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Department of **Mines and Petroleum**

RECORD 2017/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2017–18 AND BEYOND

PERTH 2017



Geological Survey of Western Australia



Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

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**Geological Survey of
Western Australia**

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Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownamina Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph by I Zibra, DMIRS

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Geological Survey work program for 2017–18 and beyond

Executive summary

Last year (2016–17) was again a very successful year for the Geological Survey of Western Australia (GSWA) and the Department of Mines and Petroleum (DMP). In 2016, the Fraser Institute's Annual Survey of Mining Companies (Fraser Institute, 2017) ranked Western Australia as the third most attractive mining investment destination worldwide and the most prospective for mineral exploration. Very pleasing was our continued improvement in perceptions of our online geoscience databases (includes online tenement and other specialist information systems) to be ranked the best in 2016. Perceptions of our mineral policy environment remained in the top 10 worldwide. This is an absolutely outstanding achievement, and an acknowledgement of the vision of those who implemented EIS and of those who have supported it since.

However, GSWA's activities planned for 2017–18 are (as was the case in the previous two years) in a macro environment characterized by slow growth in China and with low commodity prices generally. Petroleum exploration (onshore and offshore) in Western Australia remains in its serious four-year decline since 2012–13 — a decline of 80% and is now at levels last experienced in about 2005; and with no signs of any improvement soon in 2017–18. However, the four-year downward trend in mineral exploration expenditure (2011–12 to 2015–16) has now switched to rising mineral exploration activity. Other positive signs are emerging — particularly with a new focus on lithium and other battery metals, renewed interest in Western Australia's gold endowment and opportunities, and with these leading to an increase in Initial Purchase Offerings (IPO) on the ASX. Western Australia's spodumene production doubled during 2016–17, and Western Australia's iron ore exports increased yet again in 2016–17 to a fresh record of 793 million tonnes.

However, the biggest challenge for GSWA during 2017–18 remains unchanged from last year, that is, to secure long-term funding for the EIS beyond 30 June 2019 — the current limit of EIS in the budget forward estimates. EIS is currently funded from Royalties for Regions (RfR). At the March 2017 State election, a Labor government was elected, so 2017–18 will also be a time of change as policies and priorities of the new government are implemented. One of the new initiatives has resulted in the old Department of Mines and Petroleum (DMP) merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety (DMIRS), with effect from 1 July 2017. Many more changes within the public service, DMIRS and the Geological Survey are expected over the next year. The new government has also introduced a permanent ban on fracking in the South West, initiated a moratorium on fracking in the State while an Inquiry is held into the scientific aspects of fracking, and is philosophically opposed to the mining of uranium and thorium.

Last year (2016–17) was again a very busy and productive year for GSWA. For 2017–18 and using its recurrent and EIS budget totalling \$28.6 million, ~120 planned full-time equivalent (FTE) staff in 2017–18,

eight FTE contract staff funded from EIS, about 65 short-term fee-for-service contractors, and ~40 collaborative research projects partly funded by GSWA, GSWA plans to publish the following flagship products:

• Reports, Records, Bulletins & non-series books	40
• Series maps (1:100 000, 1:250 000)	4
• Other maps (including State maps & Plates)	18
• Digital information packages	15

Other headline deliverables for 2017–18 are to:

- obtaining government approval for the continuation of EIS (EIS 4)
- obtaining government funding for expansion of the Joe Lord Core Library at Kalgoorlie
- release in full GSWA's digital 1:100 000 IBG for areas covered by Geological Information Series products via GeoVIEW.WA
- release GSWA's next suite of Geophysical Modelling Products
- Release of the Ngurrupa lands soil geochemistry Record and interpreted regolith-landform map
- Release of a Record and data USB on the geochemistry of Archean granitic rocks in the South West Terrane of the Yilgarn Craton
- Release of Explanatory Notes System - Eastern Lamboo Province, Halls Creek Orogen, Murchison Domain, and Hamersley Group
- release of the interpretative report and extensive database of diamond and diamond indicator mineral occurrences, geochemistry and prospectivity for Western Australia
- release of GSWA's concept and demo of the prototype of the Mineral Systems Atlas for komatiite-hosted nickel, orogenic gold, and iron in the Yilgarn Craton
- release of a seismic interpretation of the southwestern Canning Basin
- release of the updated SEEBASE model for the entire Canning Basin (by Frogtech Geoscience)
- release of the second of the innovative product in the series Digital Core Atlas — Theia 1, Canning Basin
- moving on to better IT systems for handling the core library assets, improved lodgement of mineral production data (lodged through the online royalties system but flowing through to MINEDEX), enhancing the WAMEX online report-writing system, and assisting Geoscience Australia with its NOPIMS 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.

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

Northern Australia (which finishes in June 2020), and the MinEx CRC project. GSWA is a sponsor of the MinEx CRC and a decision on its bid for Commonwealth funding will be known during 2017–18.

Note: all currencies are Australian dollars unless otherwise indicated.

Part 1

Strategic overview

International events

Economic growth picks up

The IMF and World Bank estimate that global growth in 2016 is around 3.2% and expect global growth to be 3.5% in 2017. It was clear in mid-2017 that the economic volatility that marked the last four years had declined significantly and growth had returned to Western Europe, the US and Canada, while continued high levels of growth continued in India and China. However it must be said that China's growth has declined from the over 10% it was prior to 2013 but seems to have settled in the 6.5 – 7% range.

In April 2017 in response to Europe's improving economic situation, the European Central Bank began reducing the level of quantitative easing used to stimulate the European economy. Figure 1 shows the critical statistics underlying these growth estimates.

Sustained but not spectacular growth in the US economy during the 2016–17 financial year is a prominent feature of Figure 1a, as well as the continued growth in India's economy and a marked upturn in Japan's growth rate that arresting a marked decline in growth in US dollar terms since 2012.

The impact of slides in currencies against the US dollar is evident the US dollar denoted GDP statistics in Figure 1 where the currencies of Australia, South Korea and importantly the UK have seen depreciations against the US dollar. With the UK beginning formal BREXIT discussions with the European Union in early 2017, there is concern over the UK's depreciated pound sterling post BREXIT encouraging a flood of cheap imports into continental Europe and undercutting Euro prices.

Table 1 demonstrates economic growth rates of the same countries as shown in Figure 1 expressed in local currencies. India again is a standout, followed closely by China. Relatively strong German and UK growth bodes well for higher demand for resources coming from Europe and more demand should be driven by the economic expansions underway in Japan and South Korea.

Importantly, the risk of imminent financial collapse of Greece and potentially several larger European economies has almost totally disappeared, which has contributed to the more positive outlook of most central bankers around the world.

Figure 1b shows that the 2016 economic recovery is, at this early stage in the cycle, associated with benign inflation levels (0 to 2%) in major economies, and India at 4.9% inflation is rapidly reducing its inflation levels from the around 10% level in 2013.

Commodity prices show early signs of recovery

During 2016/17, the “battery metals” boom continued in lithium, cobalt, graphite, and vanadium but except for the last few months of 2016–17, there also appeared to be sustained price rises in thermal coal, base metals, gold, aluminium, and Tapis crude (Figure 2).

During most of 2016–17, the Australian dollar hovered around \$US0.75 (Figure 2a) providing some stability for exporters and importers but probably a little higher than the Reserve Bank’s preferred range of less than \$US0.70. Similarly, the Australian dollar purchased around Euro 0.7 for most of the year, but against the Japanese Yen and China RMB, appreciated slightly, probably because the latter is now effectively pegged to the US dollar. The US dollar gold price declined by \$US200 from its high of \$US1341 in August 2016 to \$US1141 in December 2016 in response to speculation and then the reality of US interest rates being increased after a long period of very low rates. However, the gold price increased by June 2017 to an average of \$US1260 with some speculation that it could go higher. In Australian dollar terms, the gold price was above \$AUD1600 for most of the year providing an important stimulus to WA’s gold exploration and mining industry.

Until February 2017, base metals (Cu, Pb, Zn, Ni) all show a rising trend (Figure 2c) but all declined around \$US200 per tonne in the last few months of the financial year. However, zinc maintains the around \$US 2500 per tonne price it has achieved over the last two years in response to supply concerns and the copper price has shown a marked improvement to \$US5700 per tonne average in June 2017 from its low point of \$US4707 per tonne average in September 2016. Overall, these are positive price trends that began in early 2016 and should continue as the World’s economy improves and demand from China picks up. How the diversion of more existing nickel production to lithium battery manufacture might impact the nickel price is unknown at this stage, with some commentators suggesting that there will be a two tier nickel pricing regime established with higher prices for battery grade nickel sulphate. It is within this context that BHP

announced in August 2017 that it would build a 100,000 tonne battery-grade nickel sulphate plant in Kwinana and divert its WA production to this end-use.

Iron ore and aluminium prices (Figure 1d) continued to improve during 2016–17, despite their slight drop late in the financial year. Aluminium in particular has seen a slow price rise since early 2016 to an average of \$US1887 per tonne in June 2017 and iron ore has improved to around \$US60 per tonne average in May and June 2017 from its price trough around an average \$US40 per tonne in December 2015 and January 2016.

The price of rock phosphate continues to be soft at around \$US93 per tonne average in the latter part of the 2016–17 financial year (Figure 2d).

Hydrocarbon-based energy prices (Figure 2e) have been on an upward trend since January 2016. Metallurgical coal (not produced by WA) has increased markedly in the last year to over \$US200 per tonne driven by short term supply disruptions such as Cyclone Debbie in Queensland and the impact of Chinese Government policies favouring higher grade iron ore and coking coal to minimise CO₂ emissions during iron and steel making.

From its low price point of \$US53 per tonne average in January 2016, thermal coal was an average of \$US86 per tonne in June 2017 after reaching \$US111 per tonne in November 2016.

Tapis crude prices have also risen markedly since January 2016 when one stock barrel was priced at an average \$US32.30. The June 2017 average price was \$US48 per barrel after being at the mid \$US50s most of the 2016–17 financial year.

The optimism over hydrocarbon prices does not extend to uranium which continued its dismal price run to settle at an average price of \$US20.10 per pound in June 2017. The much heralded increase in demand from the about 50 new reactors under construction around the world and dwindling supplies from reprocessing material from decommissioned former Soviet bloc sources has not eventuated, with some analysts suggesting it will be 2020 at least before prices reach \$US50 per pound.

More investment still drives the battery bubble two years after it began. At the end of June 2017, Western Australia has four operating spodumene mines (Greenbushes, Mt Cattlin, Wodgina and Mt Marion), three more at an advanced stage of permitting or under construction (Bald Hill, Pilgangoora – Pilbara Minerals, Pilgangoora – Altura) and another major discovery — Mt Holland, had been made. In 2016, Western Australia

produced approximately 41% of the World's lithium production and Greenbushes was the World's largest lithium mine.

Downstream processing of minerals is unusual in Western Australia. However, Tianqi (51% owner of Greenbushes lithium) began construction of a plant at Kwinana to downstream process spodumene concentrates to lithium hydroxide and Albermarle (40% equity in Greenbushes lithium) was widely rumoured to be considering construction of a lithium carbonate plant in the south of the state.

ASX announcements by companies suggest that if demand for lithium continues at current levels, WA's lithium production could reach 5 million tonnes of 6% lithium concentrate by the early twenty twenties.

The global average price of lithium carbonate increased 138% from US\$5,731 per tonne in June 2015 to US\$13,625 per tonne in June 2017. How much longer this very high price will be maintained before rapidly rising supply begins to influence the market is a subject of some debate.

Similar price rises in other battery metals were noted, including cobalt trading at \$US60,000 per tonne in mid-2017 and there has been a notable increase in exploration activity associated with cobalt, graphite and vanadium in the State, all driven by demand for battery metals.

2016 mineral exploration budget continues to decrease

SNL (2016) reports that World exploration budgets for greenfields, late stage and mine stage exploration all decreased in 2016. The total budget for mineral exploration, excluding for iron ore, coal, aluminium and some industrial minerals, was only \$US6.886 billion (Figure 3) with Australia recording \$US897.4 million (13% of World —Figure 4), with \$US288.8 million (or 32.2%) of the Australian total in the greenfields category.

In 2016, the global grassroots budget was \$US1.92 billion, the lowest allocation since 2004. SNL points out that this represents a year-on-year decline of 25% — more than the 21% decline in the global budget for all stages.

Although exploration budgets for all three stages of project development continued to decline in 2016, late-stage exploration continued to command the largest share of global

exploration spending, except in Australia where grassroots was marginally higher than late stage expenditure

National trends

National economy slowly recovers

The Australian government budget for 2017–18 (Commonwealth of Australia, 2017) delivered in May 2017 revealed an economy beginning to accelerate after the post resource boom slow-down in the period 2013 to 2016, during which the rapid decline in resource capital investment detracted over 1.5% annually from Australia’s GDP growth. The economy and jobs growth is improving because of business investment in mainly Sydney and Melbourne and a slight improvement in household consumption.

A “return to fiscal surplus” in 2020–21, albeit small, was predicted in the 2017–18 budget

Predicted indicators for 2017–18 included the following:

Nominal GDP	4.0	Real GDP	2.75%
Inflation	2.0	Unemployment	5.75%

The Commonwealth Government budget was predicated on improving World economic growth and resulting growth in trade, including resources.

EDI scrapped then resurrected

Although the Commonwealth Government did not extend the Exploration Development Initiative (EDI) in the May 2017 budget, on 2 September 2017 it announced a replacement scheme called the Junior Mineral Exploration Tax Credit (JMETC) scheme. This allows a portion of tax losses in a year to be passed on, via a share issue in that year, to Australian resident shareholders who will then be issued with a refundable tax offset or addition franking credits.

The scheme will be limited to \$100 million and run from 1 July 2017 to 30 June 2021 and hopefully, during an upturn in the exploration investment cycle, will be more effective than the EDI that was introduced in 2014 during a massive downturn in exploration investment. Operational details of the scheme were not available when this plan was compiled.

Foreign investment growth insipid

Foreign investment into Australia's resources sector during 2015–16 was \$AUD 27.6 billion (Figure 5a), one billion more than in 2014–15 (Foreign Investment Review Board, 2017) and just 11.1% of the FIRB-approved \$AUD 247.9 billion of foreign investment in 2015–16.

Royal Dutch Shell's takeover of east coast Australia LNG producer BG Group was responsible for the Netherlands dominating resources-related foreign investment in 2015–16. Japan and the UAE were the next largest investors with China slipping to fourth largest investor with only \$US1.74 billion.

Figure 5b shows that most of the foreign investment activity in 2014 to 2016 was in oil and gas.

Equity flows for mineral exploration

The S&P/ASX 300 Energy and Metals and Mining indices continued their general positive trends apart from the last few months of the 2016 financial year (Figure 6). More equity flowed to metals and mining compared to energy (mainly petroleum and coal) on the Australian Securities Exchange (ASX) and this is reflected in initial public offerings (IPOs) by mineral exploration companies on the ASX.

