothermal acreage release twice yearly

Continue accessioning the thin sections submission for State and Commonwealth wells and release them to the public

Continue sampling approvals for State and Commonwealth activities and monitor retrieving the analysis reports and the slides generated

Planned work program and products 2016–17

The section will continue loading legacy scanned and transcribed data for access via the web and add new data as received, continue quality control for onshore well log data submitted from industry, and create reports and data packages, available through WAPIMS.

A full WAPIMS in-house redevelopment began in March 2015 and is planned to be completed by June 2016. The new WAPIMS web application will be compatible with four browsers, has a map component for discovery and delivery of the data, and will contain the database for the GSWA core libraries.

Outcomes planned for 2016–17

Planned activities and outcomes are to:

- continue the testing and create enhancements to the new WAPIMS
- create forms and public reports to release online all the public geoscientific data captured in WAPIMS (State and Commonwealth)
- implement the Petroleum Online Submission — started on March 2016, to be finished by August 2016
- publish the Guidelines for petroleum data submission based on Part 8 and Part 9 of the *Petroleum and Geothermal Energy Act 1967*

- start digitizing to SEG-Y all the onshore line sections without digital data — priorities based on work done by Basins and Energy Geoscience section
- start planning and transcribing the 3480/3590 seismic data cartridges into a new media — 3592 cartridges — for the State surveys
- continue creating comprehensive data packages for petroleum and geothermal acreage release twice yearly
- continue accessioning the thin sections submission for State and Commonwealth wells and release them to the public
- continue sampling approvals for State and Commonwealth activities and monitor retrieving the analysis reports and the slides generated
- start planning for transferring the physical items stored at Kestrel/Recall (seismic tapes, cartridges, boxes, etc.) to a new location
- plan for relocation of the State and Commonwealth residues to the Carlisle facilities and expand the slides collection on SEIG area on the 1st floor Mineral House.

GS94 and GS96 Core Library Services

Managers: Paul Stephenson

Team members: Bill Anderson, Debbie Capel, Kaiping Chen, Joel Coulter, Peter Drobek, Natasha Euphemie, Simon Fanning, Jackie Flemming, Shachar Lazar, Andy Leighton, Ben Rooney, Josh Williams

GSWA's core libraries at Carlisle (Perth) and Kalgoorlie house important collections of samples of representative geology and mineral endowment of Western Australia. These collections have been sourced over many decades from government stratigraphic drilling, mineral industry donations, EIS Co-funded Drilling program, industry onshore and offshore petroleum drilling, geothermal drilling, water bores, and geotechnical drilling. This constitutes a significant source of pre-competitive geoscience information that promotes the mineral and energy prospectivity of the State, and encourages innovative resources exploration.

The Perth Core Library is also now the western hub of the National Offshore Petroleum Data and Core Repository (NOPDCR), and will store two-thirds of all Commonwealth-managed petroleum core derived from offshore drilling. This is managed under two agreements between GSWA, GA and NOPTA, providing a significant step towards a seamless service to the petroleum exploration industry.

The core library is used by GSWA, industry and academia as a geoscience training facility, and also houses the HyLogger spectral scanner, one of the six nodes of the National Virtual Core Library (NVCL) that collects extensive, objective, pre-competitive mineralogical data from archived drillcore.

Outcomes of work program 2015–16

Despite the industry downturn in both the mineral and petroleum sectors, usage of the Perth Core Library at Carlisle remains at very high levels, with all of the main indicators increasing during 2015–16 relative to 2014–15 — this continues the decade-long trend (Figs 38, 39). Stakeholders from the petroleum exploration sector consistently outnumber those in the mineral exploration sector by a ratio of almost 4:1. The work at the core libraries is labour intensive and, in total, about 110 km of core was laid out and about 2400 pallets accessed during 2015–16 at Carlisle.

Demand for core storage and viewing at DMP's Perth Core Library at Carlisle is close to capacity. The core storage facility is more than 90% full, and rack space is projected to run out by September 2016. Expansion of

the Perth Core Library is therefore urgent, and must be completed no later than the end of 2016 to ensure that it will remain of service into the foreseeable future.

In the State Budget delivered in May 2015, funding of \$4.81 million was approved for the capital cost of the core storage expansion, with expenditure spread over three years (2014–15 to 2016–17). However, planning work had already commenced by DMP, with the project being led by DMP's Facilities Services group.

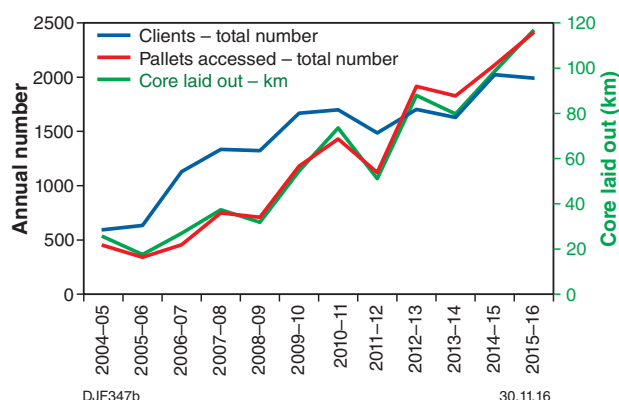


Figure 38. Perth Core Library usage statistics since 2004–05 for number of clients, pallets accessed, and core laid out

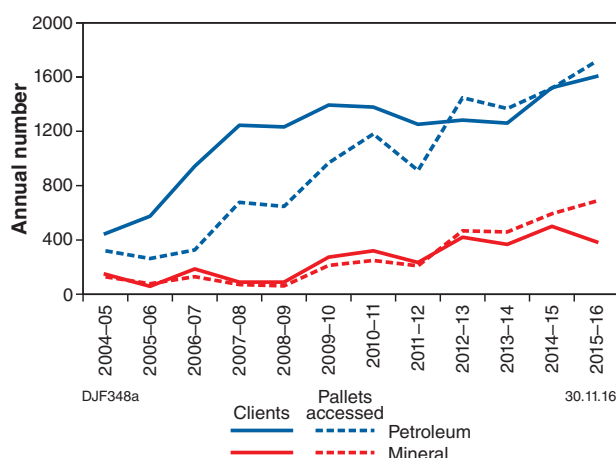


Figure 39. Perth Core Library usage statistics since 2004–05 for petroleum versus mineral clients

A second capital project planned for Carlisle (at an estimated cost of \$2.9 million) was not approved in the State Budget. That proposal was to enclose the existing uncovered external core viewing area to the southeast of the existing building. That plan was to bring all core viewing areas under cover, plus provide the opportunity to lay out confidential and open-file core separately. The plan included a conference room, kitchenette and additional unisex universal access toilets. The Commonwealth Government has acknowledged the value of the facility and offered \$1.3 million of funding towards expanding the covered viewing area, and joint Commonwealth–State funding to enclose the external viewing area was announced on 22 July 2015. The result is undoubtedly a win-win for stakeholders in all respects.

This is due for completion around October 2016.

Planned work program 2016–17

In addition to maintaining the same level of service to stakeholders, DMP's plans for Carlisle are to:

- commence and continue capital works for the expanded core storage and enclosure of the external viewing area into 2016–17
- relocate the HyLogger, which is currently in the area to be enclosed, but have it remain operational onsite at Carlisle. Once capital works are complete, the HyLogger will be housed in a climate-controlled location inside the core library building, which is due to happen in October 2016
- Purchase and use an additional high-rise turret truck (with a wire guidance system). This is an important risk mitigation measure as the old existing high-rise turret truck is subject to breakdown and liable to being out of action for five to six weeks while spare parts are obtained internationally.

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Team members: Edward Rogers, Kris Sando

The GSWA HyLogger facility is one of six State and Territory geological survey-based nodes that were established in 2009 as part of the National Collaborative Research Infrastructure Strategy (NCRIS), to provide objective mineralogical data and interpretations from drillcore (and other rock samples), thereby improving our understanding of the composition of the Australian crust. HyLogger technology collects mineral reflectance spectra in the visible near-infrared (VNIR), shortwave-infrared (SWIR), and thermal-infrared (TIR) spectral ranges, and provides objective, semi-automated interpretation of mineralogy by comparing these data to a reference library of mineral spectra using ‘The Spectral Geologist’ (TSG) software. High-definition digital images of the core are simultaneously obtained. All data are posted to a dedicated national website (the National Virtual Core Library [NVCL]) and to GeoVIEW.WA, from where they can be viewed using open-access software.

Outcomes of work program 2015–16

For the year ending 30 June 2016, the GSWA HyLogger facility collected and processed VNIR–SWIR–TIR spectral data for 41 233 m of core from 112 drillholes. These comprised 58 EIS co-funded holes, 24 geotechnical holes, and nine petroleum wells. The amount of core scanned is the second largest in the facility’s seven years of operation, and is only slightly less than for 2014–15 (Fig. 30). This was due to interruption of normal HyLogging activities for a period while the facility was temporarily relocated to make way for site redevelopment work as part of the core library expansion.

About 50% of the scanned core was derived from EIS co-funded drilling in the eastern Yilgarn Craton, and was freighted to Perth from the Joe Lord Core Library in Kalgoorlie. Other scanned core from the GSWA archives in both Kalgoorlie and Perth included material originally sourced from the Kimberley region, the Hamersley Basin, the Paterson and Musgrave Provinces, and the Capricorn and Albany–Fraser Orogens. Diamond core was also scanned from petroleum projects in the Canning and Browse Basins, as was some regolith-dominant core from shallow geotechnical drilling in the Bunbury Trough.

Some of the core from remote locations (i.e. the Kimberley and Pilbara regions) was freighted to Perth for HyLogging, using funds provided by AuScope as part of an NCRIS grant scheme. The HyLogger team was closely involved in the preparation of the grant applications to AuScope and supervision of core movement.

HyLogger staff also provided spectral data, and advice or active involvement, for several research projects including:

- collaborative EIS-funded study with CSIRO of the 3D architecture of the mantle-tapping Nanjilgardy Fault, and the gold mineralization and associated alteration spatially related to it. The final Report was released in early 2016 as GSWA Report 156, and an Extended Abstract and presentation were delivered at GSWA’s 2016 Open Day
- a collaboration with other GSWA staff to define the regional stratigraphy of the Eastern Goldfields Province, using hyperspectral, geochemical and isotopic data, validated with petrography and X-ray diffractometry (XRD)
- Harvey geosequestration drilling project (South West Hub)
- komatiite-hosted Ni mineralization at Fisher East, northeastern Yilgarn (MEconGeol, UWA/DMP)
- sedimentology and geochronology of Tumblagooda Sandstone in the Carnarvon Basin (PhD, UWA)
- depositional history and Jurassic reservoir characterization in Torosa field, Browse Basin (BSc Honours, UWA)
- hydrogeology and environmental impact to sedimentation in the Lake Walyungup, Perth Basin (MSc, UWA).

Other notable activities with which HyLogger staff were associated included:

- development of a template for a new GSWA HyLogger Record that summarizes drillhole metadata and basic mineralogical interpretations, and preparation of a first batch of five such records (in peer review)

- provision of a jointly sponsored GSWA–CSIRO–FLSmidth workshop showcasing the utility of the HyLogger for understanding mineral systems to corporate clients and users of the data. This followed successful workshops delivered in May 2014 and April 2015
- development of the ‘HyMeta’ database containing drillhole data that informs the new ‘HyLogger’ layer within GSWA’s GeoVIEW.WA map-based interface
- commissioning of a new portable/desktop XRD instrument for mineral validation work
- collaboration with CSIRO staff at the Earth Sciences Centre in Sydney and the Western Australian Centre of Excellence for 3D Mineral Mapping (C3DMM) in the interpretation and presentation of hyperspectral data, and in HyLogger maintenance
- provision of logistical and technical advice and support during installation of safety infrastructure for the redeveloped, indoor, climate-controlled HyLogger station
- provision of work experience for students from Curtin University.

Products released 2015–16

Report 156 Integrated spectral mapping of precious and base metal related mineral footprints, Nanjilgardy Fault, Western Australia (jointly published with CSIRO; significantly funded via EIS Project ES43)

Record 2016/2, Extended Abstract Integrated spectral mapping of precious and base metal-related mineral footprints, Nanjilgardy Fault, Western Australia, p. 26–30

Record 2016/2, Extended Abstract Alteration and age of the Browns Range heavy rare earth elements deposits, p. 21–25

Planned work program and products 2016–17

As of October 2016, the HyLogger will be housed in a climate-controlled location inside the core library. The facility will continue to collect and interpret spectral data from drillcore that contributes directly to increasing the knowledge of Western Australian geology and/or capabilities of the HyLogger system. Material to be analysed will include that requested by GSWA staff, academic researchers, students, and industry engaged in collaborative or other research with GSWA (including core obtained as part of the EIS). Priority of scanning is determined by a GSWA committee.

Other regular activities for 2016–17 will include periodic uploading of processed HyLogger data to the NVCL database, ensuring the release of non-confidential data to the AuScope national portal and to the DMP GeoVIEW.WA ‘HyLogger’ layer. Short GSWA reports of data processing and interpretation will be included in the final products.

HyLogger staff will collaborate in or lead several special projects in 2016–17 to:

- continue study of the regional stratigraphy of the Eastern Goldfields province
- develop procedures for using the portable/desktop XRD instrument to systematically and rapidly validate mineral identifications made by visual and hyperspectral logging of core and hand specimens. Technical support provided to GSWA geological staff using this facility
- deliver to GSWA, academic, and industry personnel of another workshop promoting the use of the hyperspectral technology.

Products planned for release 2016–17

HyLogging data processing and interpretation for assorted drillcores (numerous) (Records)

Portable XRD: applications to mineral identification in core (Record)

Two external publications — see Appendix B

Planned work program, products 2017–18 and beyond

Collection and interpretation of hyperspectral data from mineral and petroleum core will continue. HyLogger staff will continue to collaborate with GSWA colleagues and other researchers, to undertake and publish outcomes from research projects that use the HyLogger facility to collect significant fundamental data.

PART 5

EXPLORATION INCENTIVE SCHEME — DETAILED WORK PROGRAMS



ES01 Exploration and Environmental Coordination

Manager: Stephen Bandy

Team member: Steve Brown

This program aims to:

- integrate the approval process into the Mineral Titles System (eMiTS)
- track tenement applications through the various approval stages, with online access to metrics by stakeholders
- lodge and process tenement applications online and associated reporting obligations.

Planned work program, products 2016–17 and beyond

No further funding is planned under this budget item (ES01). Future work will be principally funded by DMP's recurrent budget.

Outcomes of work program 2015–16

As 2015–16 saw a significant reduction in funding, some modules in eMiTS were delayed.

<i>Planned outcomes 2015–16</i>	<i>Current status</i>
Develop a Mineral Titles geodatabase model	Suspended due to limited funding as other parts of the program were a higher priority
Continued integration of TENGGRAPH-specific business processes and workflows into eMiTS	Integration has commenced. This will be ongoing through different funding
Develop a strategy for the maintenance of tenement data using ESRI technology	Limited progress. ESRI was engaged to provide direction on web editing and desktop products
Implement TENGGRAPH enquiry replacement in production, including the provision of quick appraisal	Complete
Implement eMiTS full appraisal into the tenement approval process	Near completion. Expected release 4Q 2016
Replace the TENGGRAPH functionality that supports the spatial capture and maintenance of unsurveyed and surveyed mining/petroleum tenement/title boundaries	Suspended due to limited funding as other parts of the program were a higher priority
In conjunction with Landgate develop a strategy for the future management of surveyed tenements	Consulting with Landgate
Remove the dependence on DB2, decommission DB2 for TENGGRAPH	Suspended due to limited funding as other parts of the program were a higher priority

ES20 Government Co-funded Exploration Drilling

Manager: Margaret Ellis

Team member: Jane Forsey

This program supports innovative drilling by companies in underexplored areas. It is designed to stimulate geoscience-based, targeted exploration, and contribute to the economic development of underexplored areas in Western Australia, where additional drilling and exploration activities will lead to new discoveries and geoscience information.

The program is preferentially funding high-quality, technical and economically based projects that promote new exploration concepts and technologies. Proposals from applicants are assessed by an independent panel on the basis of geoscientific and exploration targeting merit and data generated.

An Advisory Committee, chaired by the Director General DMP and consisting of representatives from the main industry representative groups and research sector, provides advice to DMP on program guidelines. The committee, which meets twice yearly, also ensures that the program is relevant to the exploration industry.

The program refunds up to 50% of direct drilling costs. However, there is a funding cap of \$30 000 for genuine prospectors, \$150 000 for multi-hole projects, and \$200 000 for deep single-hole projects.

As a result of feedback from previous rounds of applicants, beginning in 2011 there are now two rounds of co-funding per year running either over a financial or calendar year. This has resulted in an increase in the number of offers made in a financial year and in the number of projects usually completed (Fig. 40). Successful applicants are required to complete the proposed drilling project within either the relevant financial or calendar year. Interim and final drilling reports plus core, where cored drilling is undertaken, are submitted to DMP before payment of the refunds, and the final report and core are released to open file after a six-month confidentiality period.

During 2015–16 drilling from three rounds was undertaken by exploration companies. As can be seen highlighted by the red rectangle in Figure 41, three rounds overlapped the reporting year. Round 10 projects covered the 2015 calendar year, with a number of projects drilled between July and December 2015. Round 11 projects were drilled between July 2015 and June 2016, and Round 12 covered projects drilled during the 2016 calendar year, with a number of Round 12 projects drilled in the first six months of 2016.

Outcomes of work program 2015–16

Successful drilling projects usually cannot be deemed to be so after one drilling campaign. The successes listed below are some of those announced for drilling projects which have received co-funding in 2015–16 or in previous years.

Highlights of the 2015–16 program include:

- Caravel Minerals released the maiden indicated and inferred mineral resource for their Calingiri copper deposit of 251 million tonnes at 0.34% copper (0.38% copper equivalent) for 844 300 tonnes of copper, above a 0.25% cut-off grade. A higher cut-off grade of 0.3% copper revealed a resource estimate of 143 Mt at 0.38% copper for 549 800 t copper. A lower cut-off grade of 0.15% copper returned 530 Mt at 0.27% copper for 1.4 Mt copper. More than 70% of the mineral resource is in the indicated category and includes higher grade zones from the near surface, remaining open along strike and at depth
- significant nickel sulphide mineralization was intersected during Poseidon's diamond drilling program, targeting an area 360 m north of the Emily Ann mine within the recently purchased Lake Johnston Project. Drillhole PLJD0002 intersected a 10.48 m wide zone of nickel mineralization grading 3.20% Ni, containing 5.72 m at 4.66% Ni and 1.29 m @ 10.22% Ni

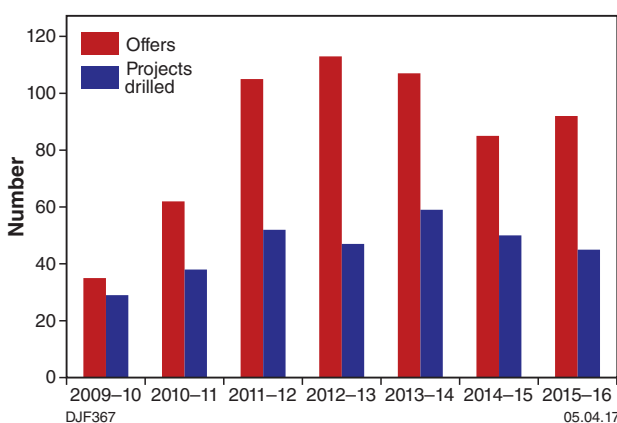
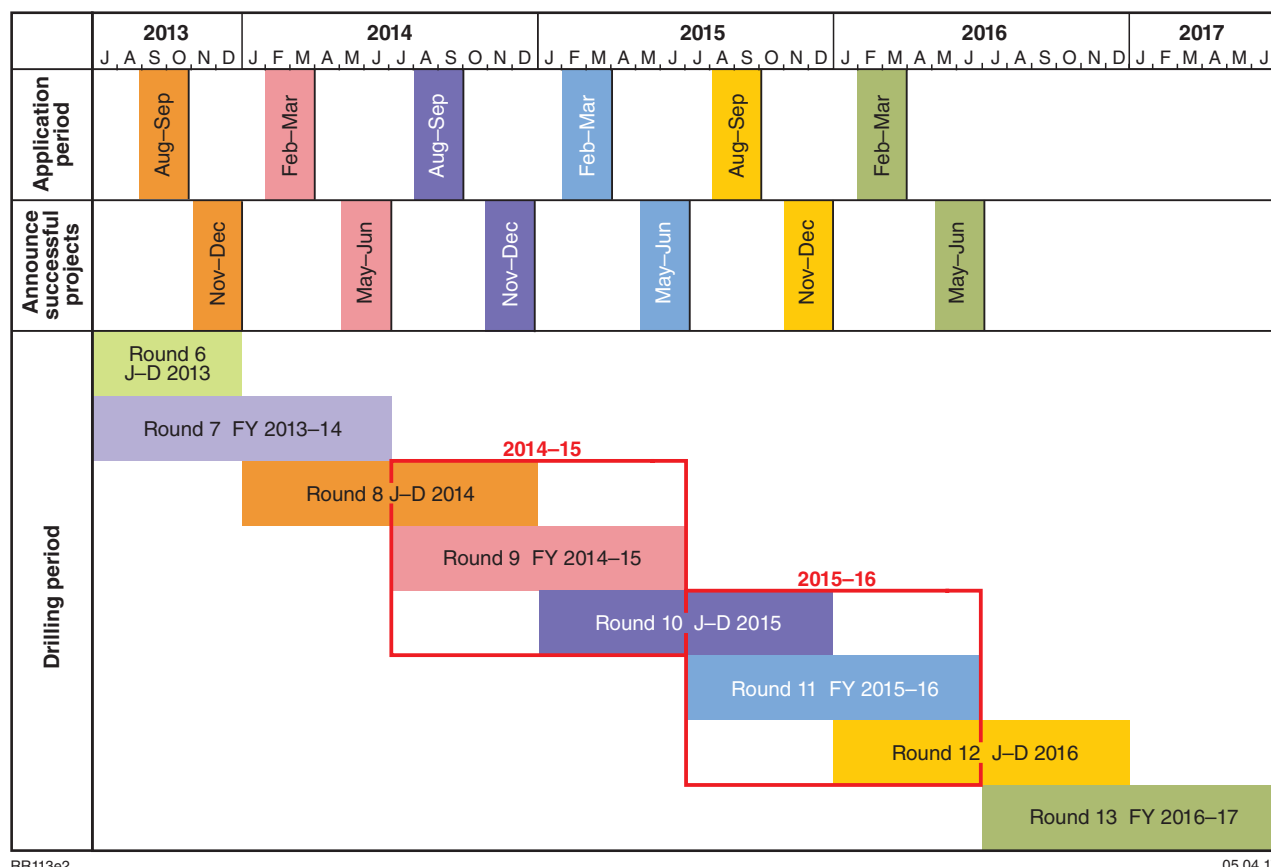


Figure 40. EIS Co-funded Drilling program — projects offered funding versus projects actually drilled, by year



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Figure 41. EIS Co-funded Drilling program — schedule of Rounds 6–13

- Gold Road Resources Limited's first diamond hole (15SYDD0003B) has been drilled at the Toppin Hill Dolerite Prospect, and completed to a depth of 501.1 m. Drilling successfully confirmed mineralization identified in previous RC drilling with an intersection of 9.14 m at 3.48 g/t Au from 143 m, including 3.48 m at 6.44 g/t Au from 143.82 m
- deep drilling confirmed gold mineralization in the Gruyere Deposit extends to more than 1100 m below surface, and 680 m below the current resource. The EIS co-funded deep stratigraphic hole successfully intersected the Gruyere Porphyry with an intersection of 92.5 m at 0.62 g/t Au from 1390 metres (57 gm).

The following outcomes were also achieved during the year:

- completion of 48 exploration drilling projects by successful recipients between July 2014 and June 2015
- drilling of 20 391 m of diamond drilling and 23 611 m of non-cored drilling
- call for applications for the 2016 round of drilling, and evaluation of applications for co-funding
- announcement of successful applications, including from prospectors, for Round 12 of Government

Co-funded Exploration Drilling to be undertaken during the 2016 calendar year, and distribution of those agreements (Fig. 42; Table 15)

- call for applications for the 2016–17 round of drilling (Round 13), and evaluation of applications for co-funding
- announcement of successful applications for Round 13 of Government Co-funded Exploration Drilling for projects to be drilled during the 2016–17 financial year, and the distribution of those agreements (Fig. 43; Table 16).

Figure 44 illustrates the wide spatial spread of drilling projects offered co-funding, together with those projects actually drilled and where drilling is in progress or still pending at 30 June 2016. A total of 647 projects has been offered co-funding up until 30 June 2016, and drilling has been completed on 321 projects. Another 44 projects have until the end of December 2016, and 48 projects have until the end of June 2017 in which to complete their drilling to retain their co-funding offers. Year-by-year statistics on the amount of diamond drilling versus drilling of all other types are illustrated in Figure 45.

General

- 1 Agnew Gold Mining Company
- 2 Anglo American - Traka Resources JV
- 3 Anglo American Exploration (Australia)
- 4 Antipa Minerals
- 5 Antipa Minerals
- 6 AusQuest Limited
- 7 Black Raven Mining
- 8 Caravel Minerals Limited
- 9 Cassini Resources Limited
- 10 David Reed
- 11 Encounter Resources
- 12 Encounter Resources
- 13 Enterprise Metals Limited
- 14 Evolution Mining
- 15 Goldphyre Resources Limited
- 16 Hanking Gold Mining Pty Ltd
- 17 IronRinger (Killarney) Pty Ltd
- 18 Kalamazoo Resources Pty Ltd
- 19 Kalgoorlie Consolidate Gold Mines
- 20 Kalium Lakes Potash Pty Ltd
- 21 Marindi Metals Pty Ltd
- 22 MRG Metals Ltd
- 23 Nexus Minerals
- 24 NiCul Minerals Limited
- 25 Northern Star Resources - Kalgoorlie Operations
- 26 Orion Gold NL
- 27 Panoramic Resources
- 28 Polar Metals Pty Ltd
- 29 Prenti Exploration Pty Ltd
- 30 Ram Resources Ltd
- 31 Redcliffe Resources Ltd
- 32 Rox Resources Limited
- 33 Rumble Resources Limited
- 34 Segue Resources Ltd
- 35 St George Mining Limited
- 36 Stirling Minerals Pty Ltd
- 37 Talisman Mining Ltd
- 38 Traka Resources Limited
- 39 Venus Metals Corporation Limited
- 40 Warriedar Pty Ltd

Prospectors

- 41 Anthony Stehn
- 42 Brutus Constructions Pty Ltd
- 43 Christopher Potts
- 44 David Pascoe
- 45 Ladislav Stanko
- 46 Peter Kerley
- 47 Steven Kean
- 48 Vanguard Exploration Ltd

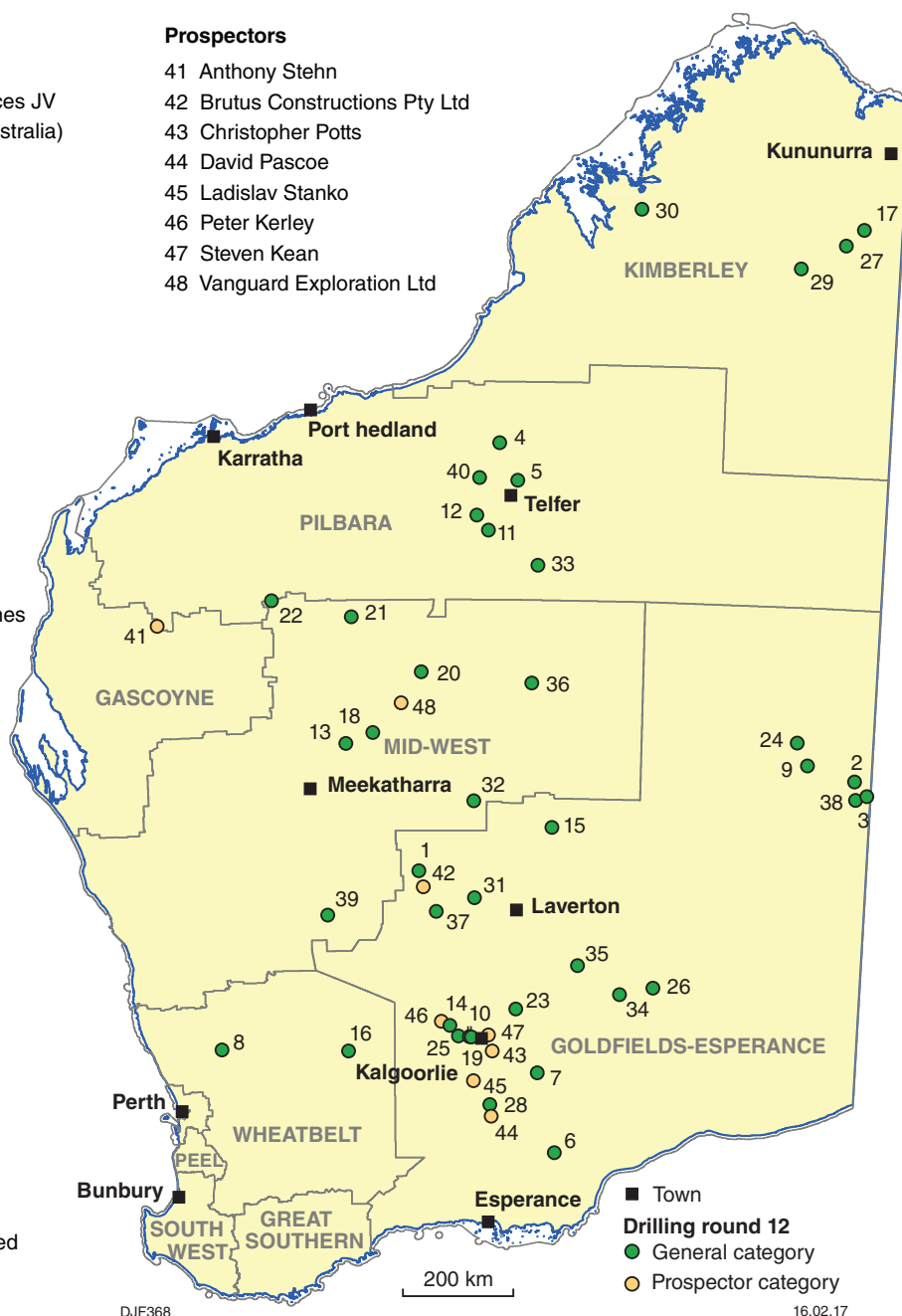


Figure 42. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 12 (for drilling during 2016)

Table 15. List of successful applicants for Round 12 of the Co-funded Drilling program (for drilling during 2016)

<i>Applicant name</i>	<i>Drilling project title</i>	<i>Target commodities</i>
Agnew Gold Mining Company	Agnew Stratigraphic	Au
Anglo American – Traka Resources JV	Musgraves Havarti Manyas La Serena project	Ni, Cu, Pt, Au
Anglo American Exploration (Aus)	West Musgraves Pepperjack and Rokpol project	Ni, Cu, Pt, Au
Antipa Minerals	Rimfire	Au, Cu, Ag, W
Antipa Minerals	North Telfer – Minyari Prospect	Au–Cu–W
AusQuest Ltd	Balladonia Nickel–Copper	Ni–Cu
Black Raven Mining	BRM – SW Target	Cu, Zn
Caravel Minerals Ltd	Wongan Hills	Cu, Au
Cassini Resources Ltd	Babylon Prospect – West Musgrave Project	Ni–Cu–PGE
David Reed	Kalgoorlie Project	Au
Encounter Resources	BM7 and BM7 East Prospects	Cu, Co
Encounter Resources	Aria Prospect	Cu, Au
Enterprise Metals Ltd	Bono GEM Anomaly	Au, Cu, Zn, Pb, Ag
Evolution Mining	Broads Dam Stratigraphic Investigation Drill Hole	Au
Goldphyre Resources Ltd	Lake Wells Potash Deep Drilling	Potash, gold, base metals
Hanking Gold Mining Pty Ltd	Copperhead Magnetic Targets	Au
IronRinger (Killarney) Pty Ltd	Killarney 3	Cu, Au, Graphite
Kalamazoo Resources	Peninsula Project	Ni–Cu–PGE
Pty Ltd	Cork Tree Copper Project	Cu
Kalgoorlie Consolidate	Oldham Range Project	Cu, Ni, Zn
Gold Mines	Central Corridor	Au
Kalium Lakes Potash Pty Ltd	Lake Sunshine Test Bores	K, Mg
Marindi Metals Pty Ltd	Prairie Downs	Cu, Pb, Zn, Ag, Au
MRG Metals Ltd	Xanadu–Pertinax Deep Hole	Au
Nexus Minerals	Pinnacles Project	Au
NiCuI Minerals Ltd	Jameson PGE Drilling, Spinifex Range Project, West Musgrave Province	Pt, Pd, Au, Cu
Northern Star Resources – Kal Ops	Star Trek Seismic Reflector	Au
Orion Gold NL	Plumridge East Gravity Targets	Ni, Cu, PGE
Panoramic Resources	Deep Diamond Drilling and Dhem, Dave Hill	Ni
Eastern Kimberley	Ni, Cu, Co, PGE	Ni, Cu, Co
Polar Metals Pty Ltd	Polar Bear Project, Nanook Gold Prospect	Au
Prenti Exploration Pty Ltd	Mad Gap Yards	Diamond
Ram Resources Ltd	West Kimberley Nickel	Ni, Cu, Co, PGE
Redcliffe Resources Ltd	Nambi Deep Drilling Program	Au
Rox Resources Ltd	Fisher East, Musket	Ni
Rumble Resources Ltd	Beadell Project Kaos and 99 IP and EM Prospects	Cu, Zn, Pb, Ag
Segue Resources Ltd	Salt Creek Complex Characterization and Prospectivity	Ni, Cu, PGE, Cr
St George Mining Ltd	Ascalon gold target	Au
Stirling Minerals Pty Ltd	Oldham Range Project	Ni, Cu, Zn
Talisman Mining Ltd	Sinclair Nickel Project – Schmitz Well South	Ni
Traka Resources Ltd	South Hill Area (Block 12 Spectrem survey area)	Cu, Ni, PGE
Venus Metals Corp Ltd	Inky South EM Copper Targets	Cu, Zn & Precious Metals
Warriedar Pty Ltd	Duke Halloysite Project	Halloysite
Anthony Stehn	Two Peaks Drilling Proposal	Au, Ag, Pb, Cu
Brutus Constructions Pty Ltd	Bottle Well Nickel Prospect	Ni
Christopher Potts	Lurgan Project	Au
David Pascoe	Waverley	Au
Ladislav Stanko	Stanko's Reward	Au, Ni
Peter Kerley	Never Can Tell	Au
Steven Kean	Turnpike	Au
Vanguard Exploration Ltd	Fairbairn Copper Project	Cu, Au

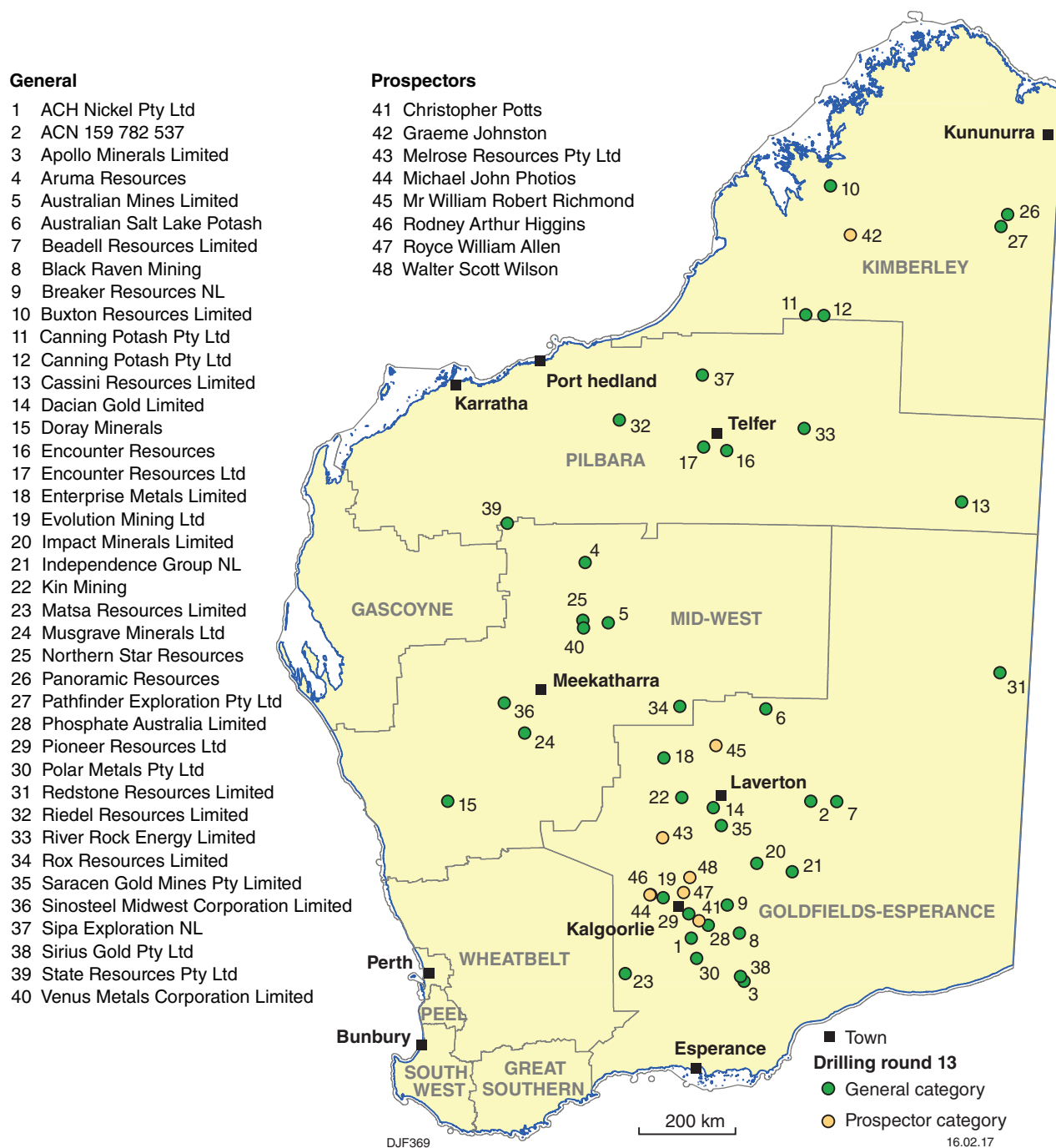


Figure 43. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 13 (for drilling during 2016–17)

Table 16. List of successful applicants for Round 13 of the Co-funded Drilling program (for drilling during 2016–17)

<i>Applicant name</i>	<i>Drilling project title</i>	<i>Target commodities</i>
ACH Nickel Pty Ltd	Foster Deeps	Ni, Au
ACN 159 782 537	Lake Rason	Sulphate of potash
Apollo Minerals Ltd	Plato Drilling Project	Ni, Cu
Aruma Resources	Bulloo Downs Copper	Cu, Au, Ag
Australian Mines Ltd	Dixon gold prospect	Au
Australian Salt Lake Potash	Lake Wells Potash Exploration	Sulphate of potash
Beadell Resources Ltd	Targetted AC Drilling at Neale	Au, Cu, Ni
Black Raven Mining	Erayinia King NW	Zn, Cu, Au
Breaker Resources NL	Bombora Prospect, Lake Roe Project	Au, base metals
Buxton Resources Ltd	Double Magic Project	Ni, Cu
Canning Potash Pty Ltd	West McLarty	Potash
Canning Potash Pty Ltd	East McLarty	Potash
Cassini Resources Ltd	X17	Zn, Pb
Dacian Gold Ltd	Callisto	Au
Doray Minerals	Gearless Well Stratigraphy	Au, Cu, Ag, Pb, Zn
Encounter Resources	Dora	Au, Cu
Encounter Resources	Millennium Deeps	Zn, Ag, Pb, Cu
Enterprise Metals Ltd	Jarrah Well	Au, Cu, Zn, Pb, Ag
Evolution Mining Ltd	Blue Funnel Deep Hole	Au
Impact Minerals Ltd	Mulga Tank Dunite	Ni and PGE
Independence Group NL	Rising Dragon	Ni, Cu, Co, Pt, Pd
Kin Mining	Merton's Reward	Au
Matsa Resources Ltd	Mt Day	Ni
Musgrave Minerals Ltd	Eelya Hill VMS	Cu, Au, Zn
Northern Star Resources	Timor North Offset	Au
Panoramic Resources	Savannah North Intrusion	Ni
Pathfinder Exploration Pty Ltd	Garnet Hills Project	Garnet, Cu, Sn, W
Phosphate Australia Ltd	Randalls	Au
Pioneer Resources Ltd	Blair Dome	Ni
Polar Metals Pty Ltd	Polar Bear Project	Au
Redstone Resources Ltd	Blackstone Range (Tollu)	Cu, Ni, Co
Riedel Resources Ltd	Charteris Creek	Cu, Mo, Au
River Rock Energy Ltd	Percival Lakes Potash Project	K, Br, Li
Rox Resources Ltd	Fisher East project	Ni
Saracen Gold Mines Pty Ltd	Red October	Au
Sinosteel Midwest Corporation Ltd	Weld Range Project	Ni, Cu, PGE, Zn, Cu
Sipa Exploration NL	Paterson North	Cu, Au, Bi, Ni
Sirius Gold Pty Ltd	North Bore	Ni, Cu, Co Pt, Pd
State Resources Pty Ltd	Turee Creek Gold	Au
Venus Metals Corporation Ltd	Curara Well	Diamonds, Au, Cu
Christopher Potts	Messina	Au
Graeme Johnston	MHY 1 Diamond Project	Diamond
Melrose Resources Pty Ltd	Jasper Well	Au
Michael John Photios	Slattery Dam	Au, Ni
Mr William Robert Richmond	Duketon gold/base metals project	Au, Ag, Cu, Pb, Zn
Rodney Arthur Higgins	Slattery Dam	Au, Ni
Royce William Allen	Gordons	Au
Walter Scott Wilson	Lady Betty	Au

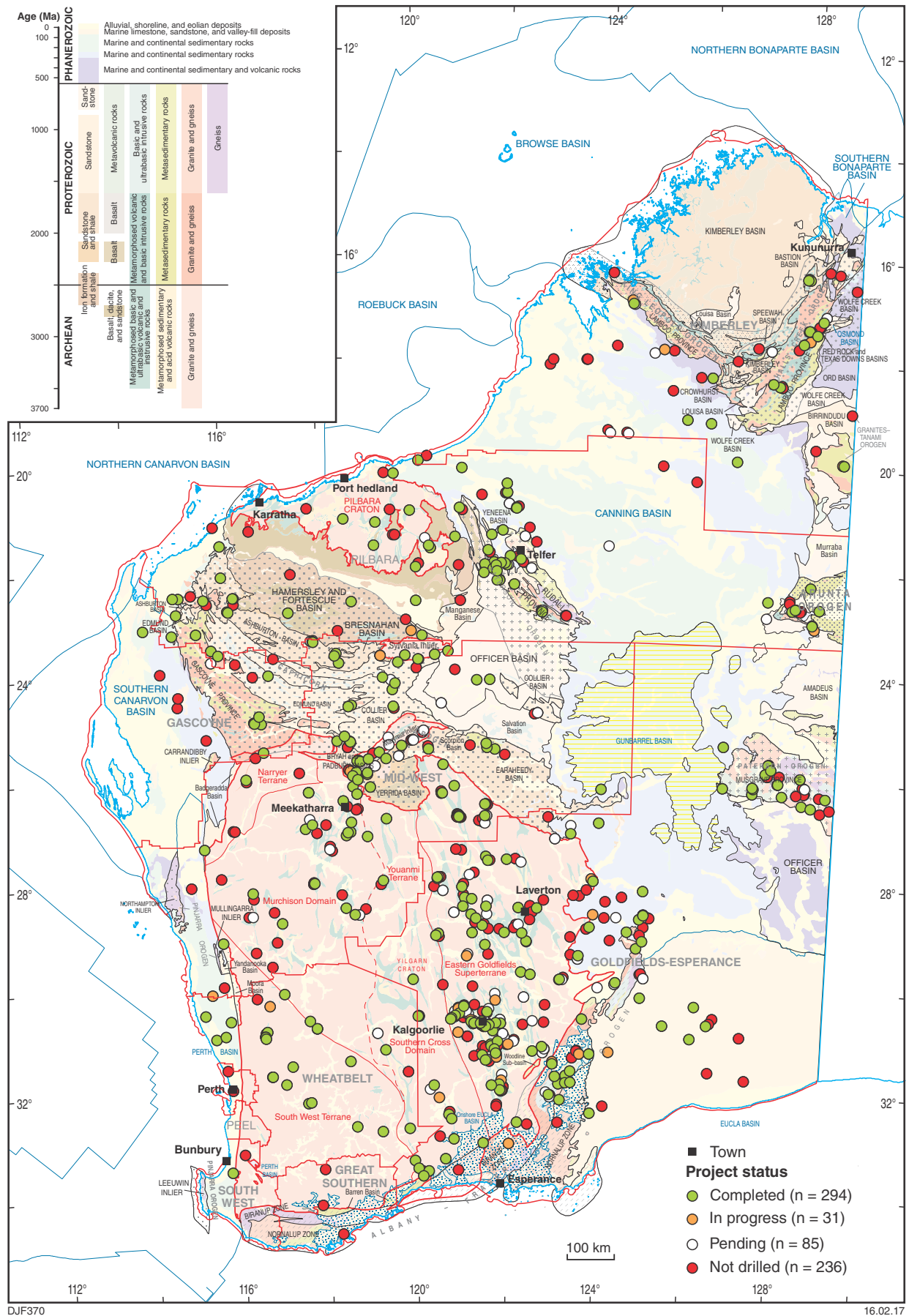


Figure 44. EIS Co-funded Drilling program — map showing projects offered funding in Rounds 1–13 inclusive (646 projects) and the status of drilling at 30 June 2016

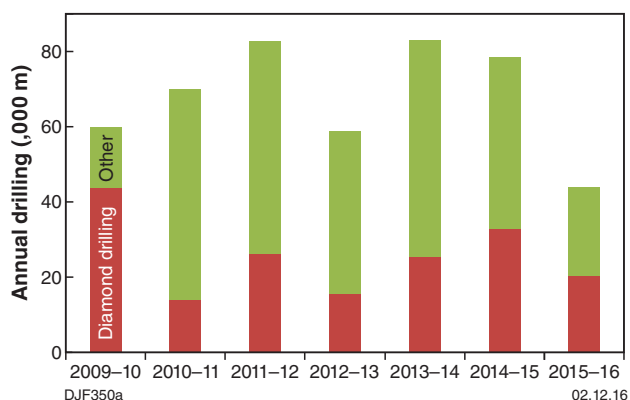


Figure 45. EIS diamond drilling versus all other drilling types

Planned work program 2016–17 and beyond

The drilling projects that were successful in gaining co-funding in Round 13 will be undertaken during the 2016–17 financial year. All relevant data and core will be submitted and subsequently released to open file.

Round 14 of the Co-funded Drilling program will be advertised, with an application period between September and early October 2016. This round is offering about \$5 million to support drilling projects undertaken during the 2017 calendar year.

Round 15 will be open for applications in late February 2017 for applications for drilling projects to be drilled during the 2017–18 financial year.

ES21 Mineral and Exploration Promotion

Manager: Gaomai Trench

The objective of the project is to promote opportunities for mineral and petroleum investment into Western Australia to accelerate mineral exploration and discovery. This involves attracting new resource investment while at the same time nurturing relationships with existing investors. Investment attraction is even more critical in these difficult times when junior mineral and petroleum explorers are starved of their life-blood — equity funding.

Promotional activities are undertaken proactively, individually through GSWA's own direct efforts, and in cooperation with 'Australia Minerals', the collective name given to joint promotional activities overseas with other geological surveys across Australia. Activities undertaken by the project include the following:

- delivery of high-impact presentations and funding of exhibition booths at major investment conferences and seminars
- conducting investment workshops and seminars for small groups
- publication of promotional materials, including maps, posters and flyers
- responding to ad hoc investor requests for geoscience information, information and advice relating to policies and regulations
- supporting the Minister for Mines and Petroleum on official travel overseas
- liaising with Chinese State-owned enterprises (SOE) with offices in Western Australia
- coordinating the China Geological Survey – GSWA Technical Cooperation Program.