There were no energy exploration or production IPOs on the ASX during the first half of the year and the number of listed ASX energy companies dropped from 233 at the end of June 2016 to 209 at the end of June 2017, a decline of 10.3%.

In contrast, there were 15 mineral exploration IPOs between January and June 2017 and IPO numbers for the 2017 calendar year are on target to be the best result since 2011 when there were 59 (Figure 7). However, there were still casualties among listed mineral companies due to backdoor listings by IT, pharmaceutical and tech companies, mergers and takeovers, and becoming unloved by shareholders. As a sign of the times, one previously listed pharmaceutical/biotech company relisted and morphed into a gold exploration company with projects in WA. Overall listing numbers for mineral companies dropped from 689 at the end of June 2016 to a low of 665 in October 2016 before rising to 674 at the end of June 2017 — a 2.2% decline compared to June 2016.

In the “Geological Survey Work Program for 2016–17 and beyond” (GSWA, 2016), it was suggested that gold and lithium investment reflected 7:30 to 8 o’clock on the Widdup investment cycle, with other commodities probably a little behind at 6 o’clock, but rising rapidly. Figure 8 shows that we have revised our estimate of the investment climate distinguishing again between the feverous activity in battery metals and gold in WA and the growing exploration interest in other commodities.

State trends

Western Australian economy still struggling

Figure 9 shows that Western Australia’s Gross State Product (GSP), fell by 2.7% in 2016-17, in real chain volume terms, with the State’s economy valued at \$233.15 billion (Government of Western Australia, 2017). The major driver of the fall in GSP was business investment, which fell by 28.6% in 2016-17, although partly offset by an increase in exports of resources, which grew by 7.3%. State final demand, the demand created by State-based business and private activity, dropped 7.2% and unemployment rose to an average of 6.2% for the financial year.

In its 2017–18 budget, the State Government predicted the State economy would grow by 3%, 20,000 new jobs would be created after unemployment peaked in 2016–17, and State Final Demand would grow for the first time in six years. A small budget surplus was budgeted in 2020–21.

New Government brings resources policy changes

The WA Labor Government elected in a landslide in March 2018 has begun implementing two resources policies included in its platform. These are a ban on new uranium mines not already approved by the previous government, and the combination of a ban on hydraulic fracture stimulation (fracking) of gas wells in the Perth metropolitan, Peel and South West regions of the State and a moratorium on fracking in the remainder of the State pending the outcome of a scientific inquiry into the technology.

In early September 2017, the Government announced that the scientific inquiry would be conducted using a panel established by the Minister for Environment under section 25 of

the *Environmental Protection Act 1986* and was expected to release its final report in August 2018.

As part of its first State budget, the Government announced an increase in the gold royalty rate from 2.5% to 3.75%, applying when the Australian dollar gold price exceeded \$1200. The measure, expected to raise \$392 million over the four year forward estimates, was a recommendation of the previous government's 2015 Royalty Rate Review (Government of Western Australia, 2015). At the time of going to press, the measure had not been voted on in parliament.

Soon after gaining office, the Government announced an amalgamation of the Department of Mines and Petroleum and the Department of Commerce, thereby creating a new entity named the Department of Mines, Industry Regulation and Safety which began operating on 1 July 2018. The new Department will regulate all non-primary industry in Western Australia, including industrial relations.

Value of WA's resource production increases

Figure 10, which graphs the three resource cycles until the end of the 2016 calendar year, shows the value of Western Australia's resource production (\$AUD93.4 billion) beginning to increase — the first year since 2013. However, total mineral and petroleum exploration expenditure and capital investment into production and export facilities were still in free-fall after the completion of major construction of gas production facilities, LNG plants and iron ore processing facilities.

For 2016–17, the total value of mineral and petroleum production rose to \$AUD105 billion, which is an impressive 19% increase from the value of \$AUD88 billion in 2015–16 (Table 2). Most of the production value increase can be attributed to the increase in iron ore production volume which was 793 billion tonnes worth \$AUD63.87 billion in 2016–17, or 2.17 million tonnes per day, or around 1 million tonnes per tide.

For the financial year ending June 2017, the only other production value increases were for cobalt, PGEs (palladium and platinum), LNG, LPG, silica sand – silicon, gold and lithium (as spodumene direct shipping ore and spodumene concentrate), with the latter rising in value from \$AUD269 million in 2015–16 to \$AUD605 million in 2016–17, and doubling in production quantity (Table 2).

While 2016–17 production value shows a welcome increase, production trends for most commodities have been disappointing (Figure 11). LNG and iron ore show strong increases in production, while diamond, zircon, nickel and crude oil show moderate longer term declines. Production of other commodities (copper, gold, alumina and coal) remains relatively flat.

Western Australia mineral sector again near top in Fraser Institute survey

Western Australia continued its leadership in significant elements of the annual Fraser Institute survey of perceptions of jurisdictional risks associated with mineral investment. In the 2016 survey (Fraser Institute 2017), our State was ranked the third most attractive mining investment destination worldwide and the most prospective for mineral exploration. Very pleasing was our continued improvement in perceptions of our online geoscience databases (includes online tenement and other specialist information systems) to be ranked the best in 2016. Perceptions of our mineral policy environment remained in the top 10 worldwide (Figure 12).

More detail on Western Australia’s rankings are provided in Table 3, and particularly on our improvement relative to other Australian jurisdictions. For the first time, WA was the leader of all jurisdictions in all categories on Table 3.

Disappointingly, trends in perceptions of some components (Figure 13) of Western Australia’s petroleum policy and regulatory environment (Fraser Institute 2016) were not as positive as those for minerals. The petroleum survey calculates a multifactor Policy Perception Index (PPI) for each jurisdiction 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.

In 2016, Western Australia’s PPI again showed a slight 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 35th for PPI (37th and 47th in previous two years) out of the 96 jurisdictions surveyed in 2016 and ranked 2nd in Australia after the Commonwealth offshore jurisdiction. Another piece of good news was the improvement in the “Regulatory duplication and uncertainty” category.

Despite launching a new online petroleum geoscience information platform widely hailed as a vast improvement on the previous system, WA lost ground in industry perceptions in the “Geological data” category.

Mineral exploration expenditure increases

During 2016–17, increasing levels of mineral exploration expenditure occurred in WA with the clear delineation of 2015 being the low point in the exploration cycle (Figure 14). Throughout 2016–17, WA has accounted for over 60% of Australia’s mineral exploration expenditure. WA has increased its share of exploration expenditure probably because of the relative importance of gold in the State’s exploration mix.

The importance of gold in the exploration mix is emphasised by Figure 15 showing the contributions major commodities and commodity groups make to total exploration spend. Gold exploration increased to \$509.5 million, or 30% in 2016–17 compared to 2015–16 and nickel–cobalt exploration increased to \$67.4 million or 40% over 2015–16 expenditure. However, the big mover was the “Others” category that increased to \$92.1 million or 50% more than in 2015–16. Constituents of the “Others” category are not known but anecdotally lithium exploration is probably responsible for the rise compared to previous years. This is consistent with the 40% rise in nickel–cobalt exploration expenditure given that these elements are, along with lithium, part of the battery metal group.

Figure 16 shows that what the Australian Bureau of Statistics calls exploration expenditure on new deposits — a proxy for greenfields exploration expenditure, has been increasing since March 2015 when quarterly new deposits expenditure was only \$43.3 million. Partly as an impact of the State Government’s Exploration Incentive Scheme, a new wave of exploration is underway in rank greenfields areas of the State including the Arunta Orogen, Tanami, Aileron Province, Paterson Orogen, Canning Basin, Yeneena Basin, Musgrave, Western Yilgarn, and Albany-Fraser.

Not only has the absolute expenditure on greenfields exploration been increasing, the proportion of greenfields exploration expenditure has also been increasing from 23.6% of total exploration expenditure in March 2015 to 30.5% in the June quarter 2017. Anecdotal evidence of mineral tenement take-up in the remote area northwest of Telfer suggests that the proportion of greenfields exploration expenditure will increase further.

Petroleum exploration expenditure slows further

Petroleum exploration expenditure in WA and adjacent Commonwealth waters fell to the lowest level since the mid-1990s (Figure 17) and WA's share of national exploration dipped to less than 47%. Low world oil and LNG prices are largely responsible for the exploration downturn although Figure 2e above demonstrates that crude oil prices are increasing. However, WA's low proportion of Australia's petroleum exploration spend is a concern suggesting there may be WA factors at play, including a decline in the number of wells being drilled to feed the expansion of LNG processing facilities in the state.

Government geoscience

Most States have geoscience initiative funding

Geological Survey organizations in Australia continue to mount powerful business cases to incentivise private sector exploration using government-funded pre-competitive geoscience surveys and improved systems for the delivery of larger and more complex information. Table 4 lists the current initiatives which for the most part are funded by government. Most of the funding goes towards programs that benefit the mineral industry, although with historically low levels of petroleum exploration in Australia, including WA, there is a case to be made for additional funding for basin-focussed pre-competitive geoscience initiatives.

UNCOVER implementation plan released

UNCOVER was established as a result of the Australian Academy of Science's 2010 Theo Murphy Think Tank which led to the preparation of a report under the aegis of the Academy that outlined the broad areas of research and other activities required to revitalise greenfields exploration in Australia.

At the request of the mineral industry and supported financially by industry and governments across Australia, 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 (AMIRA International 2017) arising from Stage 2 of the Roadmap was released in 2017 and included:

- Key scientific research and new technology development programs required for priority areas
- The status of the newly acquired and compiled data required as inputs to the research and technology development programs
- The status of existing research activity that is addressing or complementing the priority areas
- A funding plan and a recommended vehicle in which the research and technology development programmes could be undertaken through a National Research Program for Exploration Under Cover.

Geological Survey organizations across Australia have contributed funding to the Roadmap Stage 2 project and in many cases have established government-funded pre-competitive geoscience initiative programs outlined in the previous section that address key priorities arising out of the Roadmap.

While the Roadmap process has produced a well-argued and documented strategic plan for medium to long term geoscience research and pre-competitive geoscience programs, it is the need to find a balance between the industry and government funding sources required to implement the plan that is the most problematic and critical issue.

Australia has shown leadership in developing the Roadmap, which is World-leading in its scope and depth — now it needs to show leadership in developing a public–private funding model that can implement the plan over the next 20 years.

National Mineral Exploration Strategy revised

In March 2017, the Geoscience Working Group (GWG) of the COAG Energy Council resolved to update the *National Mineral Exploration Strategy*, to reflect changes in government, industry and community priorities since 2012. The revised *2017-2022 National Mineral Exploration Strategy* was approved by the COAG Energy Council at its 14 July 2017 meeting.

The GWG will deliver the strategy, in partnership with the resources industry, the research community and the services sector, by:

- **Encouraging investment** through a renewed commitment to the creation and delivery of government-funded pre-competitive geoscience from all jurisdictions, including new techniques, and a refreshed approach to the global promotion of Australia as the lead destination for investment in mineral exploration and mining.
- **Harnessing our capability**, including a cross-institutional research venture focused on delivering the applied geoscience needed for industry to better explore beneath the covered regions of Australia, as well as continued development and promotion of Australia's world-leading METS sector.
- **Protecting the environment** through provision of robust baseline pre-competitive geoscience data for evidence-based decision making and reducing the exploration footprint.
- **Supporting our people and communities** through wider engagement and clear communication of relevant geoscience information, and the economic and social benefits of a vibrant minerals industry to a broad audience.

The plan commits Australian geological survey organizations to align their programs where possible with key pre-competitive geoscience priorities identified in the UNCOVER Roadmap Implementation Plan.

MinEx CRC application gets to first base

In 2017, the MinEx CRC application was one of six applications in the 19th CRC selection round approved to progress to stage two of the assessment process and submit a full business case to support their applications.

The bid, totalling \$182 million, includes \$36 million cash and \$96 million in-kind commitments from geological surveys, industry and research organisations and seeks a \$50 million cash investment from the CRC Program.

MinEx CRC plans to break new ground by pioneering cheap, safe and environmentally friendly coiled tubing drilling to build a 3D picture of the subsurface. It will build on the technical success of the Deep Exploration Technologies (DET) CRC to address declining mineral discovery rates in Australia by novel coiled tubing drilling and related technologies to revolutionise mineral exploration. The three major themes to be explored are:

- Acquiring previously unattainable data on prospective rocks under deep, barren cover. To be carried out with the assistance of government geological surveys and in the context of the National Drilling Initiative.

- Developing cheaper, safer and more environmentally friendly methods to discover, analyse and drill-out deposits. Enhanced depth, steering and sensing capabilities will permit a dramatically reduced cost of resource definition.
- Optimising conventional drilling such as diamond drilling.

GSWA has made a commitment to the National Drilling Initiative, subject to a continuation of Exploration Incentive Scheme funding.

Part 2
Recurrent budget and work program
for 2017–18 and beyond

Context of the program

The biggest impact in the context of the Geological Survey's work program has been the election of the McGowan Labor government in March 2017, following many years of Liberal government. This has resulted in significantly different goals of the government, together with a big shake-up of the public service. The old Department of Mines and Petroleum (DMP) merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety (DMIRS), with effect from 1 July 2017.

Government policies for the resources sector

The policies for the Labor government for the resources sector involve creating the conditions that will enable the future growth of the Western Australian resources sector and deliver jobs. This is expected to be achieved by a focus on:

- supporting continual investment in exploration, which is the lifeblood of the industry;
- facilitating the development of new and innovative technologies to improve productivity and deliver efficiencies in the resources sector;
- encouraging more local jobs and apprenticeships from resources development;
- working with industry to reduce red tape, regulatory duplication, and agency processes; and
- engaging with communities to build confidence in its regulation and improve the understanding of the economic contribution of the resources sector.

The safety and health of workers is also a high priority of the State Government. This is reflected in the Towards 2020 regulatory strategy for resources safety, as well as the creation of the new Department of Mines, Industry Regulation and Safety.

A partial extract from the 2017 WA Labor Platform for matters dealing with the minerals, petroleum (including fracking), energy (including uranium and thorium), CO2 sequestration, and Asian Engagement is included as Appendix A. The Platform includes the policies of:

- WA Labor will immediately ban fracking in the Southwest, Perth, Peel and Swan Valley Regions;

- WA Labor supports a scientific approach to the regulation of fracking, and will conduct a public inquiry to examine environment, health, agriculture, heritage and community impacts prior to any fracking activity;
- WA Labor will place a moratorium on the use of fracking until such an inquiry can demonstrate that fracking will not compromise the environment, groundwater, public health or contribute adversely to climate change;
- Oppose the mining and export of uranium;
- Oppose nuclear enrichment, nuclear power and otherwise the production of dangerous radioactive waste;
- Oppose the storage of nuclear energy waste in Western Australia;
- The long term legacy issues associated with the closure and rehabilitation of mining and other industrial sites in Western Australia must be addressed as a matter of urgency to ensure that proponents, and not taxpayers, pay the costs of closure and rehabilitation;
- Introduce changes to the Mining Act directed at harmonising its process with those of the Native Title Act with a view to ensuring mining titles are processed in the shortest practical time;
- Investigate ways to increase ‘green fields’ exploration undertaken in the State.