Outcomes of work program 2015–16

In 2015–16, the project planned and coordinated the Director General of DMP's China/Asia Investment Promotion tour (April 2016) to Hong Kong and Shenzhen, China. Key activities during this trip were:

- Hong Kong:
 - o reaffirmed relationships with major investors and potential investors

- o promoted Western Australia's track record in resource development and investment attractiveness, and met with major resource investors and key industry leaders

- o gave a keynote address at Asia Mines and Money Conference, a major event aimed at resources-related business development in Asia.

• Shenzhen:

- o encouraged more investment into Western Australia's uranium industry and learnt about the uranium demand in China.

In 2015–16, the project also funded Western Australia's presence at a number of key international events including:

- Prospectors and Developers Association of Canada Annual Convention, Trade Show and Investors Exchange (PDAC)
- Annual China Mining Conference
- Exploration and mining investment seminars in Asia (some in cooperation with Austrade and Australia Minerals)
- Annual Mining Investment Asia Congress and Mines and Money Hong Kong
- mineral promotion tour to China's Hunan province, in conjunction with an international mining forum to attract Chinese investment into the Western Australia mining industry.

Planned work program and products 2016–17

Similar promotional opportunities to those mentioned above will continue to be the focus of future work programs, some of which will be undertaken in cooperation with Australia Minerals and Austrade. In addition, promotional activities in the emerging economies of India, Taiwan and Vietnam are under consideration. The European market will be closely monitored for promotional opportunities.

ES30 Regional Airborne Surveys

Manager: David Howard

Team member: John Brett

The objective of the initial phase of the Regional Airborne Survey component of the EIS that began in 2009 was the completion of medium-resolution (200–400 m line-spacing) aeromagnetic and radiometric coverage of the State. This objective was completed by June 2013 at which time the focus shifted to the acquisition of detailed (100 m line-spacing) surveys in project-specific areas. Commencing in 2013–14, the EIS remotely sensed geophysical data acquisition program was expanded to include regional reconnaissance (5 km line-spacing) electromagnetic surveys — the Western Australia Reconnaissance AEM project (WARAEM). Airborne gravity surveys, if undertaken, are included in the ES32 Regional Gravity Surveys program.

Notification of regional survey plans and status updates are published in GSWA's Fieldnotes and on the website at <www.dmp.wa.gov.au/geophysics>.

Outcomes of work program 2015–16

The Yalgoo 100 m airborne magnetic and radiometric survey (111 000 line-km of data) that commenced in May 2015 was completed and the data published (Fig. 46).

Airborne magnetic and radiometric data from non-exclusive surveys in the Leonora and Southern Cross areas were purchased and released in June 2016 to add to the volume of open-file 100 m line-spacing datasets.

Products released 2015–16

Airborne magnetic and radiometric survey at 100 m line-spacing in the area of the Yalgoo–Singleton greenstone belt

Planned work program and products 2016–17

No surveys are planned for this period.

Planned work program, products 2017–18 and beyond

The airborne survey program for 2017–18 and beyond depends on the prevailing GSWA budget. The possibility of commencing an airborne gravity survey program is under consideration (reported separately under ES32) as well as the continuation of detailed (100 m line spacing) aeromagnetic and radiometric surveys and reconnaissance (5–10 km) electromagnetic surveys.

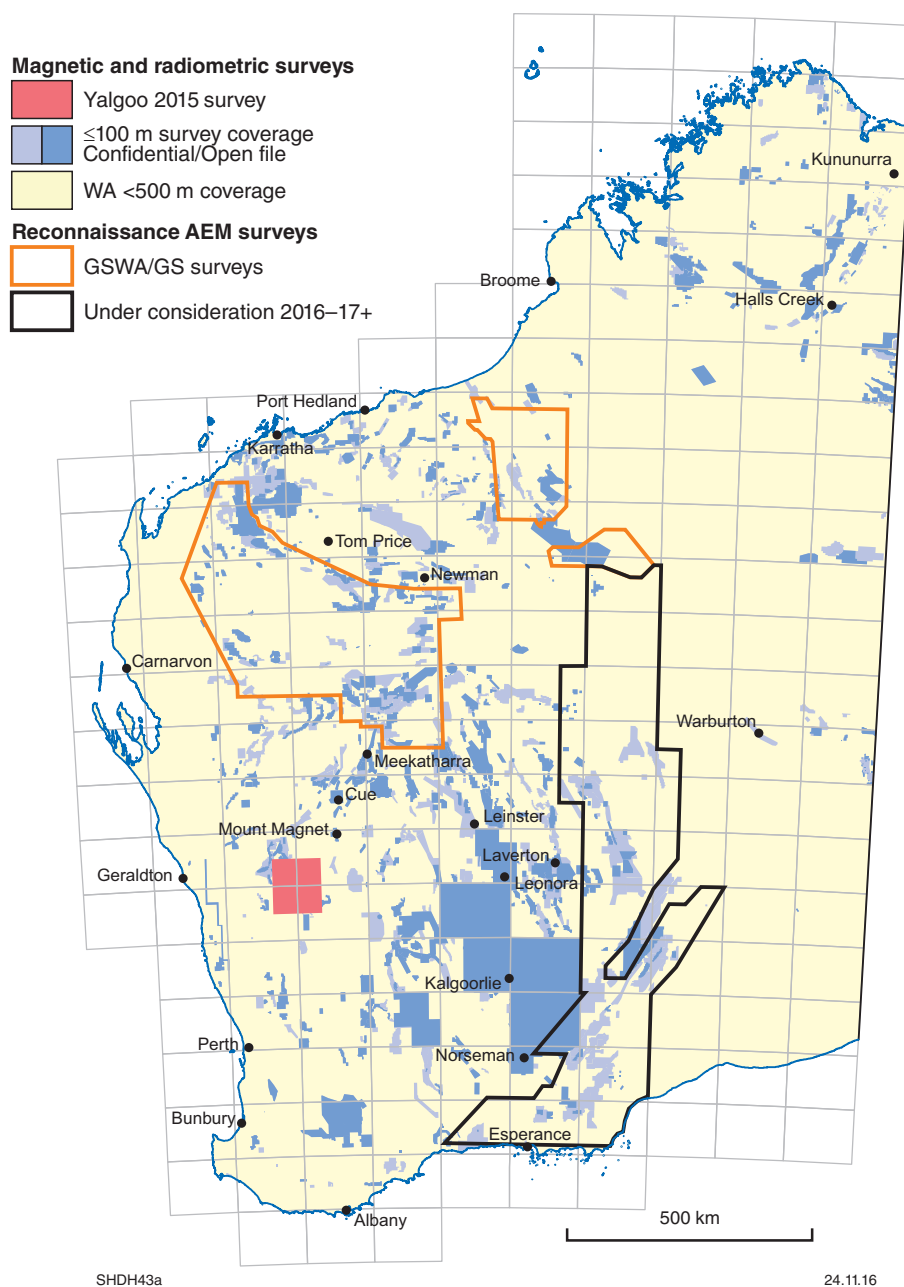


Figure 46. Regional Airborne Surveys program

ES31 Deep Seismic Survey Program

Manager: Ian Tyler

*Team members: Lucy Brisbout, Klaus Gessner, Ruth Murdie,
Catherine Spaggiari, Huaiyu Yuan*

Integrated geophysical and geological transects across the West Australian, North Australian and South Australian Cratons and their margins in Western Australia, and the intervening Neoproterozoic and Phanerozoic basins, provide a key to the geological evolution of the Australian lithosphere over some 4 billion years of Earth history. These transects also provide an understanding of the localization of mineral systems within the upper crust. In addition to the active source seismic acquisition, GSWA is collaborating on passive source surveys.

Active source

Deep seismic reflection surveys have been acquired in consultation with GA making use of National Research Facility for Earth Sounding equipment (ANSIR) where available. Exploration companies are able to contribute to lines in their areas of interest. The lines use existing roads wherever possible to minimize costs, cultural and environmental impact, and rehabilitation.

Each seismic reflection survey line is sampled for gravity, and usually for magnetotellurics (MT). Ongoing MT survey work, together with processing and interpretation will be consolidated under ES31 and will include cooperative work with the CET at UWA in the Albany–Fraser Orogen, in the Capricorn Orogen, and in the eastern Yilgarn Craton.

The deep seismic reflection surveys and MT have been complemented by targeted deployments of passive seismic arrays in collaboration with CET and the Research School of Earth Sciences at the Australian National University (ANU) to provide additional information about large-scale structures to mantle depths.

Passive source

A passive source (earthquake) survey started in early 2014 with the deployment of the Capricorn Orogen Passive Array (COPA). COPA is carried out in collaboration with the Science and Industry Endowment Fund (SIEF) Capricorn Distal Footprints project and includes collaborative research between CSIRO, UWA, Curtin University and GSWA with the objective to target mineral systems in the Capricorn Orogen. A similar study commenced in October 2013, and was completed in 2016

as a collaborative Australian Research Council Linkage Project LP130100413 ‘Craton modification and growth: The east Albany–Fraser Orogen in three dimensions’ (see also ES42 3D Geoscience and GS61 Albany–Fraser Orogen). This project investigated the lithosphere structure of the Albany–Fraser Orogen using the Albany–Fraser Experiment (ALFREX) passive seismic array. GSWA has supported the instrument deployment and data collection, and collaborated on the geological interpretation. Preliminary results were presented at the Australian Earth Science Convention in Adelaide in June 2016.

Outcomes of work program 2015–16

During 2015–16 no seismic reflection surveys and accompanying MT acquisition were carried out in Western Australia. Interpretation of the Eucla–Gawler deep seismic reflection line (13GA–EG1) was completed at workshops held in Adelaide and Perth in collaboration with GA, the Geological Survey of South Australia and AuScope, and results were presented at the Australian Earth Science Convention in Adelaide in June 2016.

Further MT acquisition in the Capricorn Orogen, supported by GSWA, continues to be carried out through CET as part of the SIEF Capricorn Distal Footprints project (Fig. 47). Two targeted passive seismic arrays continued to be deployed in 2015–16 in the areas of the Capricorn and Albany–Fraser Orogens, and were serviced and repositioned with GSWA logistical support. The COPA array in the Capricorn Orogen is being run in collaboration with CET and the Centre of Excellence for Core to Crust Fluid Systems (CCFS) as part of the Capricorn Distal Footprints project. The ALFREX array was run in the Albany–Fraser Orogen as part of a three-year ARC Linkage project with the ANU that ended in 2016.

Products released 2015–16

Record 2015/11 The Sandstone greenstone belt, northern central Yilgarn Craton: 3D modelling using geological and geophysical constraints

Windimurra Igneous Complex 3D Geomodel Series Digital Package

Sandstone Greenstone Belt 3D Geomodel Series Digital Package

11 external publications — see Appendix B

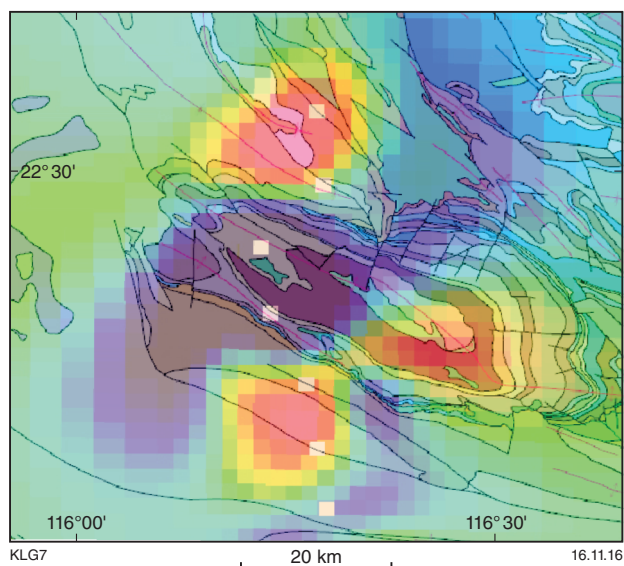


Figure 47. Conductivity at 4.5 km depth in the Wyloo Inlier area, modelled from broadband magnetotelluric sites (white squares)

Planned work program and products 2016–17

Processing and interpretation of MT in the Capricorn Orogen, supported by GSWA, will continue to be carried out through CET as part of the Capricorn Distal Footprints project.

GSWA will continue to support the deployment of the COPA passive seismic array in the Capricorn Orogen. A new permanent seismic monitoring station is being established at Telfer, funded by GSWA and installed and maintained by GA.

The COPA array is investigating the crustal structure of the Capricorn Orogen and the architecture of the lithospheric mantle. A suite of passive source methods will be applied in conjunction with the COPA to develop a technical template for revolving seismic anisotropy structure for long-operating stations.

The Albany–Fraser Orogen passive seismic array field campaign was completed in early 2016. The data is being analysed for crustal structure, velocity distribution and tectonic affiliation, and will be published in a series of journal papers and a GSWA Report.

Products planned for release 2016–17

A magnetotelluric survey across the Albany–Fraser Orogen (Report)

Release of Eucla–Gawler (13GA-EG1) seismic sections

GSWA/GA/GSSA/AuScope Plates Eucla–Gawler Deep Seismic Survey interpreted sections

GSWA/GA/GSSA/AuScope Record Interpretation of the Eucla–Gawler Deep Seismic and MT surveys

Crustal structure of the Capricorn Orogen (including MT) (Report)

COPA passive seismic array (Report)

ALFREX passive seismic array (Report)

West Gawler 3D model

Albany–Fraser Orogen 3D Model

Geophysical Modelling Reports for Seismic Surveys 10GA-YU1, 10GA-YU2, 10GA-YU3, 11GA-SC1

Four external publications — see Appendix B

ES32 Regional Gravity Surveys

Manager: David Howard

Team member: John Brett

The Regional Gravity Survey component of the EIS has the objective of completing regional medium-resolution (<4 km station spacing) gravity coverage of Western Australia — the Western Australia Reconnaissance Gravity project (WARGRAV2). The program is run in collaboration with GA under a National Collaboration Framework Agreement.

Notification of regional survey plans and status updates are published in GSWA's Fieldnotes publication and on the website at <www.dmp.wa.gov.au/geophysics>.

Outcomes of work program 2015–16

Data from the 2.5 km grid survey in the Ngururrpa lands that was completed between May and June 2015 were processed and released (4964 new stations).

The southwest Yilgarn survey which commenced in June 2015 was also completed with the publication of data from 23 736 new stations collected at a nominal 2 km spacing along public roads.

Plans for the commencement of a helicopter-assisted survey in the Wiluna region were delayed while ground

access negotiations continued with native title holders and claimants. Survey on cleared areas finally commenced at the end of June 2016 for completion in 2016–17. Any areas not cleared for access will be carried forward for completion in future surveys.

A Request for Tender was issued in June 2016 for an airborne gravity survey in the east Kimberley. It is anticipated that a contract will be awarded in July 2016 (Fig. 48).

Planned work program and products 2016–17

Completion of the Wiluna survey in areas cleared for access. Completion of the East Kimberley airborne gravity survey.

Planned work program, products 2017–18 and beyond

Area prioritization for new surveys will be determined over the course of 2016–17.

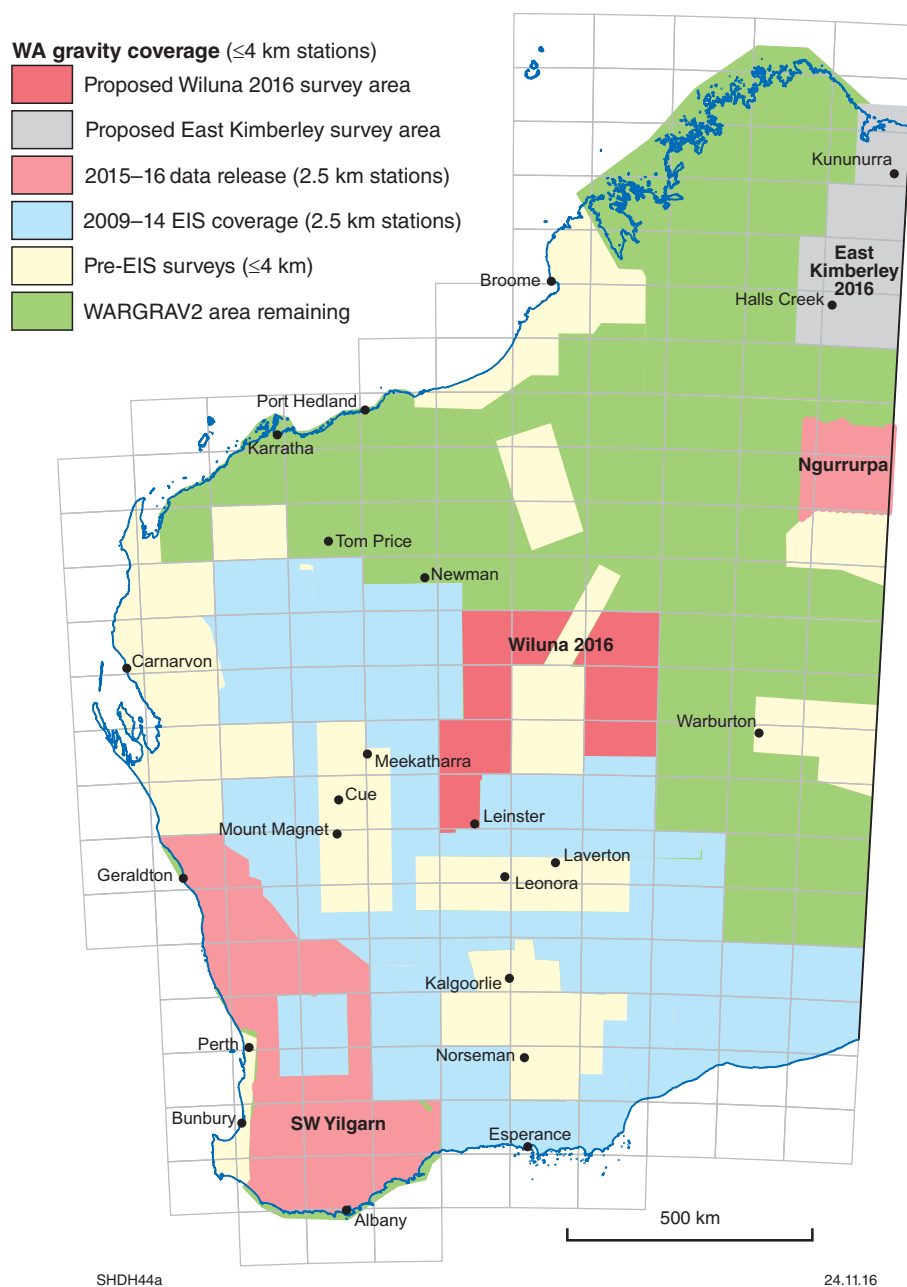


Figure 48. EIS Gravity Survey program 2015–16

ES33 Yilgarn Margin Geochemistry

Manager: Paul Morris

Team member: Nadir de Souza Kovacs

Parts of Western Australia that have a well-established mineral endowment have been subject to detailed examination in order to understand mineralization processes. Regional geophysical and geochemical datasets have extended the search space to less prospective areas — in particular craton, orogen and basin margins — resulting in the discovery of economic mineralization, such as on the southeast and northern margins of the Yilgarn Craton. Due to the lack of untenanted ground in established and new areas of mineralization, explorers are compelled to consider areas which lack contemporary, regional-scale datasets, thus increasing the exploration risk. Typically, these are areas with a thick and extensive regolith cover.

In order to better understand these areas, and provide regional-scale data to reduce the risk to mineral explorers, GSWA continues to carry out regional regolith geochemical surveys, often in tandem with the acquisition of closely spaced gravity measurements. This wider focus for the ES33 program is seen in a regolith sampling program carried out in the northeast of the State over parts of the Murrumbidgee and Canning Basins, the first time that GSWA has executed a program over basinal successions (Fig. 49). The program involved collection of 637 regolith samples at a nominal density of one sample per 12.5 km². The fine fraction of these samples, along with ferruginous lag samples where available, were analysed for at least 64 analytes, with all data released via GeochemExtract or GeoVIEW.WA on DMP's website (www.dmp.wa.gov.au). Of these regolith samples, 32 were collected from three transects across a regional fault to determine if structures are possible conduits for bedrock-derived fluids. On one of these transects, passive seismic measurements were made to investigate the thickness of regolith. An important complementary product to regolith chemistry is a map showing the distribution of different regolith–landform units. A 1:250 000-scale digital regolith–landform map of the West Arunta region is being compiled using GSWA's regolith classification scheme and approach to regolith mapping (GSWA Record 2013/7). This layer covers the LUCAS, STANMORE, WEBB, and MCDONALD 1:250 000 map sheets, and parts of HELENA and CORNISH. The Ngurruppa and Webb 1:250 000 regolith–landform maps are derived products from this digital map layer. The diversity of regolith products generated by GSWA is indicative of its commitment to better understand the regolith; GSWA is one of the few government geoscience

organizations to regularly compile and release regolith maps, resulting in an invitation to present at the Australian Regolith Geoscientists Association Meeting in February 2016.

Recognizing the expertise occult in CSIRO, programs using hydrogeochemistry as a mineral exploration tool have been co-sponsored by GSWA since 2009. This work has now been completed, and in 2015–16, two GSWA Records summarizing results of this program were published (2016/7 and 2016/9). The final phase of the hydrogeochemical work was completed in 2014–15 (M414), resulting in a MRIWA publication. GSWA funded the final analytical component of a biogeochemical study in the northeastern Yilgarn Craton – Gascoyne Province. Sampling for biogeochemistry was carried out at the same time as water sampling for the hydrogeochemistry component. The hydrogeochemistry results from the Yilgarn Craton margin project will form a significant part of a national hydrogeochemical database that is being compiled by CSIRO from 2015–18, in part sponsored by GSWA.

GSWA's use of the fine fraction of transported quartz-dominated regolith has highlighted methodology to possibly 'see through' transported cover to sequester components of buried mineralization (e.g. nano-scale metal particles) that have migrated vertically from bedrock (e.g. GSWA Record 2012/13). In order to further develop these concepts, GSWA will co-sponsor and co-research a CSIRO–MRIWA–industry project to investigate further the use of the fine fraction in mineral exploration of areas characterized by transported regolith.

Outcomes of work program 2015–16

Outcomes of the program for 2015–16 were to:

- sample and analyse regolith from 637 sites in the Ngurruppa area
- co-sponsor and co-research a CSIRO–MRIWA–industry project to examine the application of fine fraction chemistry of regolith for mineral exploration in areas of transported regolith.

Products released 2015–16

Record 2016/7 Hydrogeochemistry of Western Australia data release: accompanying notes

Record 2016/9 Improved hydrogeochemical exploration in the northwest Yilgarn

Record 2015/9 Regolith chemistry of the Balangarra area, north Kimberley

Record 2015/15 Regolith chemistry of the Bunuba and Yuriyngem–Taam areas, south Kimberley

Geochemistry of regolith samples from the Ngururpa program (digital product)

Regolith–landforms of the Balangarra area, north Kimberley, 4th Australian Regolith Geoscientists Association Conference, 42–43

Webb 1:250 000 geological series map

Drysdale – Londonderry 1:250 000 geological series map

Plate – Interpreted regolith–landform geology of the Balangarra area, north Kimberley

Plate – Interpreted regolith–landform geology of the Bunuba and Yuriyngem–Taam areas

Planned work program and products 2016–17

Compilation of results and regolith–landform mapping related to the Ngururpa program will result in the publication of a GSWA Record.

Products planned for release 2016–17

Regolith geochemistry of the Ngururpa area (Record)

Interpreted regolith–landform geology of the Ngururpa area (digital layer within the Tanami Arunta 2016 GIS package)

Interpreted regolith–landform geology of the Dambimangari area (plate)

Regolith geochemistry of the Dambimangari area, west Kimberley (Record)

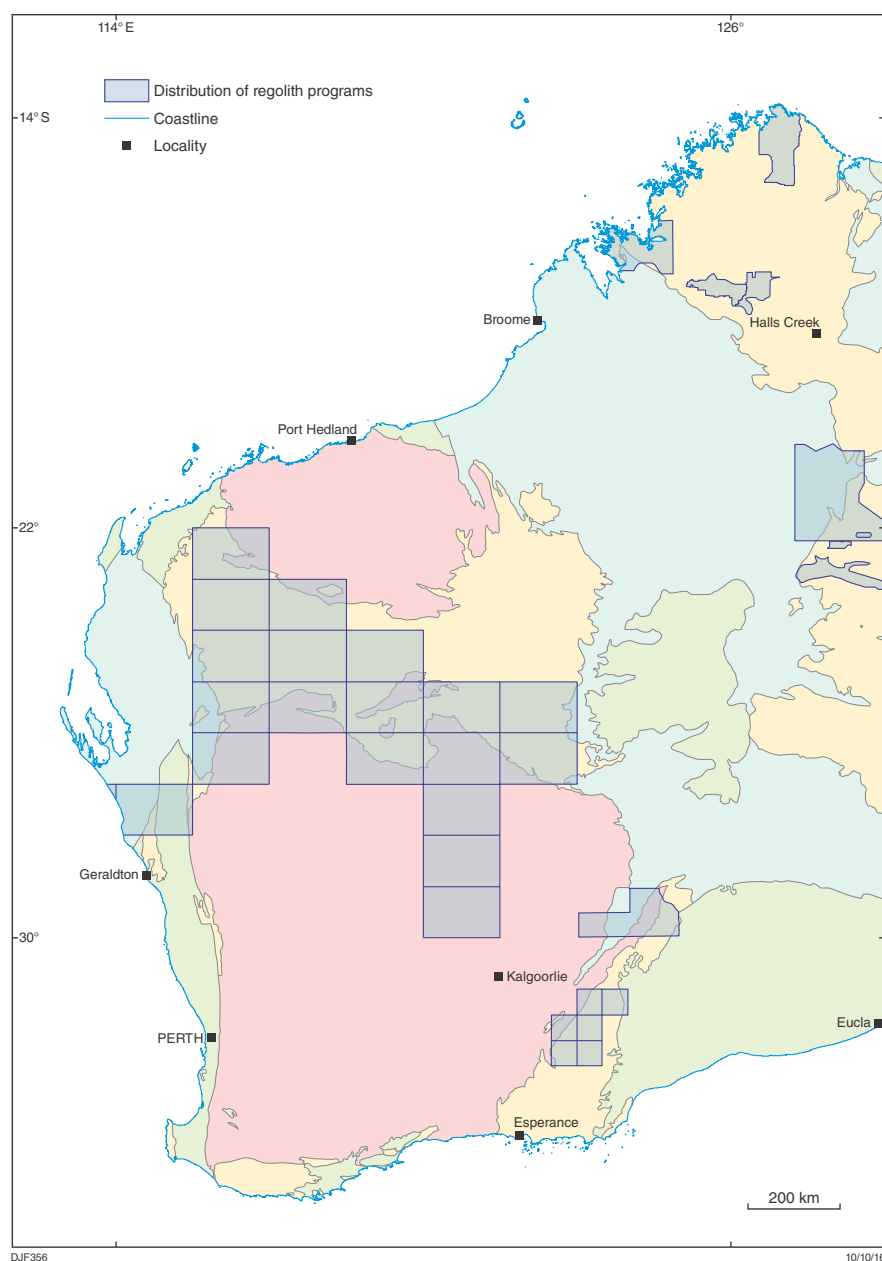


Figure 49. Distribution of GSWA regolith programs

ES40 Geology Online

Manager: Darren Wallace

Team members: Stephen Bandy, Derek Canham, Neville D'Antoine, Bhumita Fadadu, Terry Farrell, Kiran Gavni, Frank Matera, Angelia Riganti

The WA Geology Online project will better integrate GSWA's online product delivery by developing and facilitating the population of new databases and data services. These will include the development of a range of exploration databases and web-based search tools.

Outcomes of work program 2015–16

<i>Planned outcomes 2015–16</i>	<i>Current status</i>
Implement an online search tool that integrates with the field observation database (WAROX)	Ongoing
Complete an external web interface for ENS	Released; work on ENS Regolith ongoing
Implement an online discovery, subset and download tools for geophysical data	Ongoing

Planned products and outcomes 2016–17

Planned outcomes 2016–17

Implement an online search tool that integrates with the field observation database (WAROX)

Enhance ENS to include regolith and mineral systems

Redevelop DMP's Data and Software Centre

Enhance geochemistry database (WACHEM)

Develop Mining Act Section 16(3) Referrals assessment with Department of Planning

ES42 3D Geoscience

Manager: Klaus Gessner

Team members: Lucy Brisboud, Ruth Murdie, Huaiyu Yuan (Macquarie University)

The aim of the 3D Geoscience section is to increase the knowledge of Western Australia's subsurface through the integration of geophysical, geological and geochemical data in 3D structural models (see also GS62 3D Geoscience). EIS-funded collaborative projects with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling, are a large part of the 3D Geoscience section's activities.

Outcomes of work program 2015–16

Huaiyu Yuan is a GSWA-funded Research Associate in Seismology in the Australian Research Council Centre of Excellence for Core to Crust Fluid Systems (CCFS). Yuan leads the Capricorn Orogen Passive Array (COPA), a long-term earthquake tomography project that is part of the SIEF project 'The distal footprints of giant ore systems: UNCOVER Australia'.

ARC Linkage Project LP130100413 'Craton modification and growth: The east Albany–Fraser Orogen in three dimensions' (see also ES31 Deep Seismic Survey Program) investigates the lithosphere structure of the Albany–Fraser Orogen using a passive seismic array. Lucy Brisboud and Klaus Gessner from GSWA supported the instrument deployment and data collection, and now collaborate with Catherine Spaggiari, Ruth Murdie and ANU seismologist Christian Sippl on the geological interpretation.

Ruth Murdie and Klaus Gessner have worked with Eun-Jung Holden's research group at UWA's CET in ARC Linkage Project LP 140100267 'Reducing 3D uncertainty via improved data interpretation'. Dr Holden presented an overview of her group's research on data analytics for mineral explorers on GSWA Open Day in February 2016.

3D Geoscience has supported MRIWA project M470 'Multi-scale dynamics of hydrothermal mineral systems' at CET, which aims at defining measurable parameters of hydrothermal mineralizing systems that can be used as mineral exploration criteria.

Ruth Murdie and Klaus Gessner have worked with Mark Jessell (CET) and Florian Wellmann (RWTH Aachen University) on the development of quantifying and visualizing errors within 3D models. A highlight in this

collaborative space has been the successful organization of the 'Saying goodbye to a 2D Earth' international conference in Margaret River in August 2015.

3D Geoscience has supported PhD student Adam Beall at The University of Melbourne, for his modelling work on lithosphere stabilization in Archean cratons, and CET PhD student Greg Dering for mapping magmatic fabrics and brittle deformation in the Murchison Domain with an Unmanned Aerial Vehicle ('drone'). In a collaborative project with Uppsala University, PhD student Omid Ahmadi reprocessed a segment of the 10GA-YU1 seismic line near Cue.

Products released 2015–16

Record 2016/3 Integrated Exploration Platform v2.5
Record 2015/13 Saying goodbye to a 2D Earth
Record 2015/16 2nd Lithosphere Workshop Abstracts
10 external publications — see Appendix B

Planned work program, products 2016–17 and beyond

The main focus for 2016–17 will be to contribute to the interpretation of the Eucla–Gawler seismic survey, an EIS-funded collaboration with the Geological Survey of South Australia. 3D models and publications are planned for the Albany–Fraser Orogen in relation to the ANU collaboration. Results of the study will be published as an external publication and a GSWA Record is in the planning stage. Further 3D modelling work will be carried out by external collaborators on the Capricorn Orogen and the Kimberley region.

Within the ARC CCFS Huaiyu Yuan, supported by an exchange student from the Academy of Sciences, will continue his work on COPA to investigate crustal structure of the Capricorn Orogen and the architecture of the lithospheric mantle. A suite of passive source methods will be applied in conjunction with the COPA to develop a technical template for revolving seismic anisotropy structure for both long-operating and the COPA stations.

Klaus Gessner will collaborate with the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS) on the deployment of seismometers in the coastal region of northern Western Australia.

3D Geoscience staff will also contribute to a collaborative project with UWA on the crustal structure of the southwest Yilgarn Craton.

3D Geoscience will continue to support MRIWA 470 project ‘Multi-scale dynamics of hydrothermal mineral systems’. A book titled ‘The Precious Earth – Understanding Hydrothermal Ore Forming Systems’ authored by Bruce Hobbs and others is planned for publication with GSWA in 2017.

3D Geoscience will continue work with the research groups of Eun-Jung Holden and Western Australian Fellow Professor Mark Jessell at CET on ARC Linkage project LP140100267 ‘Reducing 3D uncertainty via improved data interpretation methods’.

3D Geoscience members plan to present current work at the 2016 ASEG meeting in Adelaide, at the 2016 AOGS Meeting in Beijing, the 35th IGC meeting in Cape Town, the 2016 AGU Fall meeting in San Francisco, and the 2016 EGU Meeting in Vienna.

Products planned for release 2016–17

Alteration and geochemical footprint of VMS-style mineralization, Quinns district, Murchison Domain, Western Australia (Record)

Imaging the structure of Archean fault rocks with synchrotron X-ray microtomography (Record)

The Precious Earth – Understanding Hydrothermal Ore Forming Systems (Book)

West Gawler 3D model

3D models from the Eucla Gawler Seismic line (extended abstract)

Albany–Fraser Orogen 3D model

Seismic Surveys 10GA-YU1, 10GA-YU2, 10GA-YU3, 11GA-SC1 (Geophysical Modelling Reports)

Record Specifications for submission of 3D Models to GSWA

Six external publications — see Appendix B

ES43 Mineral Systems Atlas

Managers: David Maidment, Trevor Beardsmore

Team members: Mark Hutchison, Wally Witt, CET UWA, CODES, CSIRO

Under this program, GSWA enters into research agreements with external groups or individuals to provide GIS-based exploration targeting products that effectively extol the potential of underexplored regions of Western Australia in easy-to-understand formats for geoscientists in the exploration industry. These minerals-oriented research projects are partly to fully funded by EIS, and are managed or monitored — and in some instances contributed to — by GSWA's Mineral Systems group, funded in-kind from the GS20 recurrent budget.

Significant current projects include:

- regional targeting criteria for gold mineralization in the Yilgarn Craton
- VMS fertility of Yilgarn volcano-sedimentary successions
- metallogenic studies of BIF-hosted iron ore systems in the Yilgarn and Pilbara Cratons
- mineral prospectivity studies of the Kimberley and southwest Capricorn Provinces
- chemical fingerprinting of pyrite in northern Yilgarn and southern Capricorn gold and base metal systems
- 3D architecture of the major, mantle-tapping Nanjilgardy Fault system, and spatial and chemical variations of gold mineralization and associated alteration spatially related to this structure
- diamond prospectivity of Western Australia
- AMIRA Project P1040 – Global Ore Deposit Encyclopaedia ('Data Metallogenica').

Outcomes of work program 2015–16

The two-year collaboration between GSWA and UWA to evaluate exploration techniques and identify regional targeting criteria for (buried) gold mineralization in the Yilgarn Craton was completed in late 2012. The first volume of the three-volume 'Yilgarn Gold Exploration Targeting Atlas' was released as Report 125 in late 2013, the second volume was released in early 2015 (Report 132). The third and final instalment of the trilogy (deposit-

scale targeting) was peer reviewed and revised during 2015–16, and will now be released early in 2016–17.

The GSWA Report on Phase 1 of an analysis by a CSIRO-embedded researcher of the VMS fertility of Yilgarn volcano-sedimentary successions has been peer reviewed and will be published in early 2016–17. Results have also been published in *Precambrian Research*. This project was extended for a further period to allow collection of new geochemical and geochronological data from a number of under-represented terranes, and was finally completed in late 2015. The final Report is being prepared, as are several journal papers.

Metallogenic studies of BIF-hosted iron ore systems in the Yilgarn Craton were completed in late 2015 by Paul Duuring (at the time with CET at UWA). Paul subsequently joined the staff of GSWA in early 2016 as Senior Geologist with the Mineral Systems section. In this new role Paul is completing the final Report and a series of journal papers documenting the work. He is also preparing as GSWA Records a number of interim Reports on interpretation of hyperspectral data from drillcore examined during the project. A dissertation from a UWA Honours project completed as a peripheral part of this project was released as Record 2015/3.

A complementary MRIWA- and industry-funded study of the structural controls and ore and alteration mineralogy at selected BIF-hosted iron ore deposits in the Pilbara Craton (Project M426) was completed in the first half of 2015 by a team of postgraduate and postdoctoral workers under Paul Duuring's supervision. The final report was submitted to MRIWA, and will be released as a GSWA-MRIWA co-branded publication in early 2016–17 (at the expiry of the confidentiality period).

UWA's CET completed its GIS-based regional mineral prospectivity analysis of the Kimberley region, with an analysis of the eastern arm of the Lamboo Province (Halls Creek Orogen). New interpretations of crustal architecture based on geophysical data have been published as GSWA Report 157 and in *Precambrian Research*. Results from the regional mineral prospectivity analysis have been released as GSWA Report 159, and also published in *Ore Geology Reviews*.

The UWA–CET group also began a mineral prospectivity analysis of the southeastern Capricorn Orogen during 2015–16. An overview of the results of earlier studies by

the group (previously released as GSWA Reports 113, 117 and 123 — West Arunta, West Musgrave and Gascoyne, respectively) were also published in *Ore Geology Reviews* in late 2015.

Researchers at the CODES ARC Centre of Excellence for Ore Deposit at the University of Tasmania completed the study into chemical fingerprinting of pyrite in northern Yilgarn and southern Capricorn gold and base metal systems. Results suggest that the trace element compositions of such minerals might be utilized as indicators of regional mineral fertility and deposit ‘type’. The final Report was submitted in late 2015, and it, the earlier-submitted interim Report, and the database are being prepared for release in 2016–17.

GSWA Mineral Systems and CSIRO staff completed the collaborative study of the 3D architecture of the mantle-tapping Nanjilgardy Fault, and the gold mineralization and associated alteration spatially related to it (including at Paulsens and Mount Olympus, both of which are close to plays from the fault). GSWA released in early 2016 Report 156 describing this work, and an Extended Abstract and presentation (at GSWA’s 2016 Open Day).

Dr Mark Hutchison continued developing and populating a new database and Report of diamond and diamond indicator mineral occurrences, geochemistry and prospectivity for Western Australia. This is the first major work on diamonds of Western Australia since publication of GSWA Bulletin 132 (Jaques et al., 1986) and will be of a similar style to the diamond prospectivity report for the Northern Territory (Hutchison 2012, NTGS Record 2012-001). Finalization of the Western Australian ‘diamond’ database has been delayed by negotiations to gain access to data not supplied previously to DMP in digital format.

AMIRA Project P1040 — Global Ore Deposit Encyclopaedia (or ‘Data Metallogenica’) — largely involved redevelopment of the website to provide greatly expanded capability and content, and was completed late in 2014–15.

Products released 2015–16

Report 156 Integrated spectral mapping of precious and base metal related mineral footprints, Nanjilgardy Fault, Western Australia (Wells et al; joint CSIRO-GSWA publication)

Report 157 A geophysical investigation of the east Kimberley region, northern Western Australia (Lindsay et al.)

Report 159 Prospectivity analysis of the Halls Creek Orogen, Western Australia – using a mineral systems approach (Occhipinti et al.)

Record 2015/3 Alteration mineral zonation associated with high-grade BIF-hosted iron ore; mineral mapping using hyperspectral drillcore data (Chiarelli — UWA Honours dissertation; part supported by ES43 and GS95)

Record 2016/2, Extended Abstract, Integrated spectral mapping of precious and base metal-related mineral footprints, Nanjilgardy Fault, Western Australia, p. 26–30

Report Yilgarn Gold Exploration Targeting Atlas – Volume 3

Report The mineral prospectivity of the east Kimberley Region (provisional title)

Interim and final reports A review and petrochemical study of VHMS mineralization in the Yilgarn Craton, Western Australia (collaboration with CSIRO)

Products released 2015–16

Record Mapping iron ore and alteration patterns BIF using hyperspectral data at the Beebyn deposit, Yilgarn Craton, Western Australia

Record Mapping iron ore and alteration patterns in BIF using hyperspectral data at the Windarling iron camp, Yilgarn Craton, Western Australia

Record Mapping iron ore and alteration patterns in BIF using hyperspectral data at Mt Richardson, Yilgarn Craton, Western Australia: Hole PK11DD001

Record Mapping iron ore and alteration patterns in banded iron-formation using hyperspectral data at Mt Richardson, Yilgarn Craton, Western Australia: Hole PK12DD001

Reports and database — Testing LA-ICPMS geochemistry of pyrite as a fertility and vectoring tool in exploration for orogenic gold and VHMS deposits in Western Australia — CODES progress report, final Report and database (provisional title)

Report Mineral prospectivity targeting in the southeast Capricorn Orogen (provisional title)

Report and series of external papers Metallogeny of Archaean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia

Report Exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia (co-branded publication of final report for MRIWA Project M426)

Report and database — Diamond and diamond-indicator mineral occurrences, and diamond prospectivity, in Western Australia (provisional title)

Four external publications — see Appendix B

Planned work program and products 2016–17

Most of the current portfolio of research projects are now, or soon will be, complete. Work programs related to these will largely focus on completing and releasing their respective Reports and datasets, including:

- third volume and associated digital data package for the ‘Yilgarn Gold Exploration Targeting Atlas’, dealing with deposit-scale targeting
- interim and final Reports and associated data for the study of the lithogeochemical fertility for VMS systems in Yilgarn volcano-sedimentary successions
- a series of Reports and Records detailing the results of mineralogical and metallogenic studies of Archaean BIF-hosted iron ore deposits in the Yilgarn and Pilbara Cratons
- final Report and database for the mineral prospectivity targeting work in the southeastern Capricorn Orogen
- interim and final Reports and associated database for the study of pyrite trace element chemical fingerprints of gold and base metal systems in the northern Yilgarn and southern Capricorn regions
- Report on the diamond prospectivity of Western Australia, together with its digital dataset.

In a significant new initiative, GSWA will begin transferring from UWA–CET the knowledge and technological capacity to analyse mineral systems and undertake multiscale prospectivity studies based on such analyses. Staff from the Mineral Systems section (GS20),

the Mapping section, and the GIS section will initially attend a series of training workshops provided by CET staff that has been doing such studies.

The Mineral Systems section will concurrently commence a program to validate and supplement analyses of significant mineral systems in Western Australia, with the aim of defining ‘mappable proxies’ for critical metallogenic processes. GSWA staff will set about creating statewide, digital ‘proxy layers’ derived from existing and enhanced or newly created datasets, that can then underpin GIS-based mineral prospectivity studies. The ‘proxy layers’ are planned to be delivered via an interactive Mineral Systems Atlas developed by GSWA.

Products planned for release 2016–17

Yilgarn Gold Exploration Targeting Atlas Vol 3 (Report)

A review and petrochemical study of VHMS mineralization in the Yilgarn Craton, Western Australia (Interim and final Reports)

Mineral prospectivity targeting in the southeast Capricorn Orogen (provisional title) (Report)

Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (Report and external publications)

Exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia (co-branded publication of final report for MRIWA Project M426) (Report)

Mapping iron ore and alteration patterns BIF using hyperspectral data at the Beebyn deposit, Yilgarn Craton, Western Australia (Record)

Mapping iron ore and alteration patterns in BIF using hyperspectral data at the Windarling iron camp, Yilgarn Craton, Western Australia (Record)

Mapping iron ore and alteration patterns in BIF using hyperspectral data at Mt Richardson, Yilgarn Craton, Western Australia: Hole PK11DD001 (Record)

Mapping iron ore and alteration patterns in BIF using hyperspectral data at Mt Richardson, Yilgarn Craton, Western Australia: Hole PK12DD001 (Record)

Testing LA-ICPMS geochemistry of pyrite as a fertility and vectoring tool in exploration for orogenic gold and VMS deposits in Western Australia — CODES progress report, final Report and database (provisional title) (Reports and database)

Planned work program, products 2017–18 and beyond

GSWA will continue to develop mappable Mineral System ‘proxies’, and a digital Mineral Systems Atlas to deliver these products. External expertise will be drawn upon where required.

GSWA will also negotiate new relevant collaborative research projects that will be funded from Round 3 of the EIS.

ES45 Geological Mapping and Interpretation

Manager: David Maidment

Team members: Olga Blay, Graham Eacott

The objective of this program is to undertake regional mapping of bedrock and regolith and to use geophysical data to map bedrock under thin regolith and sedimentary basin cover. Work concentrates on remote greenfields areas in Western Australia, including the Kimberley region and the west Arunta, west Tanami, Paterson and Capricorn Orogens. These areas are underexplored due to their remoteness, land access issues, and the lack of up-to-date pre-competitive geoscience datasets. This activity is providing new mapping and interpretations, and making existing legacy data available in digital format.

In the Capricorn Orogen, the accelerated mapping is improving the understanding of the geological setting of mineralization. Mapping is focused on the late Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins, which contain Abra, Western Australia's largest stratabound lead-silver-copper-gold deposit. This, combined with their age and geological setting, makes the Edmund and Collier Basins together one of the most prospective areas in Australia for large, blind, sediment-hosted base metal orebodies. The Edmund and Collier Basins also have a history of minor gold and phosphate production.

In the Kimberley region, high-quality geoscience mapping is available although some is not in GSWA's current format for digital GIS datasets. A seamless solid geology layer at nominal 1:100 000 scale and a seamless regolith layer are being created for the region. This is complemented by new field mapping, focused on understanding the timing and nature of tectonism in the Paleoproterozoic Lamboo Province, and the depositional environments and crustal architecture of Paleo- to Neoproterozoic sedimentary successions including the Speewah and Kimberley Basins. Regolith mapping has also led to a more detailed understanding of the recent development of the landscape and the nature of cover.

In the west Tanami region, the Granites-Tanami Orogen comprises Paleoproterozoic low- to medium-grade metasedimentary and metavolcanic rocks which are intruded by Paleoproterozoic granites. The metamorphic units host significant orogenic gold mineralization, with broad areas of shallow cover remaining prospective for further discoveries. These units are overlain by late Paleoproterozoic sedimentary rocks of the Birrindudu Basin, which in the Northern Territory has been shown to be prospective for hydrocarbons and hosts REE

mineralization in Western Australia. Previous geological mapping has been compiled to produce 1:100 000-scale Geological Series maps. Studies of the younger basins are ongoing to determine the ages and nature of the various successions in the area.

In the west Arunta region, the Aileron Province of the Arunta Orogen comprises Paleoproterozoic low-grade metasedimentary rocks and granites and is separated from the latest Paleoproterozoic volcanic rocks and granites of the Warumpi Province by the Central Australian Suture. Previous geological mapping is being combined with the results of recent field studies and interpretation to produce 1:250 000-scale maps for the orogen and overlying basins.

In the Paterson Orogen, previous geochronological studies have defined a broad event framework for the region between the Paleoproterozoic and Neoproterozoic. Further isotopic studies of the igneous rocks of the region have been undertaken to better understand the nature of the magmatic events and their relationships with mineralization, which includes the Telfer Au-Cu, Nifty Cu and Kintyre U deposits. The results of these studies are aimed at a better understanding of the geodynamic development of the region and the prospectivity of areas beneath cover.

Outcomes of work program 2015–16

In the Capricorn Orogen, field mapping has produced two first edition 1:100 000 Geological Series maps (LOFTY RANGE and ILGARARI) (see also GS49 Edmund and Collier Basins).

One second edition 1:250 000-scale Geological Series map (WEBB) has been produced for the west Arunta region, incorporating a new regolith map for the sheet.

A GIS data package was released for the Tanami-Arunta region, including recently produced maps, regolith geochemistry and gravity data.

Oxygen and Lu-Hf isotopic data have been collected for granitic rocks of the Rudall Province to constrain the nature of magmatism at 1590–1550 Ma. The results suggest melting of older lower crustal mafic components, possibly in a rift setting.

Products released 2015–16

LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps*

WEBB second edition 1:250 000 Geological Series map

Tanami–Arunta 2016 GIS package

West Capricorn Orogen 2016 GIS package

* See also GS49 Edmund and Collier Basins

Planned work program and products 2016–17

During 2016–17, work in the Capricorn Orogen will focus mainly on compiling the geology of the WONYULGUNNA 1:100 000 Geological Series map. A Report on the geochemistry of mafic dykes and sills in the Capricorn Orogen will be released.