In the State Budget handed down in September 2017, the Exploration Incentive Scheme remained as funded from Royalties for Regions and only funded until 30 June 2019.

Change in the public service

The McGowan Government delivered on its election promise of early 2017 and moved immediately on a 40% reduction in government departments from 41 to 25. The Government’s powerful reform agenda aims to create collaborative departments focused on whole-of-government objectives and delivering services in the most efficient way.

Other measures targeting government policies and objectives included very strict budgetary controls (its first budget was delayed and handed down in September 2017), a 20% reduction in the Senior Executive Service of the public service, and the introduction of a Targeted Voluntary Redundancy Separation Scheme (VTRSS). VTRSS is seeking to find 3000 redundant positions in the public sector state-wide. With each redundancy, the

position and the funding for that position is removed from the relevant government department.

Another step in the McGowan Government's commitment to public sector reform is a Service Priority Review, which was also underway at the beginning of 2017–18 and aimed at creating better public services at a lower cost.

Change in the departmental vision, mission, strategic intent and structure

As part of this rationalisation of government agencies, the Department of Mines and Petroleum and the Department of Commerce's regulatory and labour relations functions were amalgamated into the newly formed Department of Mines, Industry Regulation and Safety, effective from 1 July 2017. DMIRS, as the new department is known, now regulates the mining, building and construction industries and is elevating the focus on worker safety.

The department is working on *'Towards 2020 — regulatory strategy for a safe and healthy resources sector'*. Towards 2020 is the first of a series of high-level three-year rolling strategies to guide the department's efforts to raise awareness and seek compliance in the Western Australian resources sector, going beyond the day-to-day inspectorate activities. It will describe the goals, focus areas and measures of success for safety and health initiatives undertaken by the regulator and it will provide an overview of the regulator's commitments so industry can better understand why focus areas are targeted, the desired outcomes, measures and achievements.

Although DMIRS formed on 1 July 2017, the department embarked on a lengthy and extensive transition process, with numerous taskforces and working groups examining a wide suite of issues, some of which directly related to policies and directives of the new government. These included but were not limited to identifying and implementing all the functions needed for the new department to be operating as a legal entity; organisational review (industry versus function); policy function; customer-centric service delivery; opportunities for digital solutions; and equal employment opportunity and diversity. These, as well as the flow-on effects from them, are expected to be on-going throughout much of 2017–18 and probably into 2018–19 as well.

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 and Royalties for Regions (RfR), and made 12 recommendations (Table 5).

Most of these recommendations have been accepted and implemented (where possible) in previous years. However, developments during 2016–17 that relate to these long-term objectives have been updated in the 'Implementation plan' column of Table 5.

Achievements 2016–17

In 2016–17, GSWA maintained the high-level output of products funded from both Consolidated Revenue and the EIS (Table 6). A full list of GSWA products released for the year is included as Appendix B, with this including a total of 38 Bulletins, Reports, Records etc. and, in addition, there were a further 52 papers published externally on Western Australia's geoscience where at least one author was a GSWA staff member (Appendix C). A total of five 'Series maps' and nine 'Maps — other' were produced entirely by funding from Consolidated Revenue, whereas all geophysical data surveys were funded by the EIS. Other product categories were produced from a mix of Consolidated Revenue and EIS funding. During 2016–17, the amount of data released from airborne gravity surveys declined to 38 436 km (East Kimberley), but substantially more is planned to be delivered and released in 2017–18 as three further surveys are committed (Northeast Canning, Tanami, and Kidson).

The main headline numbers of products released during 2016–17 were similar to 2015–16, but the number of printed maps were less as there is now more emphasis on incorporating new information into the on-line Explanatory Notes System.

Note that the Weighted Total Published Product (WTPP), historically used as an attempt at an all-in measure of GSWA performance, was not used during 2016–17 following the formation of the new mega-department (DMIRS) and new KPI-style measures were changed across the department. The new measures are a mix of activity measures (some

of which are and will be incorporated into the descriptions of specific projects in this series of Records), determining weightings on the wider range of products produced and services offered by the Geological Survey, and improving the estimate of total resources available and work effort (number of staff and staff working hours, including the numerous consultants and contractors). For the last measure, it is estimated that there were 26 613 days of effort to produce all of the GSWA products in 2016–17, with this also including provision of technical advice (Table 6).

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). Since then, GSWA has remained productive and output oriented, but the drop in EIS funding to around \$10 million since 2014–15 has meant that the level of product output has stayed relatively constant in recent years.

Other significant target deliverables set for 2016–17 and their status at year end (status shown in italics) include:

- obtaining government approval for the continuation of the EIS. *Following the State election in March 2017, the business case and other related documentation were updated and submitted to DMP's new Minister and senior executives (DMIRS also had a new Director General from 1 July 2017), Treasury, and Department of Regional Development. EIS is currently funded through Royalties for Regions so multiple approvals are required across government*
- preparing a business case for expansion of the Joe Lord Core Library at Kalgoorlie. *Ongoing — the business case was prepared and submitted for approval; but the measure was not supported in the State Budget presented in September 2017 (where there was very tight fiscal restraint imposed across all of government*
- 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. *Released as a digital package on USB*
- 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. *Released*

- releasing GSWA's concept and demo of the prototype of the Mineral Systems Atlas. *Done and the prototype continues to be worked on*
- releasing GSWA's next suite of 3D products – Rocklea Dome and the Albany–Fraser Orogen. *Released*
- 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. *Released*
- interpreting the Eucla–Gawler deep seismic reflection survey. *Released*
- releasing Explanatory Notes System – West Musgrave Province. *Released*
- releasing Exploration targeting for BIF-hosted iron ore deposits (joint project with MRIWA). *Released*
- releasing Explorer's guide for gold in the Yilgarn Craton (Part 3). *Released*
- releasing Western Australia unearthed (part 3): the Paleozoic of Western Australia. *Released*
- revising Mineral Resources Bulletin on the Gemstones of Western Australia. *Released*
- 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. *Mostly done, though implementation of the MINEDEX–Royalties enhancement for lodging mineral production returns delayed till the first quarter of 2017–18. Use of the WAMEX on-line report writing application remains optional*
- creating TENGRAPH web, which will use the Geocortex software (that is, similar look and feel to GeoVIEW.WA). *Released*
- upgrading to GSWA's Data and software Centre on the DMP website. *Released*
- releasing an upgrade to the WA Geology mobile application, with new layers and new functionality. *Released*
- releasing an upgrade to the free GeoMap.WA software. *Released, but work continues on further upgrades*

The challenges remaining for GSWA include:

- persuading the new Labor Government for an extension of EIS funding beyond June 2019

- continuing to align GSWA’s work program to obtain maximum leverage from the industry-led roadmap of UNCOVER, GA’s *Exploring for the Future* project in Northern Australia, and the MinEx CRC drilling initiative
- 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, together with a minerals component to the online Explanatory Notes System
- lobbying for capital funds to expand the Joe Lord Core Library at Kalgoorlie
- managing the transitioning-out of GSWA’s high-productivity baby boomers in a time of strict government fiscal restraint
- managing the large number of short-term fee-for-service staff in GSWA who are funded through both the recurrent operational budget and EIS, and aligning this practice with the policies of the new Government.

GSWA’s budget 2017–18

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 — and that trend continued with the Labor budget handed down in September 2017 for the 2017–18 year and beyond. It did, however, show the \$10 million component within the departmental budget that is allocated to the EIS, including the popular and widely recognized co-funded drilling program.

The State Budget papers do not show a specific line item for the budget for the Geological Survey, but the papers do indicate that for DMIRS as a whole (including the Geological Survey) the budget allocation for 2017–18 is \$34.068 M for ‘the cost of providing resource sector information and advice to industry, community and government’. This compares with \$34.890 M for 2016–17, so the 2017–18 allocation represents a 2.3% decrease.

The 2017–18 budget decided within the department and allocated to GSWA (but excluding the EIS budget) is \$18.374 million, which is a drop of \$0.238 million (-1.3%) from 2016–17. Factors associated with the drop is the tight government fiscal constraint, low inflation rate but no adjustment for inflation, pay increases for public servants capped at \$1000 for 2017–18 per person (and a freeze in salary for the Senior Executive Service), and the on-going of both the voluntary redundancies (100% harvesting of salary and on-costs) and the ‘60/40 salary harvesting’ for staff who retire or resign (the latter is explained below).

The budget shown in previous editions of the Work Program (in earlier equivalents of the current Table 7) showed the total recurrent (or headline) funding for GSWA, inclusive of departmental corporate overheads. However, Table 7 now shows the budget amount allocated by the Director General of the department to GSWA as the discretionary funding for salaries plus direct operational funding. The difference is due to the fact that employee overheads (superannuation, workers compensation, etc.) and public utilities are paid centrally by the department. However, there is an increasing trend of more of some of the departmental costs (internet usage, Microsoft licences, mobile phones, etc.) being charged instead back to the GSWA operational budget, while corporate overheads seemingly remain the same. As a result, there is a continual squeeze on the operational (non-salary) budget of GSWA.

Overall, the squeeze on government spending — particularly on salaries — continues, with 40% of a person’s salary (60/40 rule) and related on-costs removed from the departmental budget when a staff member retires or resigns from the department. This generally equates (once related on-costs are factored in) to a ‘2-for-1’ rule, that is, two people need to retire or resign before one person can be recruited. This policy was initiated under the Liberal Government and applied during 2016–17, and will continue unchanged under the Labor Government for 2017–18.

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 consult with impacted exploration and production tenement holders. Although the cost of this is

normally within the GSWA base funding (recurrent budget), projects that are a government priority may attract special short-term funding from the Department of Premier and Cabinet. An example of that for 2017–18 is the South West Native Title Settlement, with \$0.115 million provided. Even with that extra project funding, the overall GSWA base funding declined by 1.3% for 2017–18.

Table 8 shows GSWA’s 2017–18 recurrent operational budget for both projects and their support activities. This table excludes the special funding from DPC of \$115 000 for the South West Native Title Settlement. The overall forecast distribution of funds for the projects and their support activities for 2017–18 is similar to the previous year. In the Mineral and Petroleum Resources area, the differences in expenditure are mostly related to the timing of IT projects from one year to the next. In Regional Geoscience Mapping, there is planned winding back of field mapping and expenditure in the Gascoyne Complex, Edmund and Collier Basins, and the Murchison — but with a planned increase in 3D Geology activities. In the work area of Geoscientific Editing and Publishing, the increased expenditure is related to IT projects (from across the Geological Survey) clustered under and managed through ‘Business Systems Support’.

Table 9 shows GSWA’s 2017–18 recurrent operational budget after support areas are distributed on a pro rata basis to geoscience information-producing projects.

In 2017–18, funding for the EIS is again \$10.0 million per year. The government has recognized the early successes of the EIS by extending funding, however, EIS funding in forward estimates of the current budget shows EIS apparently finishing in June 2019. GSWA is preparing a business case for extension of EIS beyond then — either by funding from the current method of Royalties for Regions or by a return to Consolidated Revenue.

Staffing related to base funding 2017–18

For 2017–18, salaries will continue to account for about 72% of GSWA’s Consolidated Revenue funding, which is unchanged from 2016–17.

Table 10 shows planned staffing of 116.7 FTE in 2017–18. This compares with actual staffing of 120.3 FTE in 2016–17, so staffing numbers remain strictly controlled and are gradually diminishing. Experience also reveals that actual staffing levels (at year end) turn

out to be less than planned or budgeted at the beginning of the year. 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 department's 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. GSWA has in past years and continues to use fee-for-service contractors in order to continue to provide services and advice, but where this is paid from the operational budget rather than the salary budget.

The staffing data of Table 10 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. At this time, EIS funding is assured to 30 June 2019, but not beyond that. Table 10 also excludes the fee-for-service staff that are funded by either the recurrent operational or EIS budgets.

Figure 18 illustrates the 20-year trends in GSWA's recurrent expenditure and employment. Actual 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 specific projects, but where employment under EIS was strictly capped at an additional eight FTE staff (who are not shown in Figure 18).

Recurrent-funded staffing recovered to a level of 133 in 2010–11 as EIS activities gathered momentum, but have stayed strictly controlled since then and have overall gradually declined to an actual level of 121 at the end of 2016–17, and with a further fall down to only 117 FTE planned for 2017–18. The sharp drop in staffing levels in the last few years has resulted from the strict budgetary restraints, and the drop is beginning to have an impact on the level of products and quality of services provided.

The government squeeze on salaries and recruitment since January 2015 means that, once again it is not possible to recruit staff into the sponsored Master's program or a graduate program this year. So although the 'baby boomers' are retiring in greater numbers, recruitment is at a much slower rate.

The strict Government controls on expenditure and staffing will continue in the short term, at least for 2017–18. Employment through short-term fee-for-service arrangements for specific project work has remained the most flexible way to achieve operational objectives while balancing budget restraints, but government policies on such arrangements are under review with the new Labor Government (see Appendix A).

The proportion of geoscientists has — since 2007–08 — slowly increased 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 56–58% of all full-time and part-time employees (Fig. 19; Table 10). Geoscientists and IT support staff (but not support staff) dominate the fee-for-service staff (not included within the data of Table 10 and Figure 19).

Appendix D shows the organizational structure for GSWA at 30 June 2017.

Strategic allocation of Consolidated Revenue funding 2017–18

Table 11 contains the result of allocating GSWA's Consolidated Revenue 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 11 reveals that 69% of GSWA's 2017–18 budget will be applied to the outcome of encouraging the exploration and discovery of mineral and energy resources and 31% will be directed towards informed land-use planning. The amounts are essentially unchanged from the previous year.

With the objective of encouraging exploration and discovery, the split between targeting minerals versus petroleum and coal is 46 basis points versus 23 basis points — totalling 69% of the GSWA budgetary resources for 2017–18. Again, these are little changed relative to 2016–17.

Pre-competitive geoscience applied to greenfields/frontier areas targeting minerals, petroleum and coal (combined) consumes 47% of the budget compared to the 22% directed towards brownfields/production areas, a ratio of about 70:30. This ratio has been maintained for many years.