Work during 2016–17 in the west Arunta region will concentrate on compiling the second edition MACDONALD 1:250 000 Geological Series map. This will update the existing interpreted basement geology, based on recent field mapping and integrate this with a new regolith layer.

A Report will be released on the geochronology of the Paleo- to Mesoproterozoic rocks of the Rudall Province and a Report prepared on the oxygen and Lu–Hf isotopic characteristics of Mesoproterozoic granitic rocks from the province. Further oxygen and hafnium isotopic data and geochemistry will be collected for intrusive rocks from the Paterson Province, focusing on Neoproterozoic granites, which are associated with gold mineralization. Whole-rock geochemical and Sm–Nd isotopic data will also be collected for previously sampled c. 835 Ma mafic intrusive and extrusive rocks in the Neoproterozoic Yeneena Basin to characterize the compositions of these rocks and how they might relate to other mafic rocks of this age elsewhere in Australia.

GIS data updates are planned for the Tanami–Arunta and Capricorn regions.

Products planned for release 2016–17

WONYULGUNNA 1:100 000 Geological Series map*

Geochemical evolution of Mesoproterozoic mafic dykes that intrude the Edmund and Collier Groups* (Report)

West Capricorn GIS update 2016*

West Capricorn Explanatory Notes update (Edmund and Collier Basins)*

MACDONALD second edition 1:250 000 Geological Series map, West Arunta

Tanami–Arunta GIS update 2016

Geochronology of granitic and metasedimentary rocks from the Tanami Region (Report)

Geochronology of the Rudall Province (Report)

Oxygen and Lu–Hf isotopic characteristics of the Krackatinny Supersuite, Rudall Province (Report)

* See also GS49 Edmund and Collier Basins

Planned work program, products 2017–18 and beyond

Work during 2017–18 and beyond in the Capricorn Orogen will focus on the compilation of legacy data of the eastern Capricorn basins and the progressive release of 1:100 000-scale Geological Series maps. A Report is also planned on the geochemical evolution of Proterozoic mafic dykes intruding the Ashburton Basin.

Further targeted studies are also planned for the Paterson Orogen, including production of a Report on the geochemistry of Neoproterozoic mafic rocks.

Products planned for release 2017–18 and beyond

West Capricorn GIS 2017 update, including WONYULGUNNA 1:100 000 Geological Series map*

East Capricorn GIS 2017, including a digital compilation of the 1:100k IBG and associated digital layers, and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earraheedy Basins*

Geochemical evolution of Proterozoic mafic dykes intruding the Ashburton Basin* (Report)

Geochemical evolution of Neoproterozoic mafic dykes and sills in the Paterson Orogen (Report)

* See GS49 Edmund and Collier Basins

ES46 Enhanced Geochronology and Acquisition of Isotope Data

Manager: Michael Wingate

*Team members: Frances James, Yongjun Lu, Ed Mikucki,
Marlene Pappicio, Tom Scillieri, John Williams*

This project extends and enhances GSWA's U–Pb geochronology program with the addition of Lu–Hf and oxygen isotope and trace element analysis of zircons, Sm–Nd isotope analysis of whole-rock samples, and a wide range of isotope-related projects conducted in collaboration with university research groups. Using these techniques to elucidate the temporal and spatial evolution of crust and mantle and to assess magmatic fertility for magmatic–hydrothermal mineral systems, particularly in underexplored areas, is an important tool for identifying new mineral provinces and reducing exploration risk.

Variations in the abundances of isotopes (mainly Sm–Nd and Lu–Hf) reveal information about the compositions and sources of magmas, and their fractionation in the Earth's crust and mantle, allowing magmas derived from the mantle to be distinguished from those derived by reworking of older crust. Measurement of Hf isotopes in dated zircon and baddeleyite crystals provides important information for understanding the evolution and architecture of the crust. This knowledge is important for understanding mineralization, because the addition of juvenile material from the mantle into the crust is commonly associated with mineralizing events. Nd isotopes, in a similar manner to Hf isotopes, reveal fractionation processes in the crust and can estimate — the time at which a source melt was separated from the mantle — a key process that directly influences the mineral endowment of a region.

The trace element compositions of zircons provide important information about water content, pressure, temperature and oxidation state of the host magma, all of which are important factors controlling magma fertility for ore formation. This zircon chemistry can be used to distinguish between mineralization-related and -unrelated granites, and used as an exploration indicator in remote or covered terrains.

Outcomes of work program 2015–16

About 2060 previously dated zircons from 78 samples were analysed for Lu–Hf isotopes during 2015–16. The samples represent igneous, metamorphic, and sedimentary rocks selected from the Eastern Goldfields Superterrane,

Murchison Domain, and Southwest Terrane of the Yilgarn Craton, the Gascoyne, west Musgrave and Rudall Provinces, the Albany–Fraser Orogen, the Amadeus Basin, and basement rocks beneath the Eucla Basin. More than 60 samples were submitted in 2015–16 for Sm–Nd whole-rock analysis, mainly from underexplored areas of Western Australia, including the Kimberley region, Capricorn Orogen, and eastern Pilbara Craton.

As isotope data are generated they are normalized to accepted GSWA standard values, checked for consistency, disseminated to GSWA projects, and made publically available online via GeoVIEW.WA and the GSWA Geochemistry (GeoChem Extract) web page. Isotope results so far have proven highly significant for understanding the crustal evolution of Western Australia, and feature prominently in GSWA publications and external journal articles. A summary of activities and recent outcomes is described below.

A project commenced in 2016 to collect new samples for geochronology, geochemistry, and isotope analyses from igneous rocks in the South West Terrane (Fig. 50), a region in which such information is scarce. Results will elucidate the geological evolution of the southwestern Yilgarn Craton, and investigate more closely the boundary between the South West and Youanmi Terranes. In addition, existing dated zircon samples from across the Yilgarn Craton are being analysed for their trace element compositions. These data will provide information on temperature, pressure, hydration, and oxidation state of the magmas from which they crystallized, and allow their potential fertility for magmatic–hydrothermal ore formation to be evaluated.

The 2014–17 ARC Linkage project 'Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: constructing a geological framework for understanding mineral systems', which involves collaboration between GSWA and Curtin University, is close to completion. This project uses in situ SHRIMP geochronology of phosphate minerals to improve our understanding of complex tectonic, low-temperature metamorphic, and mineralization events in the Capricorn Orogen and other areas in northern Western Australia. Several GSWA manuscripts and journal articles have been produced or are in progress, and two Curtin University PhD projects are continuing.

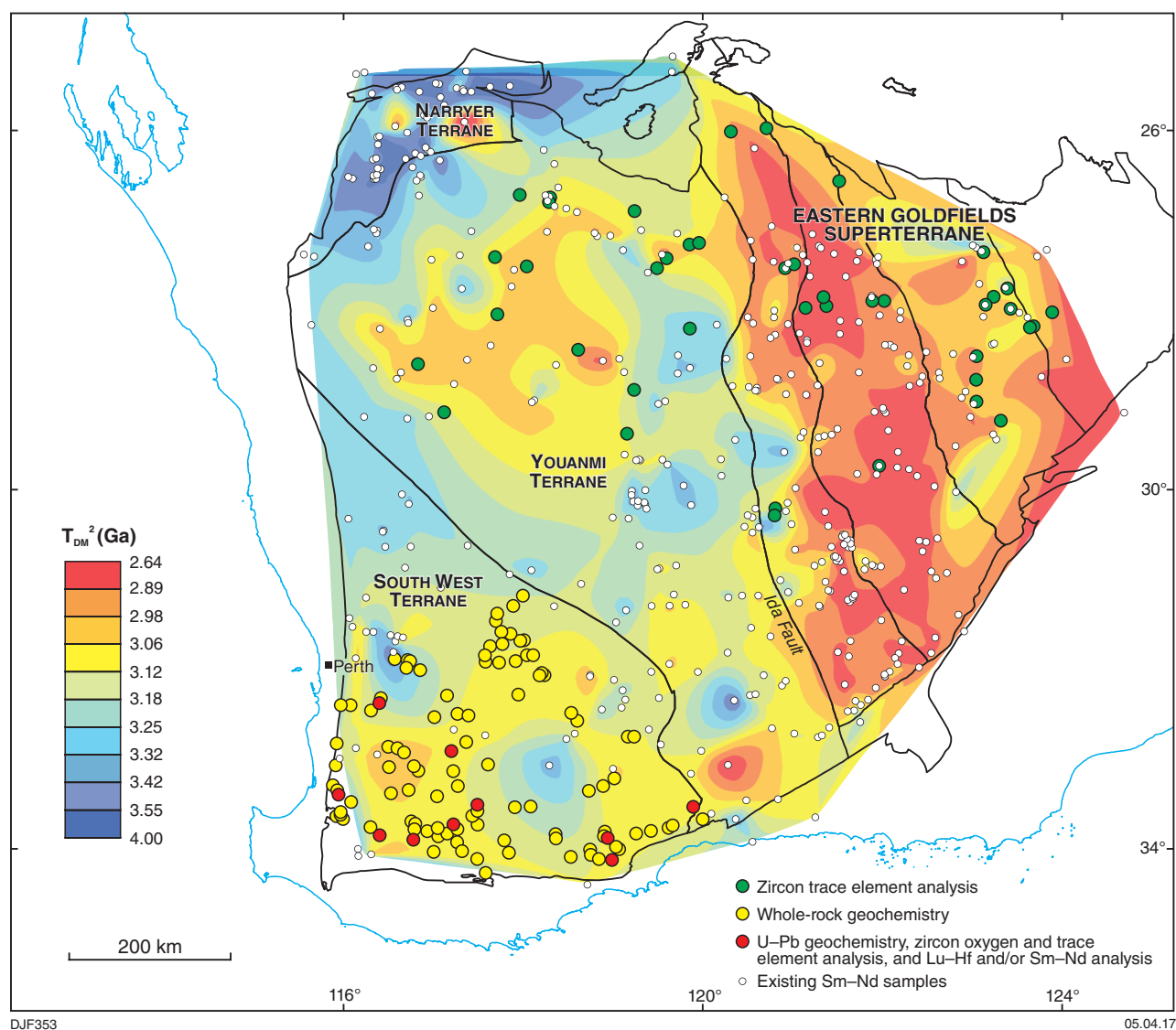


Figure 50. Samples collected and/or analysed in 2015–16 for geochronology, geochemistry, and isotope analysis in the South West Terrane (yellow and red symbols) and northern Yilgarn Craton (green symbols). Sampling in the South West Terrane is continuing, and will cover the northern area and extend across the boundary with the Youanmi Terrane. Analyses of trace element compositions in existing zircon samples (green symbols) will be extended across the entire Yilgarn Craton. The background map shows the latest (2016) GSWA update of two-stage Nd model age contours

A three-year research project commenced last year between GSWA and the Curtin node of CET to integrate geochronology and isotope geology over a range of scales, to understand and predict the locations of metallogenesis. A recent journal article illustrates how U–Pb geochronology of titanite has the potential to reveal grain-size dependent overprinting and thereby elucidate thermal histories. Outcomes now being written up as GSWA publications and journal articles include contour maps of Lu–Hf data for the Pilbara Craton and Lu–Hf and oxygen isotope data for the Rudall Province. Current efforts are aimed at finalizing the interpretation of Lu–Hf and oxygen isotope data for basement rocks beneath the Eucla Basin.

Two MRIWA-administered projects commenced in 2015–16. The first project is underway, and involves development of rutile protocols for metals exploration in Western Australia and construction of a database of rutile age and chemistry, to provide a foundation for metals exploration using rutile grains encountered in rocks and drillcore, or as detrital grains in heavy mineral concentrates from field sampling. The project includes rutile U–Pb geochronology of studied ore systems, together with studies using other relevant minerals and techniques (e.g. ^{39}Ar – ^{40}Ar in ore-related sericite; U–Pb on other ore-associated minerals), to determine and confirm accurate and precise ore-formation ages.

The second MRIWA project will use the Re–Os isochron method on sulfide minerals to determine precise ages for two classes of metal deposits in Western Australia: VHMS Zn–Pb–Cu deposits and orogenic gold deposits. Each deposit type typically contains ore-related pyrite and/or arsenopyrite. Re–Os isochron ages will be complemented by precise U–Pb and Ar–Ar ages on the selected deposits and their environs, including host-rock ages, stratigraphic ages, alteration ages, and metamorphic ages, to build a precise 4D framework of ore formation. This project is now starting, following the recent appointment of a PhD candidate at Curtin University.

Products released 2015–16

Record 2015/10 Eucla basement stratigraphic drilling results release workshop

- Extended abstract Madura Province: isotopes and crustal evolution
- Extended abstract Forrest Zone: isotopes and crustal evolution
- Extended abstract Eucla basement results: implications for geodynamics and mineral prospectivity

Lu–Hf and Sm–Nd datasets released to online applications (GeoVIEW.WA and GeoChem Extract)

Six external publications — see Appendix B

Planned work program and products 2016–17

Analyses of Lu–Hf, Sm–Nd, and oxygen isotopes will continue in 2016–17. Isotope data generated by this program will be checked for accuracy and consistency, provided to GSWA projects, and published on the GSWA website as they become available. The results will be integrated with geological and geochemical data and gravity, aeromagnetic, seismic, and magnetotelluric datasets, to advance our understanding of crustal architecture, geological evolution, and mineralization.

Syntheses will be published as GSWA Reports or Records and will inform other GSWA and external publications.

A third MRIWA project, entitled ‘Mineral systems on the margin of cratons: Albany–Fraser Orogen/Eucla Basement case study’ is commencing. This project will integrate Hf, Nd, oxygen, and sulfur isotopes, U–Pb geochronology, and whole-rock and mineral chemistry, to establish the timing, scale, and materials of lithosphere-scale mass transfer processes, and highlight areas of enhanced mantle input, within the eastern Albany–Fraser Orogen and adjacent Eucla basement rocks. Three PhD candidates have already accepted positions and are expected to be enrolled at Curtin University by September 2016.

Planned work program, products 2017–18 and beyond

The planned work program for 2017–18 and beyond will be similar to that for 2016–17. New samples will be collected during the normal course of GSWA fieldwork to address specific geological problems.

ES47 Petroleum, Coal and CO₂ Geosequestration Program

Manager: Deidre Brooks

Team members: Norman Alavi, Heidi Allen, Louisa Dent, Ameer Ghori, Peter Haines, Lorraine de Leuw, Sarah Martin, Alan Millar, Arthur Mory, Leon Normore, Charmaine Thomas, Suzanne Thomas, Yijie (Alex) Zhan

The objective of this program is to collect pre-competitive data to assist in determining the State's potential for petroleum and alternative energy sources that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms.

The Perth Basin has undeveloped tight gasfields with up to 226 Gm³ (8 TCF) of reserves located near infrastructure. The US Energy Information Agency reported in 2013 that the Canning Basin has the largest shale gas potential in Australia, and in fact the eighth largest in the world; they estimated it has in excess of 225 TCF of recoverable shale gas based on the Goldwyer Formation play alone. However, technical and geological issues have left this resource untouched. Nevertheless, innovations in technology in the US and Canada make tight gas a viable addition to the State's domestic gas market.

During the last decade, shale gas plays have become an important supply of natural gas in the US. Interest in exploring shale gas plays is rapidly spreading worldwide, including to the sedimentary basins of Western Australia. Collaborative core analysis projects with the petroleum industry are contributing to research on the shale gas potential of the Canning Basin. The success of this project has led to a decision to undertake a similar collaborative core analysis project in the northern Perth Basin this financial year.

Finally, the need for CO₂ geosequestration sites near the major emitters requires further geological studies and data acquisition. The collaborative core analysis projects in both the Canning and Perth Basins include potential reservoir and seal studies and are funded jointly by the Commonwealth and EIS. In addition, the Basins and Energy Geoscience section will continue to supply expertise and assistance to the program of work on the South West CO₂ Geosequestration Hub, which is managed by Dominique Van Gent, Carbon Strategy Branch of the Strategic Policy Group, DMP. DMP Harvey 2, 3, and 4 wells were drilled in 2014–15, with studies and analyses largely completed during 2015–16.

The Basins and Energy Geoscience team will contribute to a project involving the acquisition of new passive seismic data in the Perth Basin (ES31), and undertake reprocessing of selected 2D seismic lines in the Canning Basin and the area between the north Perth and southern Carnarvon basins to improve data quality.

Candidates for future stratigraphic drilling are currently being considered including the Western Australian portion of the Amadeus Basin to prove the existence and continuation from the Northern Territory of petroleum system elements, the southern Carnarvon Basin targeting Triassic and/or Permian source rocks, or either the northern Wallal Embayment and the Waukarlycarly Embayment where the age of the stratigraphy and petroleum potential is unknown. Preparation for stratigraphic drilling such as site selection and clearing could be undertaken in 2016–17. The drilling is planned to occur in the 2017–18 financial year, depending on the time frame to complete stakeholder engagement.

Outcomes of work program 2015–16

Canning Basin

Some of the main outcomes from studies in the Canning Basin in 2015–16 are:

- completion of a study on the characterization and correlation of the Early Permian Poole Sandstone and Noonkanbah Formation, Canning Basin, Western Australia and implications for CO₂ sequestration
- interpretation of the Canning Basin deep crustal seismic survey (data acquisition funded by EIS and data processing by GA)
- GSWA participation in core analyses of the Lower Ordovician cored in Olympic 1 and Senagi 1, drilled by Buru Energy; and Theia 1, drilled by Finder Exploration in 2015. The core analysis project is continuing into 2016–17
- support of the core analysis project — a new interactive digital product has been developed during the year, known as the digital core atlas. An atlas of all core included in the collaborative core analysis project will be compiled with interactive links at each depth where analysis results have been received. Work on completing the first atlas is continuing into the new financial year.

Perth Basin

Some of the main outcomes from studies in the Perth Basin in 2015–16 are:

- geological and geophysical contribution to the post-well analysis and reporting for the South West CO₂ Geosequestration Hub of DMP, where three new wells were completed in 2014–15
- as part of this South West CO₂ Geosequestration Hub project, GSWA commissioned palynological analyses on samples from DMP Harvey 2 and Harvey 3/A; DMP Harvey 4 samples were examined, but proved unsuitable for palynological studies.

Amadeus Basin

The main outcome from studies in the Amadeus Basin in 2015–16 is:

- further understanding of detrital zircon geochronology and Hf-isotopes of upper Ediacaran to Cambrian deposits, western Amadeus Basin.

Products released 2015–16

Report 149 Characterization and correlation of the Early Permian Poole Sandstone and Noonkanbah Formation, Canning Basin, Western Australia and implications for CO₂ sequestration

Record 2015/8 Detrital zircon geochronology of upper Ediacaran to lower Cambrian deposits (Supersequence 4), western Amadeus Basin: testing revised stratigraphic correlations

Planned work program, products 2016–17 and beyond

Continue regional geological, geophysical and petroleum geochemical studies for the Canning, Perth, Carnarvon and Centralian Basins during 2016–17 and beyond, including EIS-funded studies for petroleum systems, coal, and CO₂ geosequestration. Other projects include the:

- completion of 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
- continuation of CO₂ geological storage studies, in collaboration with GA and oil companies, in the Perth and Canning Basins. This is expected to include collaboration on core analysis with petroleum exploration companies for wells planned to be drilled for the next year in the Canning and north Perth basins
- seismic reprocessing of legacy data mainly in the Canning Basin and the area between the north Perth and southern Carnarvon basins. This newly reprocessed data can also be included as new pre-competitive data supporting future acreage releases
- publication of research results projects as GSWA publications.

Canning Basin

The planned outcomes from studies in the Canning Basin in 2015–16 are to:

- complete seismic interpretation for the new regional Canning Coastal deep crustal seismic line
- continue collaborative core analysis from recent and future wells drilled by petroleum companies in the Canning Basin including cooperative studies with CSIRO
- include digital core atlas for Canning Basin wells in collaborative core analysis projects
- investigate regional correlations and hydrocarbon potential of the lower to middle Ordovician Willara and Nambeet formations
- define the Goldwyer Formation Reference Section
- investigate petroleum source rock potential of the Nambeet Formation.

Perth Basin

The planned outcomes from studies in the Perth Basin in 2015–16 are to:

- undertake collaborative core analysis projects with petroleum companies that will be acquiring core in new wells within 2016–17, with results feeding into regional studies
- complete integration of results from the Harvey stratigraphic drilling well data and seismic
- release a Resources Bulletin for coal and lignite
- complete a review of palynological data in the Harvey region, southern Perth Basin
- plan for a passive seismic traverse.

Planned products for 2016–17 have component of EIS fund-related studies.

Products planned for release 2016–17

Hypothesis of Suture Reactivation and the Canning Basin evolution – an interpretation of the Canning Coastal Seismic Line, Canning (Record)

Digital Core Atlas, Olympic 1, Canning Basin (Interactive Digital Product)

Canning Basin Coal Resources (Record)

Record Summary of palynological data in the Harvey region, southern Perth Basin (Record)

Mesozoic Coal Resources of Northern Perth Basin (Record)

Irwin River Coal Resources (Record)

Vasse Shelf Coal Resources (Record)

Lignite Resources of the Eucla/Bremer Basin (Record)

Carnarvon Basin Coal Resources (Record)

Coal and Lignite Resources of Western Australia (Bulletin)

ES50 Strategic Industry Research Program

Manager: Margaret Ellis

Team members: CSIRO, MRIWA

This program has encompassed the following two activities:

- the expansion of research into greenfields exploration with funding support by EIS to Minerals Research Institute of Western Australia (MRIWA) of \$350 000 per annum
- the Western Australia Regional Researcher Initiative.

This latter activity is aimed at the rapid transfer of new geoscience concepts, skills and technologies into GSWA and the Western Australian minerals exploration industry. Three Western Australian Regional Researcher Initiative projects were funded by EIS with the main focus of the program in the Albany–Fraser Orogen and adjacent basement to the Eucla Basin where some formidable exploration challenges exist. The research activities of the Embedded Researcher program were completed in 2015–16.

Outcomes of work program 2015–16

Several new MRIWA projects, which are supported directly or indirectly by GSWA, received approval by the MRIWA Board this year. They are:

M462 Multi-scaled near Surface Exploration using Ultrafine Soils

M465 Deep Crustal Scale Structure, Geological Evolution and Multi-Commodity Prospectivity Analysis in the Halls Creek Orogen, Kimberley Region, Western Australia

M470 Mineral Systems on the Margin of Cratons: Albany–Fraser Orogen / Eucla Basement Case Study

M476 An Integrated Multiscale Study of Crustal Structure and Prospectivity of the Eastern Yilgarn Craton and Adjacent Albany–Fraser Orogen

In addition, four more GSWA supported projects were already in progress:

M424 Multiscale Dynamics of Hydrothermal Mineral Systems

M436 Distal Footprints of Giant Ore Systems: Capricorn WA Case Study

M446 4D Evolution of WA Ore Systems (WA4D): Re-Os Sulphide Geochemistry

M448 4D Evolution of WA Ore Systems (WA4D): Rutile – Pathfinder to Ores

One project supported by GSWA was completed and published in the reporting year:

M426 Exploration Targeting for BIF-hosted Fe Deposits in the Pilbara Craton WA, published as GSWA Report 163

The Western Australian Regional Researcher Initiative was managed by CSIRO. Three projects using embedded researchers were undertaken in the Yilgarn and Albany–Fraser – Eucla regions.

The results of two of the projects have previously been published as GSWA Report 144 Greenfields geochemical exploration in a regolith-dominated terrain: the Albany–Fraser Orogeny/Yilgarn Craton margin and as GSWA Report 145 High grade Au deposits: processes to prediction.

The third embedded researcher funded by GSWA has completed research with the aim of increasing the level of copper and zinc prospectivity in the Yilgarn Craton. The Report on the VMS exploration in the Yilgarn Craton is due to be published in 2016–17.

Planned work program and products 2016–17

Funding for the Embedded Researcher position is now complete.

The additional funding from EIS to MRIWA will continue to support the projects listed above to June 2017.