For the outcome of ‘Informed land-use planning’ (31% of total GSWA recurrent budget for 2017–18), the split of expenditure is subdivided into the following, which are again very similar amounts to previous years:

- Information on resource potential: 15 basis points
- Policy advice on resource issues: 11 basis points
- Information for R&D and the general public: 5 basis points

Recurrent budget work program 2017–18

The 2017–18 field mapping and map compilation program will extend the 1:100 000 Geological Series maps (Fig. 20) for the Murchison Domain of the Yilgarn Craton, and the 1:250 000 Geological Series maps for the Kimberley, and the west Arunta and the Amadeus Basin. The Geological Information Series (GIS) products (Fig. 21) covering the Kimberley, Murchison, East Yilgarn, Tanami–Arunta, Albany–Fraser and west Capricorn will be updated with revised interpreted IBG layers at 1:100 000 and 1:500 000 scales. Field mapping and desktop studies will continue for the compilation of GIS products for the southeast Capricorn Orogen basins, the Fortescue and Hamersley basins, and the Southwest Yilgarn. The 1:500 000 IBG map of the State will be updated, and a 1:100 000 IBG, for areas covered by Geological Information Series products, will be released via GeoVIEW.WA. There will be a further release of WAROX, GSWA’s field observation database, as a digital package. 3D products will include further 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. Explanatory Notes System entries will be completed for the Eastern Zone of the Lamboo Province in the Kimberley, the Hamersley Group, and the Murchison Domain of the Youanmi Terrane of the Yilgarn Craton.

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 limiting factor to better integration is the paucity of staff in the Mineral Systems group (now only five staff) in comparison to the large number of geoscience mapping staff and dozens of EIS-funded research projects. Development of the Mineral Systems Atlas will also continue. The group will finish constructing several significant geological proxy layers for komatiite-hosted nickel systems, and will undertake systematic analyses of gold and iron mineral systems to define mappable geological proxies for critical metallogenic processes. Design work will also begin on the interactive, digital Mineral Systems Atlas that will deliver the ‘proxy’ datasets. Development work will begin on a Mineral Deposit Explanatory Notes System. The Mineral Systems Studies section, in conjunction with MRIWA and industry, will investigate the possibility of developing a technique for direct dating of iron oxide mineralisation.

Ongoing entry of mineral deposit information will continue into GSWA’s mines and mineral deposits information database (MINEDEX), which is used throughout the department for a number of policy and approvals purposes. An area of policy focus during 2015–16 and 2016–17 was 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. The emphasis during 2017–18 will switch to improved online reporting of mineral production data into the royalties system and then automatically through to MINEDEX, which will for first time allow for ready calculation of total known geological endowment (current resource estimates and total recorded production) for all commodities — at least down to project level and in many cases down to the level of single deposits.

The Basins and Energy Geoscience section will continue its major investigations of the Canning, Perth and western portion of the Centralian Superbasin using a mix of recurrent and EIS funding. This work involves the high-priority projects of finalising interpretation of the Phanerozoic portion of the Canning Coastal seismic survey (700 line-km) and assisting Geoscience Australia plan and undertake the deep crustal seismic survey of the Kidson Sub-basin (900 km). The Basins and Energy Geoscience section is gradually switching work from the South Perth Basin to the north Perth Basin, where AWE Ltd’s discovery and development of gas in the Waitsia/Senecio fields has renewed much interest in the northern Perth Basin. The group is expected to have greater involvement

with the geoscience aspects of the Harvey geosequestration project now that the Carbon Strategy project and its staff are part of the new Geoscience and Resource Strategy Division. Exploration in the petroleum sector remains at cyclical low levels, with minimal industry-funded drilling and little interest by the petroleum sector in EIS co-funded drilling. The Basins and Energy Geoscience section will continue to compile a digital core atlas for key petroleum wells in the Canning Basin (following publication of the atlas for Olympic 1).

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 2017–18 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.

The Mineral Exploration Information section will continue to update the Guidelines for submission of mineral exploration reports under section 115A of the *Mining Act 1978*, while encouraging greater use of the voluntary on-line report writing application (WAMEX). The Petroleum Exploration Information section will continue to enhance the WAPIMS application, with this done in tandem with Geoscience Australia’s development of the National Offshore Petroleum Information Management System (NOPIMS). The Petroleum Exploration Information section, in conjunction with staff from the Perth Core Library at Carlisle, continue to operate the Perth Core Library as the western hub of the Commonwealth’s National Offshore Petroleum Data and Core Repository (NOPDCR).

Cooperative projects

GSWA is currently involved in 39 cooperative projects with geoscience research organizations including universities (Cambridge University, Curtin University, Macquarie University, Johannes Gutenberg University of Mainz, University of Tasmania, Sydney University, University of Western Australia), Frogtech Geoscience Pty Ltd, MRIWA, CSIRO (including AuScope), AMIRA, Cooperative Research Centres (CRC), Centres of Excellence, Geoscience Australia, National Geographic Society, and Thermo Fisher Scientific. Research projects being undertaken in collaboration with exploration and mining companies include those with Kalnorth Gold Mines Ltd, Northern Star Resources Ltd, and Northern Minerals Ltd. A full list of the current projects is included in Appendix E. The number of collaborative projects increased greatly with the start of EIS in 2009, concomitant with a restriction of the number of extra staff allowed within GSWA. 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.

A suite of the current projects are with Geoscience Australia and operate under the National Collaboration Framework — these include project agreements covering:

- reprocessing of vintage seismic lines from the Canning and Southern Carnarvon Basins
- acquisition of the new deep crustal seismic survey across the Kidson Sub-basin
- Eucla–Gawler deep crustal seismic reflection, gravity and MT survey, processing and interpretation
- Regional reconnaissance airborne gravity surveys (WARGRAV2)
- the National Offshore Petroleum Data and Core Repository (NOPDCR)
- The National Offshore Petroleum Information System (NOPIMS)

Further details of these current projects are contained in descriptions of individual recurrent and EIS project plans.

Recurrent budget — planned achievements 2017–18

Table 12 shows GSWA's planned achievements predominantly using 2017–18 recurrent budgetary resources, but with significant contribution also from EIS funding. Importantly,

production of 1:100 000 and 1:250 000 Geological Series maps will see a drop this year to an anticipated four 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 GIS products, GeoVIEW.WA, and 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 (Table 12).

Other significant planned outputs of the 2017–18 recurrent budget include:

- obtaining government approval for the continuation of EIS (EIS 4)
- obtaining government funding for expansion of the Joe Lord Core Library at Kalgoorlie
- release in full GSWA’s digital 1:100 000 IBG for areas covered by Geological Information Series products via GeoVIEW.WA
- release of a seismic interpretation of the southwestern Canning Basin
- release of a Report on the Liveringa Group, Canning Basin: correlating outcrop to subsurface
- release of the second of the innovative product in the series Digital Core Atlas — Theia 1, Canning Basin
- release of a Report compiling and interpreting palynology of the Harvey region, southern Perth Basin
- release of GSWA’s concept and demo of the prototype of the Mineral Systems Atlas for komatiite-hosted nickel, orogenic gold, and iron in the Yilgarn Craton
- release GSWA’s next suite of Geophysical Modelling Products
- Release of the Ngururrpa lands soil geochemistry Record and interpreted regolith-landform map
- Release of a Record and data USB on the geochemistry of Archean granitic rocks in the South West Terrane of the Yilgarn Craton
- Release of Explanatory Notes System — Eastern Lamboo Province, Halls Creek Orogen, Murchison Domain, and Hamersley Group
- moving on to better IT systems for handling the core library assets, improved lodgement of mineral production data (lodged through the online royalties system but

flowing through to MINEDEX), enhancing the WAMEX online report-writing system, and assisting Geoscience Australia with its NOPIMS 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 2017–18 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 to 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. 22). 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 (EIS3). The State election in March 2017 saw a change of government with the new government undertaking a review of all programs that were to receive funding from RfR, including the EIS. This led to a temporary suspension of some EIS activities post June 2017, including the announcement of successful applications in the Co-funded Exploration Drilling program. As a result of the review, the EIS was given \$10M per year in funding for 2017–18 and for 2018–19, with the funding source switched back to RfR, and bringing total EIS funding from 2009 to \$150 million.

EIS also aims to signal that the Western Australian Government continues to welcome 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 (in 2009) 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 2016 survey, released in February 2017, Western Australia was ranked first globally in both the Best Practices Mineral Potential Index measures and Geoscience Databases, and third in the world for the Investment Attractiveness Index (Fig. 12, Table 3). This is an absolutely outstanding achievement, and an acknowledgement of the vision of those who implemented EIS and of those who have supported it since.

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 13), with Western Australia ranked above all the other Australian states and territories in the major indices in 2016.

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 ran from July 2014 to June 2017 together with the proposed budgets for EIS3 to the end of June 2018, 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 the last survey being undertaken in the Yalgoo area in 2015–16 (Fig. 23). Most of the airborne magnetic–radiometric survey program was completed in late 2012. The program also extended the reconnaissance airborne electromagnetic (EM) surveys, with the Capricorn EM survey undertaken in 2013–14 (Fig. 24). 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.

The EIS has also supported a major expansion of the area covered by ground gravity surveys with stations spaced at 2.5 km apart (Fig. 25). In addition, airborne gravity data is being acquired in areas where ground gravity is difficult, with a survey of the East Kimberly completed in December 2016. Two further airborne gravity surveys covering the Kidson and Tanami were commenced in June and July 2017, respectively, and more surveys are planned. Figure 25 is a composite map showing the EIS-funded ground and airborne gravity surveys.

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.

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 the department’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 (for details see GS95 HyLogger and National Virtual Core Library).

Achievements 2016–17

Achievements during 2016–17, the eighth full year of operation of the EIS, are as follows:

- Drilling projects supported by the Co-funded Drilling program resulted in 27 919 m of diamond drilling and 54 380 m of non-cored drilling from 49 projects during 2016–17
- Forty two successful applicants were announced for Round 14 offers (for drilling

during 2017) under the Government–Industry Co-funded Drilling program

- The announcement of successful applicants from the R15 (2017–18 drilling) application process was delayed due to the uncertainty of EIS funding while RfR programs were being reviewed. After completion of the review process, 43 successful applicants were announced in September 2017
- Publication of the results of research on the petroleum source potential of, and an assessment of thermal maturity using bitumen, graptolite and bioclast reflectance, of the Ordovician Nambett Formation, Canning Basin based on evidence from petroleum well Olympic 1
- Publication of “Crustal differentiation in the Proterozoic Capricorn Orogen” which was a result of collaboration with researchers from Curtin University, John de Laeter Centre, CCFS and GEMOC
- Release of the geological interpretation of the Canning Basin along Canning Coastal seismic lines 14GA-CC1 and 14GA-CC2, as well as release of the publication of ‘Canning Coastal seismic survey — an overview of the Canning Basin’
- VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks, which is the last of the reports from the CSIRO embedded researcher project
- Several publications on mapping using hyperspectral data on iron ore alteration patterns in banded iron-formation of the Yilgarn Craton
- Release of the record on the regolith chemistry of the Dambimangari area, west Kimberley and the accompanying data set
- Publication of the report on the collaborative MRIWA Project M426: exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia
- Acquisition of 38 400 line km of airborne gravity data in the East Kimberley
- The first two 3D models covering the Sandstone greenstone belt and the Windimurra Igneous Complex were released.

Full details of the achievements are included in the individual program plans — see Part 5.

Cooperative projects and consultancies

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 E contains a listing of all current collaborative projects and consultancies 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.

* 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, Ameer Ghori, Peter Haines, Lorraine de Leuw, Alan Millar, Sarah Martin, Arthur Mory, Leon Normore, Suzanne Simons, Charmaine Thomas, Vije (Alex) Zhan

The primary goal of this section is to develop consistent, basin-wide 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 DMIRS and other organizations including CSIRO, the Western Australian Energy Research Alliance (WA: ERA), University of Western Australia, Curtin University, Northern Territory Geological Survey (NTGS), Geological Survey of New South Wales and Geoscience Australia (GA).

Currently, the section's focus is the Canning, Carnarvon and Perth Basins. These basins have proven petroleum systems but are underexplored, particularly in the case of the vast Canning Basin. The section is also contributing to geological mapping or new reviews of the Western Australian portion of the Centralian Superbasin including the Amadeus, Officer and Murraba Basins, and interpreting results to better understand the petroleum potential of these older basins. An investigation commenced into the little-known Moora Basin, located adjacent to the northeastern margin of the Perth Basin.

Main issues and uncertainties

Canning Basin

The main issues and uncertainties in the Canning Basin include:

- unreliable and irregularly distributed geochemical data, creating uncertainties regarding the definition and distribution of petroleum systems
- inconsistent application of stratigraphic nomenclature across the basin, especially in the Palaeozoic section, resulting in variations in formation tops between wells
- lack of biostratigraphic data in many wells and intrinsic difficulties of biostratigraphically dating some stratigraphic intervals thereby rendering uncertain correlations
- 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 well and seismic data are sparse.

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
- Poor-quality vintage seismic data and sparse/irregular regional coverage.

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 many 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 Palaeozoic component)
- very limited biostratigraphic control, stromatolites previously reported are poorly preserved, a previously reported problematic “fossil” is reinterpreted as inorganic
- 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; aircore cuttings from recent mineral company drilling need assessment

- 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 2016–17

Canning Basin

Some of the main outcomes from studies in the Canning Basin 2016–17 were:

- reassessment of the palynology from the Grant Group and Reeves Formation indicates a significant break between these units, and the likely 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 away from those sub-basins is now included in the Grant Group
- ongoing interpretation of key horizons in the southern Canning Basin provides a series of maps to better understand its resources and structural framework
- mapping of the structural elements of the western Canning Basin confirming the presence of thick sedimentary sections within the Wallal and Waukarlycarly

Embayments and the downgrade of the Samphire Graben. Report published in 2017–18 financial year.

- Publication of GSWA Record of 2017/3 on provenance, depositional setting and regional correlation of the Ordovician Carranya Formation, Canning Basin.

Perth Basin

Some of the main outcomes from studies in the Perth Basin 2016–17 were:

- assessment of the source rock potential and thermal maturity of the Perth Basin, which incorporated 1D and 2D basin models and a set of mapped source rock quality trends. Report published in 2017–18 financial year.
- Completion of a revision of palynological data from other water bores in the Harvey area, as an aid to better constraining the biostratigraphy of this area. Report published in 2017–18 financial year.
- Completion of a regional seismic interpretation and mapping project, which has led to an 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. Report and map grids to be published in 2017–18 financial year.

Amadeus Basin

Some of the main outcomes from studies in the Amadeus Basin 2016–17 were:

- improved correlations as a result of ongoing work on stromatolite biostratigraphy; publication on the biostratigraphy of the prospective Aralka Formation nearing completion. Record published in 2017–18 financial year.
- refined cross-border correlations as a result of collaboration with NTGS
- completion of the WEBB 1:250 000 mapping revises the outcrop distribution and age of northern Amadeus Basin in WA, and (based on geophysics) significantly increases the extent of covered outliers of the Amadeus Basin within the Arunta Orogen
- improved understanding of the western Amadeus Basin with second edition MACDONALD map sheet in progress

Murraba Basin

Some of the main outcomes from studies in the Murraba Basin 2016–17 were:

- publications of GSWA Record of 2017/4 on geological reconnaissance of the Southern Murraba Basin
- addition of Murraba Basin chapter to Petroleum and Geothermal Explorer’s Guide in progress following upgraded prospectivity due to similarities to the Amadeus Basin.