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APPENDICES



Appendix A

GSWA maps, books and datasets released 2015–16

Geological maps

1:100 000 Geological Series maps

BADJA, WA Sheet 2240 by *Zibra, I, Ivanic, TJ, Chen, SF, Clos, F, and Li, J*

BUNGAR, WA Sheet 2539 by *Ivanic, TJ*

DIORITE, WA Sheet 4347 by *Quentin de Gromard, R, Smithies, RH, and Howard, HM*

ILGARARI, WA Sheet 2849 by *Blay, OA and Thorne, AM*

LOFTY RANGE, WA Sheet 2749 by *Blay, OA and Thorne, AM*

MOUNT MAGNET, WA Sheet 2441 by *Zibra, I*

YALGOO, WA Sheet 2241 by *Ivanic, TJ, Li, J, Meng, Y, Guo, L, and Yu, J*

1:250 000 Geological Series maps

DRYSDALE–LONDONDERRY, WA Sheet SD 52-9 and part of Sheet SD 52-5 by *Phillips, C and de Souza Kovacs, N*

WEBB, WA Sheet SF 52-10 by *Spaggiari, CV, Haines, PW, Tyler, IM, Allen, HJ, and de Souza Kovacs, N*

State map

Geological map of Western Australia 1:2 500 000, 2015 by *Martin, DMcB, Hocking, RM, Riganti, A, and Tyler, IM*

Non-series maps

Geological interpretation of the West Musgrave Province by *Howard, HM, Smithies, RH, Quentin de Gromard, R, Evins, P, and Werner, M*

Iron ore deposits of the Yilgarn Craton, 2016 by *Cooper, RW*

Major resource projects, Western Australia — 2016 by *Cooper, RW, Wyche, NL, Strong, C, Hall, G, and Day, LJ*

Manganese deposits of the Pilbara and Capricorn regions by *Strong, C*

Mines — operating and under development, Western Australia — 2016 by *Cooper, RW, Strong, CA, Wyche, NL, Day, LJ, and Hall, G*

Plates

Interpreted bedrock geology of the East Pilbara Craton — Plate 1A by *Hickman, AH*

Interpreted bedrock geology of the East Pilbara Craton — Plate 1B by *Hickman, AH*

Interpreted bedrock geology of the East Pilbara Craton — Plate 1C by *Hickman, AH*

Interpreted pre-Mesozoic bedrock geology of the Albany–Fraser Orogen and southeast Yilgarn Craton including seismic line 12GA-T1, Plate 1, Record 2014/6 by *Spaggiari, CV and Occhipinti, SA*

Interpreted pre-Mesozoic bedrock geology of the Albany–Fraser Orogen and southeast Yilgarn Craton including seismic line 12GA-AF3, Plate 2, Record 2014/6 by *Spaggiari, CV and Brisbout, L*

Interpreted pre-Mesozoic bedrock geology of the Albany–Fraser Orogen and southeast Yilgarn Craton including seismic lines 12GA-AF1 and 12GA-AF2, Plate 3, Record 2014/6 by *Spaggiari, CV and and Brisbourn, L*

Interpreted pre-Mesozoic bedrock geology of the Albany–Fraser Orogen and southeast Yilgarn Craton seismic lines 12GA-AF1, 12GA-AF2, 12GA-AF3, 12GA-T1, Plate 4, Record 2014/6 by *Spaggiari, CV and Occhipinti, SA*

Interpreted regolith–landform geology of the Balangarra area, north Kimberley by *de Souza Kovacs, N*

Interpreted regolith–landform geology of the Bunuba and Yuriyngem–Taam areas, south Kimberley by *de Souza Kovacs, N*

Resource potential for land use planning series

Land use planning: Aboriginal land, conservation areas, mineral and petroleum titles, and geology: Western Australia — 2016

Regionally significant basic raw materials — Albany

Regionally significant basic raw materials — Esperance

Publications

Reports

Report 127 Deposition, provenance, inversion history and mineralization of the Proterozoic Edmund and Collier Basins, Capricorn Orogen by *Cutten, HN, Johnson, SP, Thorne, AM, Wingate, MTD, and Kirkland, CL*

Report 149 Characterization and correlation of lower Permian strata, Canning Basin, Western Australia, and implications for CO₂ sequestration by *Dent, LM*

Report 152 Determining crustal architecture in the east Albany–Fraser Orogen from geological and geophysical data by *Brisbourn, L*

Report 154 COBRA — Amadeus Basin Project, gravity and magnetic study of the Western Amadeus Basin, Western Australia by *Foss, C, Austin, J, and Schmid, S*

Report 155 Unravelling the upper-amphibolite facies Glenburgh gold deposit, Gascoyne Province — evidence for metamorphosed mineralization by *Roche, LK*

Report 156 Integrated spectral mapping of precious and base metal related mineral footprints, Nanjilgardy Fault, Western Australia by *Wells, M, Laukamp, C, and Hancock, EA*

Report 157 A geophysical investigation of the east Kimberley region, northern Western Australia by *Lindsay, MD, Occhipinti, SA, Hollis, JA, Aitken, ARA, and Metelka, V*

Report 159 Prospectivity analysis of the Halls Creek Orogen, Western Australia — using a mineral systems approach by *Occhipinti, SA, Metelka, V, Lindsay, MD, Hollis, JA, and Aitken, ARA*

Report 160 Northwestern Pilbara Craton: a record of 450 million years in the growth of Archean continental crust by *Hickman, AH*

Records

Record 2015/1 Geological Survey work program for 2015–16 and beyond

Record 2015/3 Alteration mineral zonation associated with BIF-hosted iron ore: mineral mapping using hyperspectral drill core data by *Chiarelli, L*

Record 2015/6 GSWA Kimberley workshop 2014: extended abstracts by *Maidment, DW*

Record 2015/8 Detrital zircon geochronology of upper Ediacaran to lower Cambrian deposits (Supersequence 4), western Amadeus Basin: testing revised stratigraphic correlations by *Haines, PW, Wingate, MTD, Kirkland, CL, and Allen, HJ*

Record 2015/9 Regolith chemistry of the Balangarra area, north Kimberley by *Morris, PA, Scheib, AJ, and de Souza Kovacs, N*

Record 2015/10 Eucla basement stratigraphic drilling results release workshop: extended abstracts by *Spaggiari, CV and Smithies, RH*

- Record 2015/11 The Sandstone greenstone belt, northern central Yilgarn Craton: 3D modelling using geological and geophysical constraints by *Murdie, RE, Gessner, K, and Chen, SF*
- Record 2015/12 The Windimurra Igneous Complex, Yilgarn Craton: an Archean layered intrusion revealed by seismic data and 3D modelling by *Ivanic, TJ and Brett, JW*
- Record 2015/13 Saying goodbye to a 2D Earth — conference abstracts 2015 (with accompanying zip file) by *Jessell, M and Gessner, K*
- Record 2015/14 Geological map of Western Australia 14th edition: Explanatory Notes by *Martin, DMcB, Hocking, RM, Riganti, A, and Tyler, IM*
- Record 2015/15 Regolith chemistry of the Bunuba and Yuriangem–Taam, south Kimberley by *Scheib, AJ, Morris, PA, and de Souza Kovacs, N*
- Record 2015/16 2nd lithosphere workshop — abstracts by *Gorczyk, W, Gessner, K, and Lu, Y*
- Record 2016/2 GSWA 2016 extended abstracts: promoting the prospectivity of Western Australia
- Record 2016/3 Integrated Exploration Platform v2.5: an innovative visual analytics plug-in for ESRI ArcGIS by *Wong, JC, Holden, E-J, Kovesi, P, Gessner, K, and Murdie, RE*
- Record 2016/4 Geology and U–Pb geochronology of the Warlawurru Supersuite and MacDougall Formation in the Mitika and Wanarn areas, west Musgrave Province by *Quentin de Gromard, R, Wingate, MTD, Kirkland, CL, Howard, HM, and Smithies, RH*
- Record 2016/5 Microstructural evolution of the Yalgoo Dome (Western Australia) by *Schiller, M*
- Record 2016/6 A field guide to the mafic–ultramafic layered intrusions of the northern Youanmi Terrane by *Ivanic, TJ*
- Record 2016/7 Hydrogeochemistry of Western Australia, data release: accompanying notes by *Bardwell, N and Gray, DJ*
- Record 2016/8 The evolution of mafic and ultramafic rocks of the Mesoproterozoic Fraser Zone, Albany–Fraser Orogen, and implications for Ni–Cu sulfide potential in the region by *Maier, WD, Smithies, RH, Spaggiari, CV, Barnes, SJ, and Kirkland, CL*
- Record 2016/9 Improved Hydrogeochemical Exploration in the northwest Yilgarn Craton, Adding Value to Underexplored Areas (with accompanying zip file) by *Gray, DJ, Reid, N, and Noble, Ryan RP*
- Record 2016/10 Evolution and deformation of the onshore Eucla Basin during the Cenozoic by *Mounsher, LC*
- Record 2016/11 Stratigraphic evolution of the southern Australian onshore Bight Basin: a record for the breakup of Gondwana during the Cretaceous by *Reynolds, S*

Non-series books

- Calendar 2016: Geological Survey of Western Australia
- Early Cretaceous ammonite (Oppeliidae: Aconecerasinae), Muderong Shale, Barrow Island F45M core by *Martin, SK*
- Fieldnotes: A Geological Survey of Western Australia newsletter July 2015 number 75
- Fieldnotes: A Geological Survey of Western Australia newsletter October 2015 number 76
- Fieldnotes: A Geological Survey of Western Australia newsletter January 2016 number 77
- Fieldnotes: A Geological Survey of Western Australia newsletter April 2016 number 78
- Mapping Western Australia: State geological maps 1894–2015
- Petroleum prospectivity of State Acreage Release Areas L15-5, northern Perth Basin, Western Australia
- Petroleum prospectivity of State Acreage Release Areas L16-1 and L16-2, Canning Basin, Western Australia
- Petroleum prospectivity of State Acreage Release Areas T15-1/ L15-2, L15-3 and L15-4, northern Carnarvon Basin, Western Australia
- Summary of petroleum prospectivity: Northern Carnarvon Basin

Datasets

1:100 000 Geological Information Series

East Yilgarn, 2016: Geological Information Series

Kimberley, 2016: Geological Information Series

Murchison, 2015: Geological Information Series

Murchison, 2016: Geological Information Series

South Yilgarn, 2016: Geological Information Series

Tanami–Arunta, 2016: Geological Information Series

West Musgrave, 2016: Geological Information Series

West Tanami, 2015: Geological Information Series

Western Capricorn Orogen, 2015: Geological Information Series

Data packages

Compilation of geochronology information, 2016

East Albany–Fraser Orogen Geological Exploration Package 2016

GSWA Open Day 2016

Sandstone, 2015: 3D Geomodel Series

Sea to scarp — geology for land use planning in the northern Swan Coastal Plain, Lancelin to Geraldton

State Acreage Release, September 2015

Windimurra, 2015: 3D Geomodel Series

Explanatory Notes System

East Yilgarn, 2016: Explanatory Notes System

South Yilgarn, 2016: Explanatory Notes System

Appendix B

GSWA external publications on Western Australian geoscience 2015–16

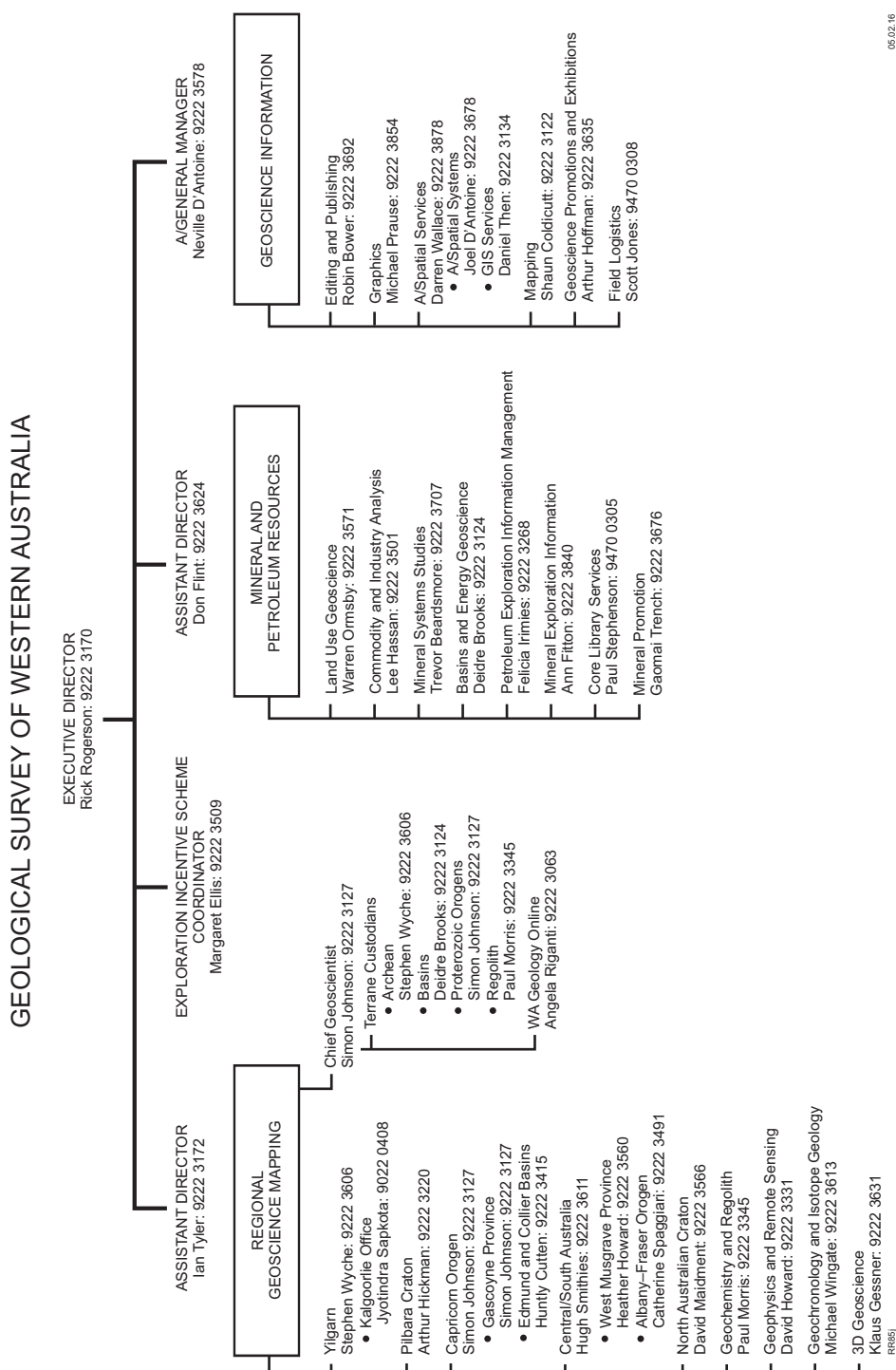
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Appendix C

GSWA organizational structure — 30 June 2016



05.02.16

Appendix D

GSWA collaborative research projects (current and historic) — 30 June 2016

Current projects

MRIWA Report project M426: predictive exploration for BIF-hosted Fe deposits in the Yilgarn Craton, Western Australia



Project manager: Associate Professor P Duuring

Partner researchers/institutions: Associate Professor P Duuring, Dr Y Teitler (Centre for Exploration Targeting [CET], The University of Western Australia [UWA])

GSWA contact: Dr T Beardsmore

Duration of project: 2012–15

Project description

Determine the geological criteria that control the location of high-grade, BIF-hosted iron ore deposits in the Yilgarn and evaluate which exploration methods are most useful for their discovery, postgraduate studies

Outputs — planned or actual

Record 2015/3 Alteration mineral zonation associated with BIF-hosted iron ore: mineral mapping using hyperspectral drill core data

Second generation regional targeting products: data generation and integration



Project manager: Professor J Miller

Partner researchers/institutions: Associate Professor S Occhipinti, Dr M Lindsey, Dr A Aitken (CET, UWA)

GSWA contact: Dr I Tyler

Duration of project: 2013–16

Project description

Provision of exploration targeting products, including software and GIS products to encourage mineral exploration in Western Australia

Outputs — planned or actual

Co-branded GSWA Reports and Records

Occhipinti, S A, Metelka, V, Lindsay, M D, Hollis, J A, Aitken, A R A, Tyler, I M, Miller, J M, McCuaig, T C, 2016, Multicommodity mineral systems analysis highlighting mineral prospectivity in the Halls Creek Orogen: Ore Geology Reviews, v. 72, p. 86–113.

Lindsay, MD, Occhipinti, SA, Aitken, ARA, Metelka, V, Hollis, JA, Tyler, IM, 2016. Proterozoic accretionary tectonics in the east Kimberley region, Australia: Precambrian Research, v. 278, p. 262–282

Report 157 A geophysical investigation of the east Kimberley region, northern Western Australia

Report 159 Prospectivity analysis of the Halls Creek Orogen, Western Australia — using a mineral systems approach

Report data package 159 Prospectivity analysis of the Halls Creek Orogen, Western Australia — using a mineral systems approach

Geological studies of the Browns Range HREE mineralization

Project manager: Dr T Beardsmore

Partner researchers/institutions: Professor B Rasmussen (Curtin University), Northern Minerals Ltd

GSWA contact: S Morin-Ka

Duration of project: 2013–15

Project description

Determine the age(s) of HREE mineralization in the Browns Range region, using xenotime geochronology; determine whether HREE mineralization is directly detectable using hyperspectral analysis; determine the distribution and composition of any associated hydrothermal alteration, using conventional thin-section petrography and the GSWA HyLogger

Outputs — planned or actual

Co-branded GSWA Report

Yilgarn Pyrite Fingerprint Database

Project manager: Professor R Large (CODES, University of Tasmania)

Partner researchers/institutions: CRC for Metals Discovery, University of Tasmania

GSWA contact: Dr T Beardsmore, Manager, Minerals Geoscience

Duration of project: 2012–15

Project description

To produce a database and associated interrogative software package that provides a chemical fingerprint for pyrite of various mineral and ore associations in a selected district of the Yilgarn Craton

Volcanic hosted massive sulfide (VMS) exploration in the Yilgarn Craton

Project manager: Dr S Barnes

Partner researchers/institutions: Dr S Hollis (CSIRO)

GSWA contact: S Wyche, Dr T Beardsmore

Duration of project: 2013–15

Project description

Part of the EIS/CSIRO Western Australian Regional Researcher Initiative aimed at rapid transfer of new geoscience concepts, skills and technologies into the Western Australian mineral exploration industry

A prospectivity study of VMS potential in the Yilgarn Craton, with deposit-scale study of Nimbus Zn–Ag(–Au) deposit, deposit- to camp-scale study of VMS mineralization at Erayinia, and a regional-scale study of the southeast Gum Creek greenstone belt. Study will make use of EIS drillcore, HyLogger data, petrography, SEM work, w/r and soil geochemistry, U–Pb zircon geochronology, geology and geophysics to establish vectors to mineralization

Outputs — planned or actual

Co-branded GSWA/CSIRO reports, peer-reviewed journal papers, and Conference proceedings

Hollis et al. 2015, VHMS mineralization in the Yilgarn Craton: greenstone prospectivity and new results from the Eastern Goldfields in GSWA Record 2015/2

Hollis, SP, Yeats, CJ, Wyche, S, Barnes, SJ, Ivanic, TJ, Belford, SM, Davidson, GJ, Roache, AJ and Wingate, MTD, 2015, A review of volcanic-hosted massive sulfide (VHMS) mineralization in the Archaean Yilgarn Craton, Western Australia: tectonic, stratigraphic and geochemical associations: Precambrian Research, v. 260, p. 113–135.



Deep Exploration Technologies Co-operative Research Centre (DET CRC)**Project manager:** Dr R Hillis**Partner researchers/institutions:** DET CRC**GSWA contact:** D Flint and Dr I Tyler**Duration of project:** 2010–18**Project description**

GSWA is an affiliate partner to the Deep Exploration Technologies Cooperative Research Centre (DET CRC). The DET CRC was established in 2010 to manage an eight-year program of research that aims to provide more successful, cheaper and safer ways to drill, analyse and target deep mineral deposits. The DET CRC has \$145 million cash and in-kind funding from the Commonwealth Government of Australia and program participants, making it the world's best-supported independent research initiative in mineral exploration

Outputs — planned or actualWebsite: <http://detcrc.com.au/>**Multiscale dynamics of hydrothermal mineral systems (MRIWA Project M424)****Project manager:** Professor A Ord**Partner researchers/institutions:** Professor A Ord, Dr W Gorczyk, Dr B Hobbs, Dr M Munro (CET, UWA); MRIWA (Project M424)**GSWA contact:** Dr K Gessner**Duration of project:** 2013–15**Project description**

The project examines the origin of giant hydrothermal deposits at scales ranging from mineral grain to lithospheric. The goal is to define measurable parameters that control the size of such systems and that can be used as mineral exploration criteria, in particular emphasizing: (i) criteria that distinguish a 'successful' from a 'failed' mineral system and; (ii) vectors to mineralization within a successful system

Outputs — planned or actual

Co-branded GSWA Records and Reports

Yilgarn gold exploration targeting Atlas**Project manager:** S Wyche**Partner researchers/institutions:** Dr W Witt (CET, UWA)**GSWA contact:** S Wyche**Duration of project:** 2010–15**Project description**

To produce an Atlas that assesses qualitatively and quantitatively various structural, mineralogical and geochemical criteria for targeting gold in the Yilgarn Craton

Outputs — planned or actual

Regional-scale targeting for gold in the Yilgarn Craton: Part 1 of the Yilgarn Gold Exploration Targeting Atlas: report data package 125 (USB flash drive)

Regional-scale targeting for gold in the Yilgarn Craton: Part 1 of the Yilgarn Gold Exploration Targeting Atlas, Report 125 (PDF online)

Regional-scale targeting for gold in the Yilgarn Craton: Part 1 of the Yilgarn Gold Exploration Targeting Atlas, Report 125 (zipped data files online)

Regional targeting criteria for gold in the Yilgarn Craton: which ones work and how well? (PDF online)

District-scale targeting for gold in the Yilgarn Craton: Part 2 of the Yilgarn Gold Exploration Targeting Atlas (USB flash drive)

District-scale targeting for gold in the Yilgarn Craton: Part 2 of the Yilgarn Gold Exploration Targeting Atlas (PDF online)
More Reports to follow.

MRIWA project M462: multiscaled near surface exploration using ultrafine soils**Project manager:** R Noble (CSIRO)**Partner researchers/institutions:** R Noble (CSIRO)**GSWA contact:** Dr P Morris**Duration of project:** 2016–18**Project description**

The project aims to refine analytical methods and enhance surface exploration success with sampling and analysing micro and nanoparticulate metals and fine particle size fractions in local site orientation surveys as well as broad regional sample sets in Australia (Yamarna greenstone belt, Paterson Province, and northeast Yilgarn margins and Northern Yandal edge). Samples from previous orientation surveys from CSIRO, industry and previous or current regional soil surveys (GSWA or industry) will be subject to a variety of size separation analyses and assessed in relation to other physical (e.g. texture), mineralogical (e.g. Fe oxides, kaolinite), biological (e.g. organic carbon) and chemical (e.g. pH, EC) properties of the samples. Micro and nanoparticulate metals will be characterized and assessed with respect to known mineralization to understand mobility in a landscape evolution context

Outputs — planned or actual

Peer-reviewed journal papers; conference proceedings; GSWA Report

Northwest biogeochemistry project — northwest Yilgarn biogeochemistry and beyond**Project manager:** Dr M Lintern (CSIRO)**Partner researchers/institutions:** Dr M Lintern, (CSIRO)**GSWA contact:** Dr P Morris**Duration of project:** 2015–16**Project description**

CSIRO will provide the client with the following:

- a database covering available biogeochemistry surveys undertaken by CSIRO to date including northwest Yilgarn, northeast Yilgarn, and site-specific studies in northern and southern Western Australia and Gawler Craton, South Australia
- a GIS file that will consist of the compiled geochemical data of all available biogeochemical surveys conducted by CSIRO and include the northwest biogeochemistry data yet to be received spatially located within Australia together with other relevant data sets such as geology
- a final report to be issued at conclusion of the project which will contain an Atlas.

Outputs — planned or actual

Final report published as GSWA Record

The distal footprints of giant ore systems: UNCOVER Australia project**Project manager:** Dr R Hough (CSIRO)**Partner researchers/institutions:** Professor C McCuaig (CET/UWA), Professor S Reddy (Curtin)**GSWA contact:** Dr I Tyler, Dr S Johnson**Duration of project:** 2013–17**Project description**

This project commenced in August 2013 and aims to begin to address the key technical risks impeding future greenfields exploration. It is a collaboration between CSIRO, UWA (through CET), Curtin University, and the Geological Survey of Western Australia (GSWA), in partnership with approximately 10 junior and one major exploration company. The project aligns with the Australian Academy of Sciences UNCOVER initiative to boost exploration geoscience research in Australia, and the Federal Government's National Exploration Strategy UNCOVER Australia Project (RP04-063)

Outputs — planned or actual

Co-branded GSWA/CSIRO/MRIWA Reports

ARC Linkage project: LP130100722 Earth's best-preserved Archean boninites: do they finally resolve the Archean mantle plume–plate controversy?

Project manager: Associate Professor D Wyman (University of Sydney)

Partner researchers/institutions: J Lowrey, R Teslyuk (PhD candidates, University of Sydney)

GSWA contact: Dr T Ivanic

Duration of project: 2014–18

Project description

To look at the geochemistry of mafic rocks in the Murchison Domain of the Yilgarn Craton. Subduction typically starts on the modern Earth with the eruption of chemically distinctive rocks known as boninites. This project will study remarkably well-preserved 2.8 billion-year-old boninites from Western Australia that may finally establish whether modern-style plate tectonics operated in the first half of Earth's history

Outputs — planned or actual

Peer reviewed journal papers; conference proceedings; PhD theses as GSWA Reports

Stratigraphic Contact Analysis Tool



Project manager: Professor M Jessell (CET, UWA)

Partner researchers/institutions: Professor M Jessell, Dr V Ogarko (3D Uncertainty Group, CET, UWA)

GSWA contact: Dr I Tyler

Duration of project: 2016–17

Project description

Develop a tool that will allow GSWA to better analyse the stratigraphic relationships inferred in arbitrary geographic subsets of current GSWA digital map products, by way of topological analysis of the mapped relationships. This will provide GSWA with the ability to assess the local relationship between Formations and Groups in a graphical form, and to compare these to textual ENS content

Outputs — planned or actual

Standalone software to analyse stratigraphic and fault relationships directly from GSWA digital maps, GSWA Report

MRIWA project M446: 4D evolution of Western Australian ore systems, Re–Os sulfide geochronology

Project manager: Professor NMcNaughton (John de Laeter Centre, Curtin University)



Partner researchers/institutions: Professor N McNaughton, Dr S Tessalina, Dr F Jourdan, V Barrote (PhD candidate) (John de Laeter Centre, Curtin University), Thermo Fisher Scientific

GSWA contact: Dr M Wingate

Duration of project: 2016–19

Project description

Provide benchmark geochronology for metals exploration in Western Australia, to complement the extensive 2D/3D geological mapping and data of the GSWA and industry. This sulfide geochronology project provides a new opportunity to introduce direct-dating of ore sulfides along with fingerprinting metal sources and will fill a major gap in 4D analysis of mineralized terrains, a topic recognized as a national deficiency. The specific aims are for two deposit types, VHMS and orogenic gold

Outputs — planned or actual

Peer reviewed journal papers; conference proceedings; GSWA Report

MRIWA project M448: 4D evolution of Western Australian ore systems (WA4D), rutile — pathfinder to ores

Project manager: Professor N McNaughton (John de Laeter Centre, Curtin University)



Partner researchers/institutions: Professor N McNaughton, Associate Professor N Evans, Dr F Jourdan, J Porter (PhD candidate) (John de Laeter Centre, Curtin University), Independence Group NL

GSWA contact: Dr M Wingate

Duration of project: 2015–18

Project description

Utilize publically available geochemical data on rutiles formed in different ore and unmineralized environments to build a geochemical database, and to add new geochemical data for rutiles from Western Australian ore systems and barren rocks. From this database, existing geochemical discriminants of mineralization will be tested, and by virtue of the enhanced capabilities of the modern analytical techniques to be employed, new discriminants will be developed for each ore commodity that will shed light on the origin of formation of rutile. The project will target Western Australian ore systems for new data, to compare and contrast against published data. The project will do the following:

- provide rapid/automated rutile identification and in situ analysis
- verify rutile mineralization ages by other geochronology methods (U–Pb, Ar–Ar)
- provide sponsor-initiated case studies of rutile geochemical/age discriminants for gold and base metal exploration in Western Australia
- provide feedback to 4D metallogenic mapping

Outputs — planned or actual

Peer reviewed journal papers; conference proceedings; GSWA Report

ARC Centre of Excellence CE11E0070: core to crust fluid systems

Project manager: Professor S O'Reilly (Macquarie University)



Partner researchers/institutions: Professor S Wilde (Curtin University), Professor C McCuaig (CET, UWA), Associate Professor C Kirkland (CET, Curtin), Dr H Yuan (Macquarie University, CET)

GSWA contacts: Dr I Tyler, Dr K Gessner, Dr M Wingate

Duration of project: 2011–17

Project description

A world-leading Centre of Excellence, driving innovative interdisciplinary research towards a new understanding of Earth's origins, fluid budgets and evolution, and delivering outcomes of tangible benefit to society. <http://ccfs.mq.edu.au/>

GSWA-sponsored projects

- 3D crustal architecture of Western Australia
- Zircon Lu–Hf constraints on Precambrian crustal evolution in Western Australia

Outputs — planned or actual

Co-branded GSWA Reports, and international journal papers, GSWA geochronology records

Report 127 Deposition, provenance, inversion history and mineralization of the Proterozoic Edmund and Collier Basins, Capricorn Orogen

Yuan, H, 2016 Secular change in Archean crust formation recorded in Western Australia in GSWA Record 2016/2.

Record 2015/16 2nd lithosphere workshop — abstracts

Report 137 Basin formation by orogenic collapse: zircon U–Pb and Lu–Hf isotope evidence from the Kimberley and Speewah Groups, northern Australia

Report 133 Tectonic links between Proterozoic sedimentary cycles, basin formation and magmatism in the Albany–Fraser Orogen, Western Australia

Report 122 The crustal evolution of the Rudall Province from an isotopic perspective

Report 120 Juvenile crust formation and recycling in the northern Murchison Domain, Yilgarn Craton: evidence from Hf isotopes and granite geochemistry

Report 115 A multi-isotopic approach to the crustal evolution of the west Musgrave province, Central Australia

Report 110 Temporal and hafnium isotopic evolution of the Glenburgh Terrane basement: an exotic crustal fragment in the Capricorn Orogen

Record 2015/5 Temporal constraints on magmatism, granulite-facies metamorphism, and gold mineralization of the Hercules Gneiss, Tropicana Zone, Albany–Fraser Orogen

Record 2013/9 Zircon U–Pb–Hf isotope evidence for links between the Warumpi and Aileron Provinces, west Arunta region

Record 2011/12 Inferences on crust–mantle interaction from Lu–Hf isotopes: a case study from the Albany–Fraser Orogen

ARC Linkage project LP130100922: chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: providing a framework for understanding mineralizing systems



Project manager: Professor B Rasmussen

Partner researchers/institutions: Professor B Rasmussen, Dr J Muhling, Ms N Piechocka, Ms I Fielding (Curtin University)

GSWA contact: Dr S Johnson

Duration of project: 2014–17

Project description

This project will combine innovative geochronology with targeted field mapping to date sedimentary successions, metamorphic events, crustal fluid flow, and hydrothermal mineralization along the recently acquired Capricorn seismic transect. The construction of a new and improved geological framework linked to deep seismic information has the potential to provide breakthroughs in our understanding of the history of this long-lived orogen and the ore deposits that it contains. The outcomes will identify the major structures and tectonic events controlling mineralization, underpinning the generation of successful exploration models

Outputs — planned or actual

PhD theses, GSWA geochronology records, cobranded GSWA Reports and international journal papers

Fielding et al., (accepted) *Economic Geology*

Piechocka et al., (in review) *Contributions to Mineralogy and Petrology*

Mapping sulfur sources in selected Precambrian terranes of Western Australia to enhance predictive targeting for gold and base metal mineralization



Project manager: Associate Professor M Fiorentini

Partner researchers/institutions: CET, UWA

GSWA contact: Dr T Beardsmore

Duration of project: 2014–17

Project description

Spatially constrained understanding of sulfur sources to form gold and base mineralization in key terranes of Western Australia

Outputs — planned or actual

Peer-reviewed journal papers, conference proceedings, GSWA Report

K–Ar dating of fault rocks

Project manager: Dr H Cutten

Partner researchers/institutions: H Zwingmann (Kyoto University); T Uysal, A Todd (ARRC, CSIRO)

GSWA contact: Dr H Cutten, Dr M Wingate

Duration of project: 2015–18

Project description

K–Ar (and possibly Rb–Sr) dating of fault rocks, fault gouge, and slickenside surfaces, to determine ages of most recent fault movements in low-grade rocks of the Edmund and Collier Basins, in which deformation events previously could be dated only indirectly. The project will hopefully be expanded to include the eastern Capricorn Orogen basins

Outputs — planned or actual

Peer-reviewed journal papers, GSWA Report

Report 127 Deposition, provenance, inversion history and mineralization of the Proterozoic Edmund and Collier Basins, Capricorn Orogen



Crustal evolution of Western Australia

Project manager: Associate Professor C Kirkland

Partner researchers/institutions: Curtin University

GSWA contact: Dr M Wingate

Duration of project: 2015–18

Project description

The main aims are to:

- produce contoured, time-dynamic Hf isotopic maps from selected regions of Western Australia
- implement SIMS oxygen analyses of GSWA mounts and contribute to isotopic data

Outputs

- Co-branded GSWA Reports and GIS layers
- Hf isotopic maps and oxygen isotopic analyses
- Western Australian atlas of crustal evolution
- Magmatic petrogenesis of the Rudall Province
- Isotopic signature of crystalline basement of the Eucla Basin

Paleoproterozoic mafic magmatism of the Kimberley Basin, Western Australia



Project manager: Dr D Maidment

Partner researchers/institutions: Dr K Orth (University of Tasmania)

GSWA contact: Dr D Maidment

Duration of project: 2012–15

Project description

The main aims are to:

- map the distribution and relationships of the extrusive mafic rocks and sedimentary interbeds
- constrain the spatial and temporal relationships of the different magmatic phases within the Hart Dolerite Sill
- search for the plumbing and drivers that lead to the eruption and intrusion of 300 000 km³ of magma
- understand the mafic volcanism in the development of Australia and in particular the North Australian Craton

Outputs — planned or actual

GSWA Report

Orth, K 2015 The Carson–Hart Large Igneous Province intrusive complex: implications for Speewah-style vanadium–titanium–iron mineralization in the Kimberley region in GSWA Record 2015/2

Hollis, JA, et al, 2013 Setting and prospectivity of a large igneous province: the 1800 Ma Hart Dolerite, Kimberley region in GSWA Record 2013/2

Report 164 Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia

West Yilgarn Craton metamorphic project

Project manager: S Wyche

Partner researchers/institutions: B Goscombe (ITAC)

GSWA contact: S Wyche

Duration of project: 2008–17

Project description

Extension of the East Yilgarn metamorphic project commenced during the pmd*CRIC. This project will document metamorphic patterns and event histories across the Yilgarn Craton. Dr Goscombe will supply a range of data including geochronology, microprobe data, petrographic information, imagery, maps and report

Outputs

GSWA Report and digital data

Yalgoo Dome structural project, Monash University

Project manager: R Weinberg

Partner researchers/institutions: Monash University

GSWA contact: Dr I Zibra

Duration of project: 2013–15

Project description

The Monash-based PhD and Honours projects are designed to provide original contributions. They will include components of both field and laboratory/office work. The field activities will be mainly focused on detailed structural mapping in key domains of the Yalgoo Dome, with the aim of producing an ideal structural cross-section through the dome to constrain its three-dimensional architecture and evolution through time. The structural work will be augmented by sampling directed at microstructural, geochemical, petrological and geochronological investigations

Outputs — planned or actual

Structural evolution of the Yalgoo Dome, Yilgarn Craton, Western Australia, Record 2014/14

Record 2014/16 Structural Evolution of the Yalgoo Dome, Yilgarn Craton, Western Australia: A Core Perspective

Yalgoo Dome structural project, Macquarie University

Project manager: S Piazzolo

Partner researchers/institutions: Macquarie University

GSWA contact: Dr I Zibra

Duration of project: 1 year

Project description

A Macquarie-based Master's project designed to examine structures and field relationships in the Yalgoo dome

Outputs — planned or actual

MSc thesis to be published as a GSWA Record

Record 2015/4 Tectonite type: their formation and significance, map production, field relationships and petrography

Narryer Terrane isotopes project

Project manager: S Wyche

Partner researchers/institutions: Professor T Kemp (UWA)

GSWA contact: S Wyche

Duration of project: 2012–16

Project description

Field inspection/sampling of the Narryer gneisses, zircon isotope work (geochronology, O isotopes, Hf isotopes — both whole grain and laser ablation) and whole-rock Hf, Nd and Pb isotope studies

Outputs

GSWA Report and external papers

Narryer Terrane structural project

Project manager: S Wyche

Partner researchers/institutions: C Passchier (University Mainz, Germany)

GSWA contact: Dr I Zibra

Duration of project: 2014–16

Project description

Detailed mapping of structure and metamorphism in the southern part of the Narryer Terrane adjacent to the Murchison Domain of the Youanmi Terrane

Outputs

GSWA report and external papers

Murchison quartz CPO project

Project manager: S Wyche

Partner researchers/institutions: M Peternell (Johannes Gutenberg University Mainz, Germany)

GSWA contact: Dr I Zibra

Duration of project: 2013–15

Project description

To carry out quartz CPO studies in Murchison shear zones, GSWA to contribute with thin sections and analyses

Outputs

GSWA report and external papers

Record 2016/5 Microstructural evolution of the Yalgoo Dome (Western Australia)

MRIWA project M470: mineral systems on the margin of cratons, Albany–Fraser Orogen/Eucla basement case study



Project manager: Associate Professor C Kirkland (Curtin University)

Partner researchers/institutions: C Kirkland, C Clark, K Evans, S Reddy (Curtin University); OKiddie (Ponton Minerals)

GSWA contact: Dr C Spaggiari

Duration of project: 2016–19

Project description

Research will focus on the partially covered terrain of the Albany–Fraser Orogen and the covered Eucla basement of Western Australia. The project will utilize a lithosphere-scale mineral systems approach to establish the fundamentals (timing, scale, material) of mass transfer processes within the crust. The project will utilize a broad range of geochronology techniques to enhance GSWA's regional U–Pb zircon coverage and will apply crustal evolution studies via novel analytical equipment to rapidly delimit domains of enhanced mantle input.

This research project includes three modules:

- *isotopic monitors of crustal evolution:* through cutting edge split stream LA-ICP-MS instrumentation (Hf in zircon, Nd in rutile)
- *petrochronology:* by coupling U–Pb geochronology (on a wide range of different mineral phases) to the grain-scale mineral chemistry as a proxy for the conditions of the crust during specific periods in time
- *sulfides sources and budgets:* through the use of multiple S isotopes combined with trace element ratios a robust fingerprint of S mobility and metal reservoirs in the region will be developed

Outputs — planned or actual

Peer-reviewed journal papers, conference proceedings, PhD theses and MRIWA report as GSWA Reports

Structural and metamorphic evolution of the east Albany–Fraser Orogen

Project manager: Dr C Spaggiari

Partner researchers/institutions: Dr C Clark, Dr T Johnson, Dr N Timms, Associate Professor C Kirkland (Curtin University), Professor T Blenkinsop, Dr J-M Huizenga (EGRU James Cook University), Dr E Tohver (UWA)

GSWA contact: Dr C Spaggiari

Duration of project: ongoing

Project description

Research into the structural and metamorphic history of the Fraser and Biranup Zones, focusing on P–T–t evolution. Methodology includes structural mapping, sedimentological analysis, microprobe analysis, pseudosections, and phosphate, titanite, and Ar–Ar dating

Outputs

Record 2014/15 Structural evolution of the Pleiades Lakes region; Northeastern Albany–Fraser Orogen, Western Australia
Report 129 Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia

Record 2011/18 P–T–t evolution of the Fraser Zone, Albany–Fraser Orogen, Western Australia

Record 2012/4 Structural and geochronological evolution of the Malcolm Gneiss, Nornalup Zone, Albany–Fraser Orogen, Western Australia

Clark et al., 2014, Precambrian Research

Kirkland et al., 2016, Precambrian Research

Scibiorski et al., 2016, Lithosphere

Geological studies of gabbroic rocks intruding the Arid Basin in the Albany–Fraser Orogen

Project manager: Dr T Johnson (Curtin University)

Partner researchers/institutions: Associate Professor C Clark, Associate Professor C Kirkland (Curtin University)

GSWA contact: Dr C Spaggiari

Duration of project: 2015–17

Project description

The principal aims of proposed research are to determine:

- the depth of magmatism and the pressure and temperature of metamorphism of the gabbroic rocks that intrude the sedimentary rocks of the Arid Basin
- a comparison to the metamorphic P-T of the sedimentary rocks (i.e. Snowys Dam Formation) of the Fraser Zone
- emplacement mechanisms and timing of gabbroic intrusions and their relationship to metamorphism

Outputs — planned or actual

Journal paper, results incorporated into MRIWA project M470

Eucla–Gawler seismic, gravity and MT survey



Project manager: Dr C Spaggiari

Partner researchers/institutions: Geoscience Australia, Geological Survey of South Australia, AuScope Earth Imaging

GSWA contact: Dr C Spaggiari

Duration of project: 2014–17

Project description

Acquisition, processing, and interpretation of the 870 km-long deep crustal reflection seismic line 13GA-EG1, from the Madura Province in Western Australia to the Gawler Craton in South Australia. This line is a continuation of seismic line 12GA-AF3

Outputs — planned or actual

Release of processed data (Western Australian component):

GSWA Open Day 2016 – February 2016

www.ga.gov.au/metadata-gateway/metadata/record/89637

Joint public release by GSWA, GSSA and GA of all acquired data and interpretation for entire Eucla–Gawler Survey: June 2016 AESC abstracts and posters www.dmp.wa.gov.au/Geological-Survey/Eucla-Gawler-Deep-Crustal-1458.aspx

Co-branded GSWA/GSSA/GA non-series map (release GSWA open day 2017) and Report 2016–17

ARC Linkage project LP130100413: craton modification and growth, the east Albany–Fraser Orogen in 3D

Project manager: Dr C Spaggiari



Partner researchers/institutions: Dr C Sippl, Associate Professor H Tkalčić, Professor B Kennett (Australian National University)

GSWA contact: Dr C Spaggiari

Duration of project: 2013–16

Project description

This is an Australian Research Council-funded collaborative project with the Seismology & Mathematical Geophysics research group at the Australian National University's Research School of Earth Sciences. To delineate the 3D structure of the east Albany–Fraser Orogen and the lithospheric structure below it, an array of passive seismic stations, the Albany–Fraser Experiment (ALFREX), is deployed from 2013–16 across the boundary of the Yilgarn Craton and the Albany–Fraser Orogen

Outputs — planned or actual

Conference proceedings, GSWA Report 2016–17, peer-reviewed journal papers:

Sippl et al., 2016, AJES

Sippl et al., in review, Geophysical Journal International

Sippl et al., in review, Precambrian Research

Evolution of the Fraser Zone, Albany–Fraser Orogen: implications for Ni–Cu sulfide potential

Project manager: Dr C Spaggiari

Partner researchers/institutions: W Maier (Cardiff University), O Kiddie (Creasy Group), C Kirkland and K Evans (Curtin University), S Barnes (CSIRO)

GSWA contact: Dr C Spaggiari

Duration of project: ongoing

Project description

Petrogenesis of mafic and ultramafic rocks of the Fraser Zone, sulfur transport and isotope studies, with links to basin evolution, metamorphism and structure. Only the southern one-third of the highly prospective Fraser Zone is exposed, so this project utilizes company-donated drillcores to map the Fraser Zone under cover, and examine host-rock relationships to the Nova–Bollinger Ni–Cu deposit

Outputs

Record 2016/8 The evolution of mafic and ultramafic rocks of the Mesoproterozoic Fraser Zone, Albany–Fraser Orogen, and implications for Ni–Cu sulfide potential in the region

Maier et al., 2016, Precambrian Research

Albany–Fraser MT survey

Project manager: Dr I Tyler

Partner researchers/institutions: Professor M Dentith (CET, UWA)

GSWA contact: Dr C Spaggiari

Duration of project: 2011–15 (not complete)

Project description

Acquisition and interpretation of deep crustal magnetotelluric data in the east Albany–Fraser Orogen, 3D MT data modelling

Outputs

Record 2014/6 Albany–Fraser Orogen Seismic and Magnetotelluric (MT) Workshop 2014: Extended Abstracts — Preliminary edition

www.dmp.wa.gov.au/documents/02-MT_acquisition_and_processing-Mike_Dentith-CETUWAMoombarriga.pdf

ARC Linkage project LP 140100267: reducing 3D geological uncertainty via improved data interpretation methods

Project manager: Professor M Jessell (CET, UWA)

Partner researchers/institutions: Professor E-J Holden (CET, UWA)

GSWA contact: Dr K Gessner, Manager, 3D Geoscience

Duration of project: 2013–17

Project description

Reducing 3D geological uncertainty via improved data interpretation methods is an Australian Research Council-funded collaborative project focusing on the quantification of errors and uncertainties in geological modelling, and the development of the Integrated Exploration Platform, a GIS-plugin that applies advanced visualization techniques to geophysical data



Outputs — planned or actual

Integrated Exploration Platform application via the CET website, co-branded GSWA Records and Reports
www.waexplorationplatform.wa.edu.au/

Record 2016/3 Integrated Exploration Platform v2.5: An innovative visual analytics plug-in for ESRI ArcGIS

Wong et al., 2016, Integrated Exploration Platform: software tools for multidata visualization and integrated interpretation *in* GSWA Record 2016/2

Holden et al., 2016, Human, machine and data: data analytics for mineral explorers *in* GSWA Record 2016/2

Structure and physical properties of Archean granulites and fault rocks

Project manager: Dr J Liu, School of Earth and Environment (UWA)

Partner researchers/institutions: Dr J Liu, Prof K Regenauer-Lieb (School of Earth and Environment, UWA)

GSWA contact: Dr K Gessner

Project duration: 2013–14

Project description

Understanding the microstructure and physical properties of Archean granulites and fault rocks will help to better understand recently acquired seismic reflection data in the northern Yilgarn craton and across the Youanmi Terrane – Eastern Goldfields Superterrane boundary. The proposed work includes processing of synchrotron radiation based X-ray micro-computed tomography to characterize a number of rock samples including rare occurrences of granulite facies metamorphic rocks and brittle fault rocks of Archean age that may represent the oldest known products of earthquakes on Earth

Outputs — planned or actual

Gessner K, Zibra I, Liu J, Paesold M, Toy V, Xiao X, Regenauer-Lieb K, Menegon L 2014, Using Synchrotron X-ray microtomography to image structure and porosity in sheared Neoarchean granite, Yilgarn Craton, Western Australia: Proceedings Australian Earth Science Convention, Newcastle, 2014, p.151–152.