Moora Basin

Some of the main outcomes from studies in the Moora Basin 2016–17 were:

- bitumen was analysed from Goonderoo 1, 1A cores and cuttings; GC-MS data provided some information about original ole composition, but samples were quite degraded
- field examination relocated “fossil” sites near Moora that were reported in the 1950s; these are reinterpreted as psuedofossils (probably silicified aragonite needle clusters)
- Examination of stromatolites in the field and in drill core to improve age constraints; heavy silicification thus far downgrades the biostratigraphic value of this material and better material is desirable

Regional studies

The main outcome from regional studies 2016–17 is:

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

Products released 2016–17

Record of 2017/4 on Geological Reconnaissance of the Southern Murraba Basin

Paleontology Report 2017/1 An Early Devonian fish fauna from an unnamed sandstone in petroleum exploration well Wendy 1, northern Perth Basin

Record of 2017/3 on Provenance, depositional setting and regional correlations of the Ordovician Carranya Formation, Canning Basin

A Booklet in the Western Australia unearthed series “A Paleozoic perspective of Western Australia”

Petroleum prospectivity of State Acreage Release Areas L17-1, L17-2, L17-3, L17-4 and L17-5, Canning Basin, Western Australia

Planned work program and products 2017–18

Regional geological, geophysical and petroleum geochemical studies for the Amadeus, Canning, Carnarvon, Moora, Perth and Officer Basins will continue during 2017–18 and beyond. During 2017–18, new areas of study will include:

- an expansion on the previous palynological review of the Harvey Ridge to include all of the southern Perth Basin. This will lead to a future reassessment of the stratigraphy compared to the northern Perth Basin
- provide input and assistance to GA prior to acquisition of a new regional seismic line in 2018 and drilling of a stratigraphic well in 2019 in the Kidson Sub-basin of the Canning Basin
- assist with QC of reprocessing of vintage 2D seismic lines in the Southern Carnarvon Basin and Coolcalalaya Sub-basin, and the Canning Basin
- seismic interpretation and mapping of the Southern Carnarvon Basin and continued interpretation of the Canning Basin – both projects incorporating the newly reprocessed data
- building 3D depth models of significant geological surfaces in the southern Perth Basin and southwestern Canning Basin
- compilation of a Digital Core Atlas for Theia 1, Sally May 2, and Nicolay 1.

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
- Publication of a field study of the Permian Liveringa Group and division of subsurface sections

- publication of the Report on seismic interpretation and mapping of the western Canning Basin
- Continued seismic interpretation of the Palaeozoic in the southern Canning Basin
- Interpretation of new airborne gravity surveys that were acquired over the Canning Basin in June and July 2017
- Write Record on Cobb Embayment, southeast Canning Basin

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

- publication of a palynological data review for the Harvey region and commence a similar review that encompass all of the remainder of the southern Perth Basin
- publication of a report on the seismic and structural interpretation of the southern Perth Basin
- Publication of a report on the petroleum geochemistry and petroleum systems modelling of the Perth Basin
- Revision of stratigraphy in Wendy 1 and surrounding wells.

Carnarvon Basin — continuation 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
- new age constraints on the Tumblagooda Sandstone.

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
- commence new analysis of well samples.

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

- possible further analysis to determine the origin of bitumen from the fractures within cores from Goonderoo 1 and 1A
- publication of 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
- ongoing studies of biostratigraphy including publication on the Aralka Formation
- cross-border collaboration with NTGS (including joint fieldwork) to facilitate better understanding of the evolution and resource potential of the Amadeus Basin
- examine recently acquired aircore samples from mineral company drilling to assess potential for organic geochemistry and palynology.

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 GSWA's Unearthed series)
- release of external publications related to many of the above topics.

Products planned for release 2017–18

The Wallal Rift System: geology and petroleum potential (Record)
 The Liveringa Group, Canning Basin: correlating outcrop to subsurface (Report)
 Seismic interpretation of the southwestern Canning Basin, Western Australia (Report)
 Revised geology of the Cobb Embayment, Canning Basin (Record)
 Seismic and structural interpretation of the southern Perth Basin (Report)
 Petroleum geochemistry and petroleum systems modelling of the Perth Basin, Western Australia (Report)
 Complete expanded extent and improved correlation of the Aralka Formation, Amadeus Basin (joint NTGS/GSWA Record)
 Petroleum prospectivity of State Acreage Release Areas, Western Australia
 Paleontology Reports (ad hoc, as required)
 Play types of the Canning Basin (Poster)

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 assessed, and recommendations or advice 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 DMIRS.

The number of proposals received as normal workflow from other government agencies decreased slightly in 2016–17, although there were a substantial number associated with the South West Native Title Settlement project.

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 (Fig. 26) in close collaboration with other government agencies, industry and other divisions within DMIRS. 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.

Considerable work was undertaken with other government agencies to incorporate new information received from the public comments.

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.

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 2016–17

The section produced the following outcomes:

- Additional funding continued to be provided for the South West Native Title Settlement project (Fig. 26). The new computer-based system for improving the efficiency of the assessment process and the extension of the ‘screening’ assessment process to a ‘full’ assessment system was completed. 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. Ten ‘full’ assessments and 650 ‘screening’ assessments for potential land tenure changes were completed specifically for this project. These assessments are additional to the 808 referrals listed below in the ‘products released’ table.

- Building upon work with the South West Native Title Settlement project, a new computer database, data input and assessment system (the Land Use Assessment or ‘LUA’ system) was completed for all Land Use Geoscience referrals. This new system was developed to facilitate full electronic referrals from the Department of Planning, Lands and Heritage when they become available.
- Consultation commenced with local government in the Goldfields region to discuss strategic land use planning around Goldfields town sites. In particular, the section worked closely with the City of Kalgoorlie–Boulder to identify a new industrial site. A prospectivity study identified a suitable area about 10 km south of the Kalgoorlie city centre close to other relevant features, that is, transport and utility infrastructure.
- The section has been assisting Main Roads WA with the identification of areas with potential for gravel resources for use in long-term road maintenance and construction throughout the State.

Products released 2016–17

Provision of information, advice and assessments in response to requests from other government agencies — 808 referrals dealt with

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

Planned work program and products 2017–18

The section will continue to provide information, advice, and assessment in response to routine requests from other government agencies. The estimated number of referrals are expected to continue at similar levels to those experienced in 2016–17, that is, about 800 referrals for the year (Fig. 27). In addition, the section also works on a range of special high-priority projects. Where the priority is set by other government agencies or by shires.

Additional funding will continue for the South West Native Title Settlement project to fund one additional fee-for-service geologist to facilitate the section’s role in this project. It is anticipated that there will be substantial land assessment ‘screening’ and approvals associated with the South West Native Title Settlement.

Contingent upon the completion of a new computer system within the Department of Planning, Lands and Heritage, full electronic integration will take place with the new DMIRS LUA system initially for around 40% of all referrals. Once completed, the

integration will result in significant efficiency gains for these referrals by removing the need for most data entry and spatial data creation.

The section will continue to contribute to the Strategic Assessment of the Perth–Peel region. The Department of Premier and Cabinet, which is leading this project, advises that a revised draft for public consultation is planned for the first half of 2018 subject to government decision-making in late 2017.

A revision of the titanium–zircon mineralization mapping will be completed after consultation with industry. This updated mapping will be published on the department’s online GeoVIEW.WA system and available for downloading from the Data and Software Centre. This will replace the former printed 1:50 000 scale map sheets. This will facilitate updating as new information becomes available.

Assistance with the identification of areas with potential for gravel resources for use in long-term road maintenance and construction for Main Roads WA will be completed this year. Learnings from this work will be included in a publication on the gravel resources of South Western Australia with the aim to assist others, particularly local governments in the search for these important road building materials.

Products planned for release 2017–18

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2018 (map)

Atlas of gravel resources: South Western Australia. Record and digital dataset

GS14 Commodity and Industry Analysis

Manager: Nicole Wyche (acting)

*Team members: Roger Cooper, Caroline Strong, Amanda Jones, Jutta Pagel,
Lyn Day*

The Commodity and Industry Analysis (CIA) group tracks mineral exploration activity to allow DMIRS to provide data and specialist technical advice on most mineral commodities. Data are collected on mineral exploration activity, mineralised sites, mineral resources, mineral production and mining activity. Users of CIA group outputs include other DMIRS groups, other government agencies, research organisations, minerals industry, and the community stakeholders.

A key component of this service is the maintenance and enhancement of Western Australia's mines and mineral deposits information database (MINEDEX). It is the one system within the department that has a broad view of industry activity (current and historic) and, unlike other database systems in DMIRS, it is not designed around a regulatory and structured workflow. However, MINEDEX has strong links to other departmental systems for maximum efficiency and minimised duplication of data and effort — including EARS (environmental), SRS (resources safety), RMS (royalties) and Records (records management). MINEDEX maintains information on all mineral commodities and specialises in keeping track of industry activity — not only at a broad project level, but also down to the operating status and location of every site. MINEDEX also specialises in 'geological endowment' — keeping track of all mineral resource estimates, mineral production, and mineralisation styles.

MINEDEX data (which is dominantly textual) can be accessed directly via the departmental website, and viewed spatially via the TENGRAPH and GeoVIEW.WA online systems, and on most maps produced by GSWA. In addition, the CIA group produces a range of commodity-related publications, often with an investment promotion theme, as well as providing data for other Geological Survey publications.

The CIA group also has a regulatory role and is responsible for the assessment of Mineralization and Resource Reports submitted in support of Mining Lease applications.

The group is also responsible for providing Mining Act advice on expenditure exemptions/extensions of term, Retention Licences/retention status, combined reporting, and reports for Special Prospecting Licences (SPLs) for the Warden's Court. Sterilisation Reports, which form part of some Mining Proposals, are also assessed to ensure that important resources or reserves are not being sterilised by proposed in-pit disposal of tailings or waste rock.

Outcome of work program 2016–17

The dominant routine work of the CIA group is maintenance of MINEDEX content, with this done so that the desired products and services are produced and provided efficiently. The following tables summarise the work completed in 2016–17. Some of this work began to be measured (from April 2017) as part of the Key Performance Indicators of the department.

- A total of 1089 tenure-related activities were carried out (mostly related to the Mining Act, but also includes advice to JTSI on State Agreement matters)
- The group monitors a variety of data sources to keep MINEDEX current, with about 3400 items used in 2016–17
- As commodity specialists, the CIA group receives a large number of queries for assistance (despite the database being online), with 1025 queries dealt with — of which the majority (86%) were assisting staff within DMIRS.

<i>Tenure-related assessment tasks 2016–17</i>	<i>Number</i>	<i>KPI measure</i>
Mineralisation reports and resource reports (Mining Lease applications)	67	Yes
Sterilisation reports (as part of Mining Proposals)	2	Yes
Expenditure exemptions and extensions of term	494	Yes
Retention Licences and retention status applications	45	Yes
SPL reports for the Wardens Court	51	Yes
Extractive Industries Licences	41	No
Mining Proposals	344	No
Combined reporting	41	No
Advice to JTSI on State Agreements	4	No
Total	1089	

<i>Data sources consulted for updating of MINEDEX 2016–17</i>	<i>Number</i>
ASX reports	2253
WAMEX reports	410
Annual environmental reports (AER)	148
SRS alerts (from Resources Safety Division’s SRS database)	107
MINEDEX–RMS (Royalties) messaging	174
Form 5s	255
Section 40E permits	86
Total	3433

<i>Queries 2016–17</i>	<i>Number</i>	<i>Source</i>
Resources Safety, DMIRS	370	DMIRS
Environment, DMIRS	376	DMIRS
Royalties, DMIRS	56	DMIRS
Resources Tenure, DMIRS	12	DMIRS
Ministerials	15	DMIRS
Departmental ‘other’	55	DMIRS
Companies and consultants	84	External
Academia and research entities	14	External
Other external entities	17	External
Individuals	26	External
Total	1025	

Products planned for 2016–17	Status
Major Resource Projects, Western Australia — 2017 (map)	Released
Mines – Operating and Under Development, Western Australia — 2017 (map)	Released
Iron Ore Deposits of the Pilbara Craton, 2017	Released
Significant Exploration Activity in Western Australia ('Hotspots' map update) – four updates during the year	General hotspot posters released July 2016, January 2017, June 2017. Special version (Li, Ta, graphite, REE, Zn, Co, U, zircon, and Ti–V) prepared for low emissions conference (October 2016)
Gemstones Bulletin (second edition)	Released
Investment Opportunity Flyers released for cobalt, copper, gold, graphite, lithium, nickel, potassioim, REE, vanadium, and zinc	Released
Manganese mineralization in the Pilbara Craton and Capricorn Orogen (digital product)	Released
Western Australian Atlas of Mineral Deposits and Petroleum Fields 2017 (A4 booklet)	Released
Western Australian Mineral Deposits and Petroleum Fields, 2017 (map)	Released

In addition to the products released, the CIA group provided hand-crafted sets of MINEDEX data on mines, deposits and prospects for inclusion on several published map sheets and assistance was also provided to external authors of manuscripts.

MINEDEX Developments

Several upgrades have been made to this database and application (which was launched in 2008) during 2016–17 to improve efficiency of data entry and data accessibility/extractability. The current version of MINEDEX is version 0.15.13.

The major data improvement project for the year was the MINEDEX–RMS integration project, which involved redesign of the Production Report forms used by the Royalties Management System (RMS) so that accurate mineral production data for all minerals could be collected for MINEDEX — with the long-term goal of users being able to undertake 'mineral endowment' calculations for all commodities by combining estimates

of mineral resources with mineral production; this will be a major enhancement in prospectivity assessments.

Prior to this project, only gold production data could be transferred routinely to MINEDEX. After this project is completed, all producers of minerals where royalty is calculated on an *ad valorem* basis will report production to the department by both site and tenement of origin, and with this done using allowable/controlled commodity units of measure. *Specific Rate* production data (gathered via Royalty Returns, not Production Returns) will be assigned to mine sites within MINEDEX by using database internal messaging. These changes will allow future production data for all commodities to be messaged from the royalties system (RMS) into MINEDEX. This project required a large amount of data clean-up in both MINEDEX and RMS. The project is due for completion in late 2017.

The CIA group also plans to change to a Geocortex-based data entry platform for the spatial component of MINEDEX; testing of this new system is continuing. MINEDEX spatial data are currently maintained by use of ArcEditor; the new solution is technically equivalent for MINEDEX purposes but considerably cheaper.

Planned work program and products 2017–18

Recurrent MINEDEX maintenance and regulatory activities will continue throughout 2017–18. The expected workload will be similar to that listed in the tables above for 2016–17 statistics on activities. Tracking of completed KPI and non-KPI tasks will continue according to internal procedures.

Once the new RMS Production Reports are live (expected late 2017) additional workload in the form of MINEDEX update requests will be expected (in the short term) as tenement holders contact the CIA section to ensure correct sites and tenements are available for lodging mineral production reports.

We are currently exploring the possibility of addressing compatibility issues between MINEDEX and modern web browsers more recent than Internet Explorer v.5, with a business analysis planned for 2017–18. This may initiate a redevelopment of the MINEDEX user interface during 2018–19.

The following table lists the planned products for 2017–18:

Products planned for release 2017–18

Major resource projects, Western Australia (map)

Mines – operating and under development, Western Australia (map)

Significant exploration activity in Western Australia ('hotspots' map poster)

Investment opportunity flyer updates and A1 maps for the following commodities: antimony, coal, chromium, cobalt, copper, diamond, garnet, gold, iron ore, lead, lithium, manganese, nickel, phosphate, potash, rare earth elements, titanium–zircon, tungsten, uranium, vanadium and zinc

Planned work program and products 2018–19 and beyond

As well as the usual products produced annually, other products are compiled only every two years, so are planned to be produced in 2018–19 but work will start on them in 2017–18. These include the iron ore deposits of the Pilbara (map and digital product), iron ore deposits of the Yilgarn (map), Western Australian atlas of mineral deposits (A4 booklet and wall map).

New products for 2018–19, once that the MINEDEX–RMS system is developed and installed, should include state-wide maps and datasets of mineral endowment, estimated mineral resources and cumulative historic production.

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

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

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 and successful. 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's 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 has been complemented by projects funded by the Exploration Incentive Scheme (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.

The section maintains a strong scientific capacity. It retains three of the geologists recruited via the GSWA Geology Masters (GeM) program (which provides Geology Honours graduates early professional development via completion of a Master's degree). Previous group member Lisa Roche resigned from GSWA in early 2017 to pursue professional development opportunities in the mineral exploration industry, but Dr Lee Hassan transferred back into the group in late 2016 to complete and publish some significant work on VMS systems, prior to her scheduled retirement in the latter part of 2017. Dr Lena Hancock continues to contribute her mineralogical expertise, and to manage and further develop the HyLogger facility (Project GS95). Dr Paul Duuring, recruited in early 2016, has considerably expanded the capacity and scope of the group for individual and team-based mineral systems studies, and is also a significant contributor to the continuing professional development of less-experienced team members. Dr Franco

Pirajno (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 2016–17

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 metallogenic interpretations, and also provide useful tools for targeting mineral deposits at all scales, thereby reducing the technical risk of discovery for resource companies.

VMS systems

The EIS-funded collaborative study of the VMS fertility of Yilgarn volcano-sedimentary successions was completed in late 2015. The results of the analysis of then-existing public domain data were published in GSWA Report 165 and in the journal *Precambrian Research* during 2016–17. Studies of the litho-geochemistry and geochronology of a number of under-represented terranes using newly collected data have also been compiled and are to be published in another GSWA Report in the coming year; some of the new work on the Nimbus, Teutonic Bore and King VMS deposits has also been published in *Precambrian Research* and presented at a variety of international conferences (see Appendix C and the work program for Project ES43).

Lee Hassan completed her study of variably deformed and metamorphosed Kingsley VMS deposits near Wheatley, in the South West Terrane of the Yilgarn Craton, and the GSWA Record describing this work will be published in early 2017–18. She also published in *Ore Geology Reviews* a short paper on tellurides occurring at the Yuinmery and Austin VMS deposits (see Appendix C). Studies of the geochemical and spectral footprints of metamorphosed and deformed VMS mineralization in the Quinns district of the Yilgarn Craton were published in the journal *Economic Geology*, and some of this work will also be published early in 2017–18 as a GSWA Report.

Representative diamond drillcore was acquired from one of the more significant deposits in the Manindi VMS 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 (described in GSWA Report 141).

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 group 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 a GSWA Report is being prepared describing the full details of the study. The age of the 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 commenced an examination of the metallogeny of the Paterson Orogen, using material available in the GSWA sample archive, obtained by collaborations with companies active in the region. Samples of buried basement rocks in the northern part of the Orogen have been collected for geochronological and petrochemical analyses, from core obtained by the EIS Co-funded Exploration Drilling program.

Lena Hancock and other GSWA and resource company colleagues completed the 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 came out of confidentiality in late 2015, and was published as GSWA Report in early 2016–17.

GSWA 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. Some results from this and similar, previously completed, studies were presented in August at the 35th International Geological Convention in Cape Town, South Africa.

Josh Guiliamse continued his systematic study of gold deposits in the Ashburton Basin, focussing primarily on the Mt Clement deposit, reviewing historical exploration data, field reconnaissance mapping and sampling of the local geology, logging and sampling of drillcore archived by GSWA, and petrographic and geochemical analysis of samples. Preliminary results were presented at the FUTORES-II conference in June 2017. This and subsequent work contributes 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.

The technical report authored by Trevor Beardsmore on the geology and metallogeny of the Agnew–Lawlers was published in early 2017 as GSWA Report 167, with the permission of the corporate owner of that report.

Nickel systems

Lauren Burley continued preparing her Master of Economic Geology dissertation on the Fisher East komatiite-hosted nickel mineralization for publication as a GSWA Report and as an article in *Ore Geology Reviews*. She is now undertaking a program of systematic, regional-scale sampling of lithostratigraphy and selected komatiite-hosted nickel sulfide systems adjacent to the boundaries between Kurnalpi, Burtville and Yamarna Terranes, as part of a larger collaborative project between GSWA, CSIRO and UWA, to understand the tectono-stratigraphic and metallogenic evolution of the far eastern Yilgarn Craton. She also began a study of the geochemical fertility of mafic volcano-plutonic rocks of the Warakurna Large Igneous Province for Ni–Cu–PGE mineralization, using targeted mapping and sampling of mafic intrusive rocks in the Edmund and Collier Basins, and petrological and litho-geochemical analyses.

Iron systems

The EIS-funded government–academia–industry collaborative study of BIF-hosted iron ore metallogeny in the Yilgarn Craton (part of Project ES43) was completed prior to project leader Paul Duuring joining GSWA in early 2016. Some of the results of mapping iron ore and associated alteration using spectral data from the HyLogging were published in 2016–17 as a series of GSWA Records. An overall synthesis is to be published as a GSWA Report and as a series of external publications. The study of Yilgarn iron ore systems is being extended with a program to obtain ages for hydrothermal iron mineralization, beginning with selected iron deposits in the Weld Range, Koolyanobbing and Windarling regions. Initial work during early 2017 focussed on SHRIMP U–Pb dating of cogenetic phosphates, using the facility at the John de Laeter Centre, Curtin University. A study on the physical–chemical characteristics and source of mineralizing fluids responsible for the Weld Range iron deposits has been submitted to the journal of Economic Geology.

The final report for the study of BIF-hosted iron ore metallogeny in the Pilbara Craton, completed by UWA–CET as part of MRIWA Project M426 (partly EIS co-funded), was released from confidentiality as GSWA co-badged Report 163.

Mineral Systems Atlas

In a significant new initiative, the section has commenced work to create an interactive, GIS-based Mineral Systems Atlas, which will deliver ‘mappable geological proxies’ for critical metallogenic processes, that are derived from systematic ‘mineral systems analyses’ of known or probable mineral systems in Western Australia. The mappable geological proxies are to be created from existing and enhanced or newly created public domain datasets, for use in GIS-based mineral prospectivity studies by mineral explorers. The Atlas will be engineered so that constituent ‘proxy layers’ are automatically updated whenever the underpinning databases are modified.

As part of a ‘proof of concept’ study, the Mineral Systems Studies group has defined mappable proxies for komatiite-hosted nickel systems, and commenced work to generate several high-priority geological proxies for this mineralization type. This early work has highlighted issues with access to, and content of, information in GSWA’s data holdings, prompting the group to initiate a review of all GSWA databases, with the goal of identifying and effecting improvements. Such improvements will include expanding the

information content of the MINEDEX database to include comprehensive published mineral deposit age data, which the Mineral Systems Studies section continued compiling throughout 2016–17.

GSWA also began developing 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 attended two training workshops provided by UWA–CET staff.

Other activities

Several members of the section are co-authoring papers on the Fisher East nickel deposits, Yilgarn and Pilbara iron deposits, and the metallogeny of the Paterson Orogen, that will be included in the ‘Australian Ore Deposits’ monograph to be published by the Australasian Institute of Mining and Metallurgy.

The section also continued to manage or monitor a number of other minerals-oriented research initiatives funded by GSWA’s Exploration Incentive Scheme (refer to the work programs for Projects ES43 and ES50). This included supervision of a study by UWA MSc student Henry Roll on the nature of gold mineralization at the Coyote gold deposit. This project included the logging and sampling of drillcore archived by GSWA and the interpretation of associated spectral data. The resulting thesis will be published as a GSWA Record.

<i>Products scheduled for release in 2016–17</i>	<i>Current status</i>
Report 163 MRIWA Report Project M426: exploration targeting for BIF-hosted Fe deposits in the Pilbara Craton, Western Australia	Published
Report 167 The geology, tectonic evolution and gold mineralization of the Lawlers region: A synopsis of knowledge to 2001 (authorized release of Company Technical Report)	Published
Record 2016/13 13 th International Ni–Cu–PGE Symposium, Fremantle, Australia, Abstracts, p.16, The Fisher East nickel sulfide prospects	Published
Record 2016/14 Mineralogy of gold from the Paulsens and Mount Olympus deposits, northern Capricorn	Published
Record 2016/16 Mapping iron ore and alteration patterns BIF using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia	Published
Record 2016/17 Mapping iron ore and alteration patterns in BIF using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia	Published
Record 2016/18 Mapping iron ore and alteration patterns in BIF using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia	Published

Record 2016/19 Mapping iron ore and alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia	Published
Record 2017/2 GSWA Open Day 2017 Extended Abstracts, p. 1–3, Tools for discovering BIF-hosted iron ore deposits in the Pilbara Craton	Published
Record 2017/6 TARGET 2017, Perth, Australia, Abstracts, p.18–19, Creating exploration tools from data and knowledge: an example using a mineral systems analysis of nickel-sulfide prospectivity for the Eastern Goldfields Superterrane	Published
Geological setting and nature of nickel mineralization at Fisher East, NE Yilgarn Craton (provisional title; based on MEconGeol dissertation) (Report)	In preparation
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
Alteration and age of the Browns Range heavy rare earth elements deposits (Report)	In preparation
External publications — see Appendix C	Published

Planned work program and products 2017–18

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 and nature of mineralizing fluids for 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.

Work in 2017–18 on VMS systems will involve further field and laboratory studies of the geological settings and metallogeny of deposits at the Manindi camp.

Ongoing studies of REE systems will include field geological mapping and sampling, and laboratory studies of fluid inclusions and alteration at the John Galt deposit, to place constraints on the physical and chemical condition of mineralization. The group will also embrace any opportunities that arise for industry-collaborative metallogenic studies of other REE deposit types in Western Australia.

Also continuing during 2017–18 is the collaborative pilot study of gold prospectivity for the Kurnalpi region using gold nugget morphology, geochemistry and regolith setting. Work during the early part of the year will focus on establishing the depositional context(s) of the gold nuggets with respect to regolith evolution. At least one GSWA Report will be published describing the results of the pilot study, and the Mineral Systems group will also co-author a publication describing the newly developed methodology for quantitative trace-element analysis of gold grains. Studies of gold provenance and prospectivity using “alluvial” nuggets will be expanded to other districts and terranes, pending negotiation of projects and sourcing of suitable sample material.

The study of the Mt Clement gold deposit will be completed and the results published, following which there will be reconnaissance mapping, sampling and laboratory studies of less well documented deposits in the region, to further the larger study of the metallogeny of the Ashburton Basin. The metallogenic analysis of the Paterson Orogen will continue, and include targeted, field-based logging and sampling of drillcore from significant domains, arranged where necessary via newly developed government–industry collaborative projects.

Field mapping and sampling, and petrological and lithogeochemical studies will be completed for the mafic Warakurna large igneous province, its Cu–Ni–PGE prospectivity assessed, and the results published. The study of regional nickel prospectivity of the eastern Yilgarn Craton will also continue, within the context of the larger GSWA–CSIRO–UWA collaborative project to understand the tectonostratigraphic evolution of that region.

The group will investigate the prospects for developing a technique for direct dating of iron-oxide minerals, that includes a collaborative, GSWA–MRIWA–industry-funded project to develop matrix-matched standards for geochronological analyses of hydrothermal iron oxides.

Development of the Mineral Systems Atlas will also continue. The group will finish constructing several significant geological proxy layers for komatiite-hosted nickel systems, and will undertake systematic analyses of gold and iron mineral systems to define mappable geological proxies for critical metallogenic processes, assisted where

possible by subject matter experts in other organisations. Design work will also begin on the interactive, digital Mineral Systems Atlas that will deliver the ‘proxy’ datasets.

Development work will begin on a Mineral Deposit Explanatory Notes System.

The Mineral Systems Studies section will continue to manage or monitor — and where relevant be involved with — other collaborative minerals-oriented research initiatives being funded by GSWA.

GSWA Products planned for release 2017–18

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

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

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

The significance of the Mount Clement gold deposit for metallogeny in the Ashburton Basin (Report)

Provenance fingerprinting of gold from the Kurnalpi Goldfield (Report)

Controls on hydrothermal alterations and gold mineralisation at Coyote deposit, Western Australia. Roll, H 2017, MSc thesis, University of Western Australia, 44 p. (Record)

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

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

Origin of rare earth element mineralization at the John Galt prospect, East Kimberley (Report)

SHRIMP U–Pb dating of xenotime from the Wolverine and John Galt REE desopits (Geochronology Records)

Planned work program, products 2018–19 and beyond

The Mineral Systems Studies group will continue examining significant Western Australian mineral systems. This work will be done in close collaboration with GSWA’s regional mapping section, and as appropriate with other government and 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 GSWA. The group will continue to lead the development of mappable Mineral System ‘proxies’, and a digital Mineral Systems Atlas to deliver these products,

as well as advance the concept of a 'Minerals' layer to the statewide Explanatory Notes System. Future products may include targeted prospectivity studies.

GS43 Geochemistry and Regolith

Manager: Paul Morris

Team members: Nadir de Souza Kovacs, Sara Jakica

The geochemistry of rocks and regolith, and the mapping of the distribution of different regolith types are data integral to an increasing number of geoscience studies throughout GSWA, as well as forming the basis of regional regolith geochemistry programs. This growth in the use of geochemistry reflects in part the refinement of analytical processes related to litho-geochemistry (enabling more precise and accurate analysis of a wide range of elements at low concentrations), the reduced per-sample analytical costs, and the shortened turnaround time. More sophisticated regolith mapping has resulted from the increasing availability and quality of satellite imagery (e.g. ASTER), and geophysical data attuned to near-surface cover (e.g. AEM). Algorithms for simplification of map layers reduce the level of subjectivity in onscreen digital mapping, and provide quantitative data on the distribution of different regolith types.