National Virtual Core Library — Western Australian node

Project manager: Dr L Hancock, Manager, GSWA HyLogger Facility

Partner researchers/institutions: AuScope with NCRIS funding, CSIRO

GSWA Contact: Dr L Hancock

Project duration: ongoing

Project description

GSWA houses, manages and operates a HyLogger-II semi-automated core logging facility as part of the National Virtual Core Library (NVCL) project. GSWA owns the HyLogger, maintains it and provides operational staff as a co-investment in the project. Systematically captures hyperspectral data for all mineral and petroleum drillcore in its Perth and Kalgoorlie core libraries. Provides data and interpretations to the NVCL and other third parties

Outputs — planned or actual

Periodic geoscience publications utilizing HyLogger data

Procedural publications

www.dmp.wa.gov.au/Geological-Survey/HyLogger-spectral-scanner-1396.aspx

Current projects with Geoscience Australia: National Collaborative Framework (NCF) activities

Project manager: Dr R Rogerson

Partner researchers/institutions: Geoscience Australia

GSWA contact: Dr I Tyler, D Flint

Duration of project: ongoing

Australian National Virtual geophysical laboratory (CMCG4003A–001388)



Eucla–Gawler deep crustal seismic reflection, gravity and MT survey, processing and interpretation (G4003AP–A6)



Canning Basin CO₂ storage project (CMCG4003A–PA6)



NOPTA — Offshore Petroleum and Greenhouse Gas Data Management Project — National Offshore Petroleum Data and Core Repository (CMCG4030–P1)

Management of the National Offshore Petroleum and Greenhouse Gas Data Repository (CMCG4003A–P3)

WA regional 100 m magnetic and gamma-ray spectrometric surveys 2015–22 (WARMS100) (CMCG4003A–000782)



WA Reconnaissance Airborne EM Surveys 2013–20 (CMCG4003A–PA4)



WA Reconnaissance Gravity Surveys 2013–20 (WARGRAV2) (CMCG4003A PA5)



South West Hub 3D seismic survey project (CMCG4003A-PA2)

COMPLETED PROJECTS

COBRA project — Amadeus Basin: Central Oz Basins resource assessment

Project manager: Dr S Schmid (CSIRO)

Partner researchers/institutions: CSIRO

GSWA contact: Dr P Haines

Duration of project: 2014–15

Project description

Assess the mineral and unconventional hydrocarbon potential of Central Australian sedimentary basins by applying and bringing together new technology and systems thinking from hydrocarbon and minerals research

Outputs

Report 154 Amadeus Basin Project, gravity and magnetic study of the Western Amadeus Basin, Western Australia

Integrated spectral mapping of Au-hosted mineralization, Nanjilgardy Fault (CSIRO)

Project manager: Dr M Wells (CSIRO)

Partner researchers/institutions: Dr M Wells, Dr T Cudahy, Dr C Laukamp (CSIRO)

GSWA contact: Dr L Hancock

Duration of project: 2013–15

Project description

Process and cross-calibrate HyLogger and ASTER data to develop a 3D mineral map of the Mount Olympus area, Turee Creek/Ashburton Basin. Cross-section 3D model of the Nanjilgardy Fault corridor, combining spectral data with other geophysical datasets

Outputs

Report 156 Integrated spectral mapping of precious and base metal related mineral footprints, Nanjilgardy Fault, Western Australia

Determine the age of gold mineralization at the Paulsens mine, northern Capricorn Orogen, using monazite and xenotime geochronology

Project manager: Dr S Johnson

Partner researchers/institutions: P Tornatora (Northern Star Resources Ltd)

Professor B Rasmussen (Curtin University), Dr J Muhling (UWA)

GSWA contact: Dr S Johnson

Duration of project: 2014–15

Project description

The primary aim of this study is to determine the age of gold mineralization at the Paulsens Mine, using monazite and xenotime geochronology. However, a secondary aim is to provide further constraints on the age of stratigraphic units hosting the deposit as well as to determine the age of deformation and fabric formation throughout the region. These magmatic, depositional and structural events may be recorded by a variety of geochronometers including zircon, baddeleyite, monazite and xenotime

Outputs — planned or actual

GSWA co-branded Report, GSWA geochronology records

Joint inversion of gravity and magnetic data along three Youanmi seismic traverses, Western Australia

Project manager: Dr L Alonso Gallardo Delgado (CICESE, Mexico)

Partner researchers/institutions: Dr L Alonso Gallardo Delgado (CICESE, Mexico)

GSWA contact: Dr K Gessner

Duration of project: 2013–14

Project description

Joint inversion of the gravity and magnetic data existing along three seismic traverses (YU1, YU2 and YU3) that cross the northern part of the Yilgarn Craton, Western Australia to: i) produce fully collocated density and magnetization sections along the three existing seismic profiles of the Youanmi survey; ii) integrate the estimated distribution of density and magnetization contrasts into geospectral images of the subsurface; iii) provide a preliminary geophysical description of the integrative images and its possible correlation to major granite–greenstone boundaries and ultramafic igneous complexes of the crossed terranes

Outputs

Gessner, K, Jones, T, Goodwin, JA, Gallardo, LA, Milligan, PR, Brett, J, Murdie, R 2013, Interpretation of magnetic and gravity data across the Southern Carnarvon Basin, and the Narryer and Youanmi terranes in Western Australia: multiscale edge detection (worms), forward modelling, and cross-gradient joint inversion, *in* Youanmi and Southern Carnarvon Seismic and Magnetotelluric (MT) Workshop 2013: Extended Abstracts, compiled by S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 65–77.

ARC Linkage project LP110200747 — prospectivity of late Archean basaltic and gabbroic rocks associated with major gold and base-metal deposits

Project manager: Professor R Cas

Partner researchers/institutions: Monash University

GSWA contact: S Wyche

Duration of project: completed

Project description

To establish a new set of criteria for determining which Archean rock units are most likely to contain major gold and base-metal deposits. GSWA to provide in-kind support over the life of the three-year project

Outputs

PC Hayman, SE Hull, RAF Cas, E Summerhayes, Y Amelin, TJ Ivanic and D Price, 2015, A new period of volcanogenic massive sulfide formation in the Yilgarn: a volcanological study of the ca 2.76 Ga Hollandaire VMS deposit, Yilgarn Craton, Western Australia: Australian Journal of Earth Sciences, v. 62, p. 189–210.

Hayman, PC, Thébaud, N, Pawley, MJ, Barnes, SJ, Cas, RAF, Amelin, Y, Sapkota, J, Squire, RJ, Campbell, IH and Pegg, I 2015, Evolution of a ~2.7 Ga large igneous province: a volcanological, geochemical and geochronological study of the Agnew Greenstone Belt, and new regional correlations for the Kalgoorlie Terrane (Yilgarn Craton, Western Australia): Precambrian Research, v. 270, p. 334–368.

Albany–Fraser Orogen deep crustal seismic reflection and gravity survey

Project manager: Dr I Tyler

Partner researchers/institutions: Geoscience Australia; AngloGold Ashanti; Independence Group NL, National Research Facility for Earth Sounding (ANSIR)

GSWA contact: Dr C Spaggiari

Duration of project: 2011–15 (completed)

Project description

The Albany–Fraser deep crustal seismic reflection survey was conducted across the southeastern margin of the Yilgarn Craton and the adjacent Albany–Fraser Orogen through to the Madura Province during April to June 2012. The seismic lines provide images of the deep crustal structure through to the Moho across the entire orogen

Outputs

Record 2014/6 Albany–Fraser Orogen Seismic and Magnetotelluric (MT) Workshop 2014: Extended Abstracts

Plate 4 Geological interpretation of the Albany–Fraser Orogen and southeast Yilgarn Craton seismic lines 12GA–AF1, 12GA–AF2, 12GA–AF3, 12GA–T1

<http://dmpbookshop.eruditetechnologies.com.au/product/geological-interpretation-of-the-albanyfraser-orogen-and-southeast-yilgarn-craton-seismic-lines-12ga-af1-12ga-af2-12ga-af3-12ga-t1.do>

Albany–Fraser Orogen deep crustal seismic reflection survey

Geoscience Australia Deep Seismic Reflection Profiles: L201 Albany–Fraser Orogen

National Geochemical Survey of Australia

Project manager: Dr P Morris

Partner researchers/institutions: Geoscience Australia

GSAW contact: Dr P Morris

Duration of project: completed

Project description

GSAW to provide in-kind resources to conduct survey and to pay for geochemical analyses

Outputs

National Geochemical Survey of Australia project

Record 2013/4 The National Geochemical Survey of Australia — selected interpretations for Western Australian data

MERIWA project M414: improved hydrogeochemical exploration in the northwest Yilgarn — adding value to underexplored areas

Project manager: Dr D Gray

Partner researchers/institutions: CSIRO/MRIWA

GSAW contact: Dr P Morris

Duration of project: completed

Project description

Earlier work by the authors had developed hydrogeochemical indicators for lithology, hydrothermal alteration and prospectivity analysis for the northern Yilgarn Craton. These methods were applied in the northwest Yilgarn Craton to develop a provisional mineral prospectivity view of the area. This region has a much lower density of demonstrated mineral resources than the northeast Yilgarn Craton, although the geology is similar. Overall, results for this study support previous research demonstrating the value of groundwater chemistry for defining lithological changes, hydrothermal alteration and mineralization

Outputs

MRIWA Project M414: Gray, DJ, Reid, N and Noble, RRP, 2014, MRIWA Report 306: Improved Hydrogeochemical Exploration in the Northwest Yilgarn Craton: Adding Value to Underexplored Areas

Western Australia ASTER geoscience map

Project manager: Dr T Cudahy

Partner researchers/institutions: CSIRO (Centre for 3D Mineral Mapping)

GSAW contact: Dr I Tyler

Duration of project: completed

Project description

CSIRO will use image processing and in-house software to process 1000 ASTER Level 1B scenes of Western Australia sourced initially from Geoscience Australia

Outputs

http://c3dmm.csiro.au/WA_ASTER/

www.dmp.wa.gov.au/16942.aspx#21007

AuScope: <http://portal.auscope.org/portal/gmap.html>

Integration of physical process evidence into coastal adaption and planning

Project manager: RG Gozzard

Partner researchers/institutions: Department of Planning, Department of Transport, Damara P/L

GSWA contact: RG Gozzard

Duration of project: completed

Project description

Application and refinement of a multiscaled and multidisciplinary approach to coastal hazard and coastal landform stability assessment by identifying and quantifying changes to coastal landforms within a hierarchy of compartments defined by geological and geomorphological criteria at different scales

Outputs

Sea to Scarp: Applied geology for land-use planning in the southern Swan Coastal Plain

WA Coast: Gascoyne

WA Coast: Pilbara

WA Coast: Cape Naturaliste to Lancelin

WA Coast: Rottnest Island

WA Coast: Lancelin to Kalbarri

Earaheedy Basin — environmental evolution of the Tooloo Subgroup

Project manager: Dr P Pufahl

Partner researchers/institutions: Dr P Pufahl, Dr E Hiatt (Acadia University)

GSWA contact: Dr F Pirajno

Duration of project: completed

Outputs

Report 130 Sedimentology and stratigraphy of the Paleoproterozoic Frere Formation, Western Australia: implications for the evolution of the Precambrian ocean

External papers

Agouron Institute Pilbara drilling project

Project manager: R Buick, Earth and Space Sciences and Astrobiology Program (University of Washington)

Partner researchers/institutions: A Anbar (Arizona State University), D Johnston (Harvard), J Kaufman (University of Maryland), A Knoll (Harvard), T Lyons (University of California, Riverside), R Summons (MIT), D Sumner (University of California, Davis), G Love (University of California, Riverside), A Dutkiewicz (Sydney University), S George (Macquarie University), G Webb (Queensland University of Technology), and S Wyche and K Ridge (GSWA). The project is funded by the Agouron Institute

GSWA contact: Dr A Hickman

Duration of project: 2010–18 (drilling of the first three holes was completed in September 2012)

Project description

The project drilled short diamond drillholes (<450 m) into three Archean and Paleoproterozoic formations in the Pilbara region of Western Australia: i) c. 3.15 Ga Coucal Formation (Coonterunah Subgroup of Warrawoona Group); ii) <2.63 Ga Carawine Dolomite (Hamersley Group) and >2.63 Ga Jeerinah Formation (Fortescue Group); c. 2.59 Ga Marra Mamba Iron Formation (Hamersley Group) and >2.63 Ga Jeerinah Formation. The main purpose was to seek and investigate evidence of early life and environments, particularly associated with changing oxygen levels. A second purpose was to resolve the controversy about the age and origin of early Precambrian hydrocarbon biomarkers

Outputs

Drillcores for scientific study, periodic reports to participating institutions, and publication of research results

Summary of previous Pilbara geoscientific drilling projects (to 2009) by Roger Buick

Summary of Agouron project (2012)

ARC Linkage project LP0883970: prospectivity of the Windimurra–Narndee Layered Complexes, Western Australia (ANU)

Project manager: Professor R Arculus (ANU)

Partner researchers/institutions: J Mavrogenes, O Nebel (ANU), GKennedy, R Langford (Maximus Resources, 2009/Flinders Mines, 2010–12)

GSAW contact: Dr T Ivanic

Duration of project: 2009–12

Project description

The Late Archean (~2.8 Ga) Windimurra–Narndee Layered Igneous Complexes (WNLC) of the Yilgarn Craton of Western Australia collectively form the largest Archean ultramafic–mafic igneous intrusion in Australia. The petrology of the rock types is known in the very broadest outline, and a significant amount of exploration has taken place for gold, platinum group elements (PGE), uranium, vanadium, and a variety of base metals. But overall we lack detailed knowledge of the igneous stratigraphy, character and number of magmatic components, relationships of the Windimurra and Narndee Complexes, and their structural evolution. All of these are fundamental in terms of identification of probable zones of precious and base metal mineralization. The aims of this project are building on previous studies to obtain these data, and construct a model for the origins, evolution, and mineral prospectivity of the complexes

Outputs

Record 2010/19: A time transect through the Hadean to Neoproterozoic geology of the western Yilgarn Craton — a field guide

Journal article on the age of Narndee Igneous Complex

Journal article on Lu–Hf isotopic systematics of Windimurra Igneous Complex

Journal article on the magma chamber processes of the upper zone of the Windimurra Igneous Complex

Exploration targeting products

Project manager: Professor M Dentith (CET, UWA)

Partner researchers/institutions: Professor TC McCuaig, Professor M Dentith (CET, UWA)

GSAW contact: Dr I Tyler

Duration of project: completed

Project description

Targeting products to help junior and mid-sized explorers translate GSAW datasets into ground acquisition and drill targets

Outputs

Lindsay, M, Aitken, A, Ford, A, Dentith, M, Hollis, J and Tyler, I 2016, Reducing subjectivity in multi-commodity mineral prospectivity analyses: Modelling the west Kimberley: Australia, Ore Geology Reviews, v. 76, p. 395–413.

Report 142 Mineral prospectivity of the King Leopold Orogen and Lennard Shelf: analysis of potential field data in the west Kimberley region

Report 123 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province

Zipped data files: 3D architecture, structural evolution, and mineral prospectivity of the Gascoyne Province

Report 117 Mineral systems analysis of the west Musgrave Province: regional structure and prospectivity modelling

Zipped data files: Mineral systems analysis of the west Musgrave Province: regional structure and prospectivity modelling

Report 113 An integrated geological and geophysical study of the west Arunta Orogen and its mineral prospectivity

Tectonic evolution and lode gold mineralization in the Southern Cross district, Yilgarn Craton: a study of the Meso to Neoproterozoic missing link

Project manager: Assistant Professor N Thebaud

Partner researchers/institutions: Assistant Professor N Thebaud, Professor M Barley (CET, UWA)

GSAW contact: S Wyche

Duration of project: completed

Project description

ARC Linkage grant; develop a superior tectono-metamorphic model of the gold-endowed Youanmi Terrane in the Yilgarn Craton

Outputs

Record 2013/11 Geological setting of mineral deposits in the Southern Cross district — a field guide

West Kimberley MT survey

Project manager: Professor M Dentith (CET, UWA)

Partner researchers/institutions: CET, UWA

GSWA contact: Dr D Maidment, Dr J Hollis

Duration of project: completed

Project description

Acquire MT across Kimberley as part of the Kimberley Science and Conservation Strategy

Outputs

Report 136 A magnetotelluric survey across the Kimberley Craton, northern Western Australia

ARC Linkage project LPO883661: understanding the stratigraphic and structural architecture of late Archean basins and the context of their gold deposits

Project manager: Professor R Cas

Partner researchers/institutions: Monash University

GSWA contact: S Wyche

Duration of project: completed

Project description

Understanding the stratigraphic and structural architecture of late Archean basins and the context of their gold deposits

Outputs — planned or actual

Squire, RJ, Allen, CM, Cas, RAF, Campbell, IH, Blewett, RS and Nemchin, AA 2010, Two cycles of voluminous pyroclastic volcanism and sedimentation related to episodic granite emplacement during the late Archean: Eastern Yilgarn Craton, Western Australia: *Precambrian Research*, v. 183, no. 2, p. 251–274.

Bentley Supergroup Volcanics

Project manager: Professor R Cas (Monash University)

Partner researchers/institutions: Monash University

GSWA contact: Dr RH Smithies

Duration of project: completed

Project description

PhD study

Outputs

Report 118 Geochemical evolution of rhyolites of the Talbot Sub-basin and associated felsic units of the Warakurna Supersuite

ARC Linkage project LP0883812: magnetostratigraphic and isotopic dating of Devonian Reef Complexes**Project manager:** Professor P Cawood**Partner researchers/institutions:** Tectonics Special Research Centre, UWA**GSWA contact:** R Hocking**Duration of project:** completed**Project description**

Magnetostratigraphic and isotopic dating and correlation of Devonian Reef Complexes (two years); GSWA to provide in-kind support

ARC Linkage project LP100200127: constraining conditions and timing of orogeny and reworking in the west Musgrave Province**Project manager:** Dr RH Smithies**Partner researchers/institutions:** Dr D Kelsey, Professor M Hand, Professor A Collins (University of Adelaide)**GSWA contact:** Dr RH Smithies**Project description**

Application of advanced geochronological and microstructural techniques to address significant uncertainties in the thermo-tectonic evolution of the west Musgrave Province

Outputs

Walsh, Kelsey, Kirkland, Hand, Smithies, Clark, and Howard (in press) P–T–t evolution of a large, long-lived, ultrahigh-temperature Grenvillian belt in central Australia: Gondwana Research, doi:10.1016/j.gr.2014.05.012

Walsh, Raimondo, Kelsey, Hand, Pfitzner and Clark 2013, Duration of high-pressure metamorphism and cooling during the intraplate Petermann Orogeny: Gondwana Research, 24, p. 969–983.

Howard, Smithies, Kirkland, Kelsey, Aitken, Wingate, Quentin de Gromard, Spaggiari, Maier 2015, The burning heart — The Proterozoic geology and geological evolution of the west Musgrave Region, central Australia: Gondwana Research 27, p. 1419–1429.

Musgrave Province: Honours student mapping**Project manager:** Dr RH Smithies**Partner researchers/institutions:** Dr D Kelsey, Professor M Hand, Professor A Collins (University of Adelaide)**GSWA contact:** Dr RH Smithies**Duration of project:** completed**Project description**

Honours projects as required

Outputs

Record 2009/14 Complex strain in mylonites from the western Musgraves, North of the Mann Fault, Western Australia

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

Record 2009/1 Age constraints and deformation history of the Shag Hill mylonites, western Musgraves

Record 2009/15 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 2009/12 A kinematic, metamorphic, geochemical and geochronological framework for intracratonic reworking in the western Musgrave Block, central Australia

Seismic framework of the northwestern part of the Canning Basin

Project manager: J Haworth

Partner researchers/institutions: Professor M Dentith, Professor A George (UWA)

Duration of project: completed

Project description

Collaborative research involving a PhD student to research the seismic framework of the northwestern part of the Canning Basin

Outputs

Report 140 Regional structural and stratigraphic study of the Canning Basin, Western Australia

Report data package: Regional structural and stratigraphic study of the Canning Basin, Western Australia

West Musgrave MT survey

Project manager: Professor M Dentith

Partner researchers/institutions: Professor M Dentith, Dr A Aitken (CET, UWA)

GSWA contact: Dr RH Smithies

Duration of project: completed

Project description

Map deep crustal and upper mantle structures across the west Musgrave Province

Outputs

Report 114 Imaging crustal structure in the west Musgrave Province from magnetotelluric and potential field data

Zipped data files: Imaging crustal structure in the west Musgrave Province from magnetotelluric and potential field data

ARC Linkage project LP0990455: developing a new tectonothermal and mineralization history for the Capricorn Orogen, Western Australia: assisting mineralization in greenfield terrains

Project manager: Professor B Rasmussen

Partner researchers/institutions: B Rasmussen, I Fletcher, J Muhling, S Sheppard (UWA and Curtin University)

GSWA contact: Dr S Johnson

Duration of project: three years (2009–12)

Project description

Dating low temperature phosphate minerals; timing of deposition, deformation, low- to medium-grade metamorphism and hydrothermal mineralization

Outputs

Zi, J, Rasmussen, B, Muhling, J, Johnson, SP, Thorne, AM, Korhonen, FJ and Cutten, HN 2015, In situ U–Pb geochronology of xenotime and monazite from the Abra deposit in the Capricorn Orogen, Australia: dating hydrothermal mineralization and fluid flow in a long-lived crustal structure: *Precambrian Research* 260, p. 91–112.

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, EA 2011, Two collisions, two sutures: Punctuated pre-1950 Ma assembly of the West Australian Craton during the Ophthalmian and Glenburgh Orogenies: *Precambrian Research* 189, p. 239–262.

Record 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

Report 146 Korhonen, FJ, Johnson, SP, Fletcher IR, Rasmussen, B, Sheppard, S, Muhling, JR, Dunkley, DJ, Wingate, MTD, Roberts, MP, Kirkland, CL 2015, Pressure–temperature–time evolution of the Mutherbukin Tectonic Event: a model for Mesoproterozoic intraplate reworking of the Capricorn Orogen: Geological Survey of Western Australia.

Record 2010/5 The Glenburgh Orogeny as a record of Paleoproterozoic continent–continent collision

Nullarbor Limestone project

Project manager: Professor N James, Department of Geological Sciences, (Queen's University) Kingston, Ontario

GSA contact: R Hocking

Duration of project: completed

Project description

Cenozoic evolution of the Nullarbor Plain

Outputs

Report 119 Cenozoic evolution of the Nullarbor Plain paleokarst, southern Australia

Report 111 Sedimentology of the Miocene Nullarbor Limestone; southern Australia

4D interpretation of the Proterozoic West Tanami and its minerals systems (MERIWA project M389)

GSA contact: Dr I Tyler

Duration of project: completed

Project description

Sponsorship of project M389: west Tanami, 4D interpretation of the Proterozoic West Tanami and its minerals systems

Application of zircon double-dating to diamond exploration

Project manager: Professor B McInnes (CSIRO, John de Laeter Centre of Isotope Research)

Partner researchers/institutions: CSIRO, John de Laeter Centre of Isotope Research

GSA contact: Dr I Tyler

Duration of project: completed

Project description

Proposal to conduct field trials in the Kimberley for the application of zircon double-dating to diamond exploration — GSWA commitment to purchase extra days of SHRIMP, MERIWA Project M405

Outputs

MERIWA Project M405

MERIWA Report 292: Application of U–Th–Pb–He double dating techniques to diamond exploration

In-place leaching of oxidized gold ores (MERIWA project M409)

Project manager: Dr I Roberts

Partner researchers/institutions: CSIRO

GSA contact: Dr L Hassan

Duration of project: completed

Project description

This study developed novel systems for recovering gold from currently uneconomic oxide gold resources in Australia by using a modified in situ leaching method. Three lixiviant systems were studied, and gold was recovered using an ion exchange resin. A literature review identified microbial processes which may hold potential for leaching of oxide gold ores. Sponsorship of project M409

Outputs

MERIWA REPORT 291: In-place leaching of oxidised gold ores

Greenfields geochemical exploration in a regolith-dominated terrain: the Albany–Fraser Orogen/ Yilgarn Craton margin (MERIWA project M411)

Project manager: Dr C Spaggiari

Partner researchers/institutions: CSIRO minerals Downunder Flagship — I González-Álvarez, RR Anand, R Hough, W Salama, C Laukamp, MT Sweetapple, Y Ley-Cooper, I Sonntag, M Lintern, T Abdat, M leGras, J Walshe

GSWA contact: Dr C Spaggiari

Duration of project: completed

Project description

This project examined techniques to aid greenfields geochemical exploration in a regolith-dominated terrain. Research included regolith and whole-rock geochemistry and trace element mobility, regolith stratigraphy, petrography, remote sensing data analysis, and EM data interpretation

Outputs

MRIWA Report 305

Report 144 Greenfields geochemical exploration in a regolith-dominated terrain: the Albany–Fraser Orogeny/Yilgarn Craton margin

Completed projects with Geoscience Australia: National Collaborative Framework (NCF) activities

Project manager: Dr R Rogerson

Partner researchers/institutions: Geoscience Australia

GSWA contact: Dr I Tyler, D Flint

Duration of project: ongoing

Canning Coastal deep crustal seismic reflection and gravity survey, processing and interpretation (G4003APA7)

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