Several factors make geochemical data attractive to a wide range of users. These include: acquiring sufficient quality control data throughout the preparation and analysis procedure to determine if data are fit-for-purpose; analysing for a wide range of elements, thus catering for a wide customer base; and storing and making available data in a set format using easy-to-use software tools. GSWA has addressed these issues by acquiring data from laboratories selected by tender using rigorous criteria. Having a number of such suppliers means that analytical programs can be tailored to the sample media and the program outcomes. Data quality are checked by inclusion of 10% quality control samples by the provider, with a further 10% inserted 'blind' by GSWA. Each sample is analysed for between 55 and 64 elements. Data are stored in GSWA's corporate WACHEM database, which includes records of laboratory-related analytical techniques, sample duplicates, analyses of reference materials and analytical blanks. These data are linked daily to the sample's metadata in the WAROX database, and made available on GeoVIEW.WA. At the end of June 2017, The WACHEM database held over 54 000 analyses, of which over 6 800 (12.6%) were data for reference material or analytical blanks, and 3.9% were analyses of sample duplicates. The lower than expected number of duplicates reflects the incorporation of legacy data (generated by the Chemistry Centre of

WA), which lacked these QC data. Legacy data loading in 2008 accounted for over 10 000 samples, whereas peaks in 2012 and 2016 reflect loading of data from GSWA's regional regolith geochemistry programs, and litho-geochemistry programs carried out in the Albany–Fraser Orogen and Eastern Goldfields respectively (Fig. 28).

Regolith mapping is carried out by both members of the Geochemistry and Regolith group, and by GSWA mapping geologists. These users are catered for by a scale-independent regolith-landform classification scheme applicable regardless of geological terrain. This is complemented by a documented approach to regolith mapping which explains the use of geophysical and remotely sensed data, orthophotos, existing geological mapping, and point observations from GSWA's WAROX database in the compilation of maps.

Outcomes of work program 2016–17

In order to make geochemistry data more accessible, GSWA embarked on a program to centralise geochemical data regardless of origin, and ultimately acquire a software application that would permit flexible searching capabilities of these combined data. In late June 2017, the capabilities of the WACHEM database were expanded to store non-GSWA data, in particular data from CSIRO and tertiary institutions.

With GSWA's regolith geochemistry programs focussing on greenfields terrains, there has been a need to investigate what sort of sample media can provide some 'vision' through cover bedrock, and potential bedrock-hosted mineralization. In desert terrains dominated by eolian deposits, the fine (silt and clay) fraction of regolith has proven useful as a multi-element sample medium, especially when combined with a partial extraction approach during analysis. Recently, GSWA investigated the potential of biogeochemistry, specifically the chemistry of spinifex to detect abnormal fluid fluxes over regional faults, and whether this chemistry is indicative of fluids migrating from bedrock mineralization. The combined fine fraction and spinifex chemistry data from the Ngururpa area of northeastern Western Australia shows promise.

The 2D regolith-landform mapping is now being augmented by extension into 3D and 4D space. Since 2011, GSWA demonstrated the application of single-station passive seismic to provide estimates of shallow cover, with published case studies from the eastern

Yilgarn Craton and Eucla basin. The use of this technology is being further extended by purchase of four more recording devices, capable of providing an array coverage. Current work with CSIRO aims to integrate the passive seismic approach with regional AEM data captured over the Capricorn Orogen.

In conjunction with the John de Laeter Centre at Curtin University, GSWA embarked on a program of (U–Th)/He dating of ferruginous duricrust in mid–late 2016. This is a pilot program to determine, initially on a statewide scale, if the age of this material varies significantly. With increasing analytical sophistication, it is hoped that these data will become a routine part of GSWA’s regolith program.

Planned work program and products 2017–18

- Ongoing evaluation of new analytical techniques, including both laboratory-based and portable techniques
- Continued population of the WACHEM database
- GSWA record on the (U–Th)/He dating of duricrust
- First edition of 1:500 000 scale State regolith map
- Record on methodology for compilation of State regolith map

GS45 Pilbara Craton

Manager: Arthur Hickman

Team: GSWA staff as required

The Pilbara Craton provides Australia's best preserved geological record of Eoarchean to Mesoproterozoic crustal evolution. It also includes several of the world's oldest examples of various styles of mineralization, revealing how these varied with tectonic setting.

Paleoproterozoic metasedimentary rocks in the east Pilbara provide exceptionally good fossil evidence of early life on Earth and, with the recognition of distal impact ejecta layers, reveal that Earth experienced two major asteroid impact events at 3470 and 3460 Ma.

Although the craton underlies approximately 400 000 km² of northwestern Australia its total exposure is less than 70 000 km², and almost 90% of this is located in the northern Pilbara. Between 1995 and 2005 this northern part of the craton, 60 000 km² in area, was the subject of a collaborative mapping project between GSWA and Geoscience Australia. The project was established to clarify the tectonic evolution of the granite–greenstone terranes in the northern Pilbara, and how this evolution influenced mineralization. The 1995–2005 phase of the project enabled the release of 30 new 1:100 000-scale geological maps and seven revised 1:250 000-scale maps. From 2005 onwards data from the project continued to be released through additional maps, reports, and digital products.

The Pilbara mapping project resulted in a major revision of the stratigraphy, structure, and crustal evolution of the northern Pilbara Craton, with important implications for its mineral potential. Extensive geochronology established that the east Pilbara exposes the oldest granite–greenstone terrane of the craton, named the East Pilbara Terrane. Repeated volcanic cycles and contemporaneous intrusion of granites over 310 Ma (3530–3220 Ma) constructed this terrane in the form of an extensive volcanic plateau overlying older crust. Isotopic data reveal that the older crust included widespread felsic igneous rocks, mainly 3680–3550 Ma, that were derived from partial melting of substantially older mafic crust. The tectonic evolution of the East Pilbara Terrane was dominated by vertical tectonic processes instead of horizontal crustal growth and recycling that are typical of Phanerozoic-style plate-tectonic processes. Episodic vertical crustal growth and reworking in the East Pilbara Terrane explains its present dome-and-keel crustal

architecture, which has no Phanerozoic analogues. This provides an explanation for the rarity of large mineral deposits in the east Pilbara Terrane because fluid sources were more restricted than in plate-tectonic settings such as magmatic arcs above subduction zones.

The crustal evolution of the Pilbara Craton experienced a fundamental change at c. 3200 Ma, when the 300 Ma continental volcanism and vertical deformation of the East Pilbara Terrane was abruptly replaced by rifting, continental breakup, and the commencement of plate-tectonic processes. Only post-3200 Ma successions of the craton contain mineralization formed by plate-tectonic processes, and it is these processes that produced the largest mineral deposits.

Mineralization in the Pilbara Craton is extremely diverse and spans 650 Ma, from the 3480–3460 Ma VMS deposits of the Dresser and Duffer Formations (Warrawoona Group) to 2850–2830 Ma rare-metal pegmatites of the Split Rock Supersuite. The most economically important mineral commodity has been iron ore, with total historical production in excess of 300 Mt. Iron ore deposits are enriched Mesoarchean banded iron formations in the Gorge Creek and Soanesville Groups. Gold and copper mineralization is present throughout the East Pilbara Terrane but all the deposits are relatively small. Larger gold deposits are located along shear zones within late Mesoarchean sedimentary basins (Mosquito Creek and Mallina), but individual deposits are nevertheless small by Australian standards. Tin and tantalum have long been mined from pegmatites and secondary alluvial deposits but the current exploration focus is mainly on lithium. Current Pilbara resources of 3.9 Mt Li₂O comprise approximately 40% of the state's total resources.

Project work is currently focused on completion of a detailed geological Report on the east Pilbara Craton and on fully populating the ENS database for the northern Pilbara.

Outcomes of work program 2016–17

A geological Report describing a study of new zircon Lu–Hf and whole-rock Sm–Nd isotope data from the Mount Edgar Dome (East Pilbara Terrane) was written and will be released in 2017–18. The study, undertaken jointly with Curtin University, concluded that the Paleoarchean magmatic events in the East Pilbara Terrane, from 3460 to 3220 Ma,

mainly involved reworking of existing crust as opposed to addition of new juvenile material. Such crustal recycling is consistent with the volcanic plateau tectonic model and inconsistent with Phanerozoic-style subduction. A geological Report reviewing the Eo–Mesoarchean crustal evolution of the east Pilbara Craton was partly written, and will be completed in 2017–18. This Report includes a compilation of all available geochronological data on the east Pilbara and uses these data to supplement previously published information on crustal evolution. Contributions were made to five external papers, two being published in 2016–17 and three being submitted to publishers. Additions were made to the ENS database during work on the GSWA Reports.

Products released 2016–17

External publication: Lithostratigraphy and structure of the early Archean Doolena Gap greenstone belt (Precambrian Research)

External publication: Processes of crust formation in the early Earth imaged through Hf isotopes (Precambrian Research)

Planned work program and products 2017–18

The geological Report on the Eo–Mesoarchean geology of the east Pilbara Craton will be completed and released. Following completion of this Report, work will commence on writing up existing geological, geophysical, and geochemical information acquired from, and in association with, GSWA 2012 drilling of the Hickman Impact Crater. This will eventually be released in a GSWA Report. Further contributions will be made, as required, to the special volume ‘Archean, building the core of a continent’ (Western Australia unearthed series). Additional entries will be made to the ENS database, and journal papers will result from collaboration with a number of external workers.

Products planned for release 2017–18

East Pilbara Craton: a billion year record of Eoarchean, Paleoarchean, and Mesoarchean crustal evolution (Report 143)

Hf insights from the Mount Edgar Dome (Report)

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

External publication: Taking the pulse of the early Earth (Nature Geoscience)

External publication: SIMS microanalysis of the Strelley Pool Formation (Precambrian Research)

External publication: Pilbara Craton: Geology and metallogeny (Aus IMM monograph)

Planned work program and products beyond 2018

Work beyond 2017–18 will include completion of the Pilbara component of the ENS database and release of the digitally generated Explanatory Notes. A geological Report on the Hickman Impact Crater will compile and interpret all existing information from GSWA drilling (2012), a GSWA low-level airborne geophysical survey, and geochemistry of meteorite fragments and melt glass.

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 are 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, including the role of crustal differentiation processes and the thermal drivers of intracratonic orogeny, which lasted for well over one billion years. Other advances include the precise dating of numerous ore deposits in the Province (as well as the Capricorn Orogen) and the link between mineralization, hydrothermal fluid flow to major crustal structures and regional-scale orogenic events.

Outcomes of work program 2016–17

Personnel issues have affected the work program during 2016–17, with the manager having spent more than eighteen months acting in the Chief Geoscientist position (GS53). However, time has been spent compiling the geology of 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). Several external publications were released throughout the year, which highlight the role of crustal differentiation, the timing of mineralization across the Province, and the drivers of intracratonic orogeny.

Collaboration with Professor Birger Rasmussen at Curtin University has continued under an ARC Linkage grant. A significant proportion of time was spent supervising two PhD students as well as providing advice and working closely with various researchers in the UNCOVER Australia: Capricorn Distal Footprints project, which have resulted in the submission of several co-authored external journal publications.

Products released 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*

Crustal differentiation in the Proterozoic Capricorn Orogen (Report 168)

Two external publications that highlight the link between mineralization and regional-scale orogenesis

Two external publications that highlight crustal differentiation processes and the drivers of intracratonic orogeny

Planned work program and products 2017–18

Most of 2017–18 will be focused on supervising the two PhD students associated with the collaborative ARC Linkage project with Professor Birger Rasmussen. Both student projects are scheduled for completion at 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, as well as the thermal drivers of intracratonic orogeny across the Province. The results will be released as several Open Access external journal publications.

Products planned for release 2017–18

Final update of the Western Capricorn Geological Information Series 2018 (including UAROO and WONYULGUNNA* 1:100 000 Geological Series maps; digital product), including updated digital Explanatory Notes for the Gascoyne Province, Edmund and Collier, Wyloo, Shingle Creek and Turee Creek Groups

Three of four ‘Open Access’ external journal publications resulting from PhD student work

Release of a Capricorn Orogen project web page on the DMIRS site that summarizes the geology of the Gascoyne Province and Edmund and Collier Basins (GS49)

* EIS product

Planned work program, products 2018–19 and beyond

No work is planned for the 2018–19 financial year. However, both student theses will be released as GSWA Reports.

Products planned for release 2018–19

Two student PhD theses released as GSWA Reports

GS49 Edmund and Collier Basins and Eastern Capricorn Basins

Manager: Simon Johnson

From July 2017 and with the completion of 1:100 000-scale mapping of the Edmund and Collier Basins, the GS49 project will 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 VMS-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 2016–17

The 2016–17 work program has focused on compiling Edmund and Collier Group rocks on the UAROO and WONYULGUNNA 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 Irregularly 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 Record early in the 2017–18 financial year.

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 931–799 Ma fault movements (the Kuparr Tectonic Event).

The compilation of legacy data (aerial photographs, field notebooks and samples) for the Eastern Capricorn Basins project continued to gain pace during the latter part of the financial year.

Products released 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, ERRABIDDY, MARQUIS, CALYIE, TANGADEE, MOUNT EGERTON, MULGUL, MILGUN, TEANO, ELLIOTT CREEK, ULLAWARRA, CAPRICORN, EDMUND, MANGAROO, MAROONAH, MOUNT VERNON, JAMINDI, THREE RIVERS, CARDAWAN, UAROO, TOWERA, LYNDON, LOFTY RANGE, and ILGARARI 1:100 000 Geological Series maps

* EIS product

Planned work program and products 2017–18

Work during 2017–18 will continue on the compilation of legacy data (aerial photographs, field notebooks and samples) for the Eastern Capricorn Basins project and work will begin on the construction of seamless 1:250 000-scale digital geology layers with the progressive release of 1:250 000-scale mapping tiles (e.g. (NABBERU, STANLEY, PEAK HILL) as digital layers on the Eastern Capricorn Geological Information Series digital product. Work will continue on the K–Ar geochronology of fault gouges, in collaboration with Professor Zwingmann of Kyoto University, and Dr Tonguc Uysal and Andrew Todd of CSIRO. This work will focus on the Eastern Capricorn Basins, and potential correlation with abundant mineralization will be investigated.

Products for release 2017–18

Final update of the Western Capricorn Geological Information Series 2018 (including UAROO and WONYULGUNNA* 1:100 000 Geological Series maps; digital product), including updated digital Explanatory Notes for the Edmund and Collier Basins, Gascoyne Province, Wyloo, Shingle Creek and Turee Creek Groups

Recognition of a new Mesoproterozoic mafic intrusive event in the Capricorn Orogen* (Record)

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

‘Open Access’ external journal publication on the K–Ar dating of fault rocks in the Edmund and Collier Basins

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

* EIS product

Planned work program, products 2018–19 and beyond

Work during 2018–19 will focus on the continued compilation of legacy data (aerial photographs, field notebooks and samples) of the Eastern Capricorn Basins, and the progressive release of 1:250 000-scale mapping tiles as digital layers on the Eastern Capricorn Geological Information Series digital product. Work will also focus on the writing and update of explanatory notes for the Eastern Capricorn Basins. Reports or ‘Open Access’ external journal articles will be released on the continuing K–Ar dating of faults throughout the Capricorn Orogen.

Products planned for release 2018–19

Ongoing compilation of legacy data (aerial photographs, field notebooks, and samples) for the Padbury, Bryah, Yerrida and Earraheedy Basins*

Eastern Capricorn Geological Information Series 2019 including at least one 1:250 000 mapping tile (NABBERU)* and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earraheedy Basins)*

One or more ‘Open Access’ external journal publication on the K–Ar dating of faults in the Eastern Capricorn Basins

* EIS product

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Hugh Smithies

Team members: Matt de Paoli, Jyotindra Sapkota, Melissa Drummond, Stephen Wyche

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 2016–17

New mapping and integration of data and stratigraphic information have been applied to the East Yilgarn GIS north of Kalgoorlie–Boulder in the Menzies and Davyhurst regions. The new 1:100 000-scale interpretation of this area has been released. Explanatory Notes (ENS database) have been completed and published for the Menzies and Leonora areas.

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 Open Day in November included a series of talks, workshops and core displays that attracted more than 100 members of the local geological community.

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 2016–17

East Yilgarn Geological Information Series 2017 update

Eastern Goldfields komatiites and nickel deposits excursion guide (GSWA Record 2016/12)

Abstracts volume for the 13th International Ni–Cu–PGE Symposium (GSWA Record 2016/13)

Abstracts volume for the TARGET 2017 conference (GSWA Record 2017/6)

Planned work program and products 2017–18

The ongoing revision of the East Yilgarn GIS to incorporate the new structural and stratigraphic framework will continue. In 2017–18, new geological interpretation will focus on the region between Kalgoorlie and Norseman, and the greenstones west of Menzies between Davyhurst and Mount Ida. Explanatory Notes coverage will include parts of the Kalgoorlie–Kambalda 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.

GSWA will also collaborate with Professor Ray Cass of CODES (University of Tasmania) to study the geological setting of the Golden Mile Dolerite at Kalgoorlie.

Products planned for release 2017–18

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

Towards a geochemical barcode for the Eastern Goldfields (GSWA Record)

External publications relating to work program where appropriate

Yilgarn portal for DMIRS website (East Yilgarn)

Planned work program, products 2018–19 and beyond

Beyond 2017–18, 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. Comprehensive GIS databases including metamorphic and non-GSWA geochronological data covering the Yilgarn Craton are also in preparation.

Products planned for release 2018–19

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

Yilgarn metamorphism GIS layer

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, Huntly Cutten, Olga Blay

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. Explanatory Notes System (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 2016–17

The continued update and release of State geoscience data layers were a high priority during 2016–17. Work concentrated on updating the 1:500 000 tectonic units layer and work has begun on the construction of a seamless 1:500 000 State regolith layer. The section continued populating the data entry module of ENS with the publication of 101 new lithostratigraphic units and updates to 53 units, bringing the total number of

published lithostratigraphic units to 793. The GSWA field and rock observation database (WAROX) was released for the first time as a statewide dataset, with annual updates scheduled for the end of each field season. It contains ~ 240 000 field observations, ~ 65 000 structural measurements, ~ 50 000 field photographs and sketches, as well as regolith and landform information, sample location data and petrographic descriptions.

The third part in the concise Geology of Western Australia (WA Unearthed) series ‘A Palaeozoic perspective of Western Australia’ was published, while work on the Archean part is now underway. Several geotourism products were released including virtual tours of the State’s meteorite impact structures and the mafic–ultramafic intrusions of the Youanmi Terrane of the Yilgarn Craton, as well as the release of the ‘Stepping Stones’ walking tour via the smartphone app ‘Everythere’.

The section is responsible for GSWA content of department webpages: it routinely supervises content updates and the creation of new pages, coordinated the half-yearly revision of all GSWA pages, and assisted the transition from the DMP to the new DMIRS website.

Products released 2016–17

Compilation of WAROX (field observation and rock database) data, 2017 (statewide data release)

Update to the 1:500 000 tectonic units layer

Extended ENS content over existing and new geological provinces

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

Geotourism virtual tour of State meteorite impact structures

Virtual tour of the mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton

Release of ‘Stepping Stones’ geotourism tour on the smartphone app ‘Everythere’

Planned work program and products 2017–18

Work during 2017–18 will focus on the update of our online data delivery systems and on progress towards the addition of key data layers to GeoVIEW.WA such as project-specific seamless 1:100 000-scale geology polygons, linear structure and geology, and regolith–landform layers. Updates are also planned to the 1:500 000 orogenic events layer

to ensure consistency with the newly updated 1:500 000 tectonic units layer. 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 2017–18 will be to finish the 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 continue on the development of a State metamorphic map (at various scales) due for delivery in mid 2018–19.

Population of ENS and WAROX, monitoring of the style and quality of GSWA geoscience, and overseeing GSWA database capture and validation will continue. Work on the completion and testing of a regolith module for the Explanatory Notes System will continue with release expected in 2018.

Work will continue on the fourth (Mesozoic) and fifth (Archean) parts of the concise Geology of Western Australia (WA Unearthed). Work will continue on the compilation and publication of Explanatory Notes for State impact structures and associated lithostratigraphic units. Several geotourism products are planned including a popular-geology book on Kalbarri and a fact sheet on Kennedy Range.

Products planned for release 2017–18

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

Compilation of WAROX data, 2018 update

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

Update of 1:500 000 orogenic events layer

Release of a regolith–landform module for ENS

Extended ENS content (including regolith) over existing and new geological provinces

Explanatory Notes for State impact structures and associated lithostratigraphic units

Popular-geology book on Kalbarri

Popular-geology fact sheet on Kennedy Range

Planned work program, products 2018–19 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.

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) are 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 tectonothermal 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 an understanding of the prospectivity of the State.

The sensitive high-resolution ion microprobes (SHRIMPs) in the John de Laeter Centre at Curtin University are used extensively by GSWA for U–Pb dating. GSWA also dates detrital zircons using laser-ablation inductively coupled mass spectrometers (LA-ICPMS) in the John de Laeter Centre, which allow very 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 Geochronology and Isotope Geology 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 also 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 2016–17

About 100 rock samples were processed for U–Pb geochronology by GSWA’s laboratory, and 67 were analysed up to 26 May 2017 by GSWA geochronologists using the SHRIMP facilities at Curtin University. Figure 29 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 Province, the Yilgarn Craton (Youanmi and South West Terranes, and Eastern Goldfields region), the Albany–Fraser, Capricorn, and Pinjarra Orogens, the Kimberley region, the Edmund Basin, and in basement rocks beneath the Canning Basin. Results are published as Geochronology Records, 89 of which were published during 2016–17. Some of the achievements for 2016–17 are outlined below.

In the Capricorn Orogen, new SHRIMP U–Pb geochronology was conducted on granites, mafic igneous rocks, and supracrustal rocks in granite–greenstone basement rocks of the Wyloo, Rocklea, and Sylvania Inliers. The results in all three inliers indicate major felsic magmatic events at c. 3.2 and 2.9 Ga, and inheritance of 3.5–3.3 Ga zircons. Detrital zircon ages for quartzite in the Sylvania Inlier indicate significant components at c. 3611, 3574, and 3516 Ma. Analysis of Lu–Hf and oxygen isotopes (as part of project ES46) in zircons from the basement inliers will elucidate the origins of these rocks and explore links with other regions, such as the East Pilbara Terrane. Additional geochronology will be conducted in conjunction with Fortescue Group and Hamersley Basin project GS63.

Geochronology of detrital zircons from the Lamboo Province has prompted a re-examination of geodynamic models for the region. Existing models invoke collision of the Kimberley Craton with the proto-North Australian Craton at 1832–1808 Ma, possibly involving an intervening oceanic arc. However, remarkably similar zircon age spectra across the Lamboo Province at 1870–1855 Ma are difficult to reconcile with exotic terranes separated by ocean basins. Instead, the new data suggest the North Australian Craton was largely assembled prior to c. 1870 Ma.

The Geochronology and Isotope Geology Section continues to provide sample materials and/or analytical and laboratory support to several PhD and MSc projects at Curtin University and the University of Western Australia that are conducted in areas of interest to GSWA. These projects include: 1). geological evolution of the northern Capricorn

Orogen, 2). geological evolution of the northern Gascoyne Province, 3). facies characterization and provenance of the Yarragadee aquifer, and 4). precise timing of Cu–Mo–Ag–Au mineralization in the South West Terrane.

Products released 2016–17

Compilation of geochronology information, 2017 (includes 89 new Geochronology Records on USB)

Report 164 Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia

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

Extended abstract Mafic dyke swarms and large igneous provinces in Western Australia get a digital makeover: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract In situ phosphate dating of orogenic gold mineralization at Paulsens mine, southern Pilbara: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract Revised tectono-stratigraphy of the Kimberley Basin, northern Western Australia: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract Post-Giles Event evolution of the Musgrave Province constrained by (multi-method) thermochronology: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Twelve external journal articles and 11 conference abstracts (see Appendix C)

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

Planned work program and products 2017–18

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.

A new one-year project will employ Ar/Ar geochronology of pyroxene to date mafic igneous rocks that could not be dated using U–Pb zircon or baddeleyite geochronology. This study is made feasible by new analytical instrumentation (Argus VI mass spectrometer) in the WA Argon Isotope Facility of the John de Laeter Centre at Curtin University, which permits precise analysis of minerals that contain only trace amounts of potassium. The project will demonstrate the technique by analysing several mafic samples that have been dated previously by U–Pb methods, and then apply the technique to date samples that could not be analysed by other methods.

Products planned for release 2017–18

Compilation of geochronology information, 2018

External journal articles and contributions to GSWA publications

Planned work program and products 2018–19 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 2018–19

Compilation of geochronology information, 2019

External journal articles and contributions to GSWA publications

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 2016–17

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.

The MAGIX data repository of company airborne survey data continued to grow. During 2016–17, 65 new company airborne survey datasets containing about 302 000 line-km of data were received for inclusion in the repository. At 30 June 2017, the MAGIX repository contained some 9.5 million line-km of company data from 2283 surveys. Open-file datasets are available for download via the department's GeoVIEW.WA online system.

Planned work program, products 2017–18 and beyond

The planned work program for 2017–18 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 member: Christopher Phillips

The North Australian Craton comprises most of the northern part of the Australian continent and incorporates a complex assemblage of terranes, basins and igneous provinces that range in age from Neoproterozoic to Phanerozoic. The craton is host to numerous 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–Cu (Sally Malay), Fe (Koolan Island) and V (Speewah). In Western Australia, the craton comprises Paleoproterozoic rocks exposed in the Kimberley, west Tanami, and west Arunta regions, which are overlain by sedimentary rocks of the Neoproterozoic Centralian Superbasin and the Phanerozoic Canning, Ord and southern Bonaparte Basins.

In the Kimberley region – which forms a focus area for the project – metasedimentary and meta-igneous rocks of the 1912–1788 Ma Lamboo Province are exposed along the upthrust margins of the overlying Kimberley Basin. The Lamboo Province has been subdivided into the King Leopold Orogen, which forms a northwesterly trending belt to the south of the Kimberley Basin and the Halls Creek Orogen, which forms a northeasterly trending belt to the east. The Lamboo Province records a complex history of sedimentation, magmatism and deformation that has been interpreted to reflect collision of the Kimberley Craton with the proto-North Australian Craton. The 1835–1740 Ma Kimberley Basin comprises an extensive shallow marine to fluvial sedimentary basin that extends across the Lamboo Province and possibly has correlatives in isolated sedimentary outliers around the margins of the basin. Extensive mafic intrusive and volcanic rocks within the basin comprise the c. 1795 Ma Hart–Carson Large Igneous Province. These rocks are overlain by sedimentary successions of Meso–Neoproterozoic age that include the Carr Boyd, Birrindudu and Louisa Basins.

Second edition 1:250 000 Geological Series mapping programs in 1986–1989 and 1990–1995 were focused on the King Leopold and Halls Creek Orogens, and were accompanied by SHRIMP U–Pb zircon geochronology and extensive whole-rock geochemistry, in

collaboration with AGSO (now Geoscience Australia). The current work program is expanding the coverage of second edition 1:250 000 Geological Series mapping, with the aim of delivering seamless coverage across the Kimberley region. Production of 1:100 000 Geological Series maps previously focused on the Halls Creek Orogen during the 1990–1995 mapping program, and has recently been extended into the King Leopold Orogen during the current work program. Targeted studies examining aspects of the geology of the Kimberley region have accompanied the geological mapping. These include dating of sedimentary units, igneous suites and tectonothermal events, geochemical and isotope studies of magmatism, and the studies of the sedimentology and volcanology of basin successions.

Current work includes progressive extension of the 1:250 000 Geological Series mapping, a project examining the age, character and correlations of Paleo–Neoproterozoic sedimentary basin outliers, and a study evaluating geodynamic models of the Paleoproterozoic development of the Lamboo Province.

Outcomes of work program 2016–17

The work program for 2016–17 involved the publication of a report on the geology of the eastern zone of the Lamboo Province, with the report drawing together work from GSWA, Geoscience Australia, Curtin University and the University of Western Australia. This report documents the sedimentology, geochronology, isotope characteristics and geochemistry of metasedimentary and igneous rocks in the eastern part of the Halls Creek Orogen. The study defines a robust time–event framework for the eastern zone, forming a key reference point against which other similarly aged successions in the North Australian Craton can be compared.

A 2017 Kimberley Geological Information Series digital data package was also released, which includes new images of airborne gravity data flown over the east Kimberley in 2016, regolith mapping and geochemical data for the Dambimangari area of the west Kimberley, and updates to GSWA databases.

A study of the pressure–temperature–time (P–T–t) evolution of the King Leopold Orogen was commenced in 2016–17, in order to better constrain the development of this understudied orogenic belt. This involved the collation of existing samples from the

GSWA sample collection, preparation and description of polished thin sections and initial calculations of metamorphic conditions based on microprobe data. This study is continuing, and will include dating of in situ monazite to provide time constraints on metamorphism, as well as analysis of $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology data recently obtained from the orogen.

Fieldwork was carried out in the eastern Kimberley in 2016, which included helicopter-supported sampling as part of a broader study of previously undated sedimentary outliers. A suite of samples were collected that will allow for more robust correlations between these units and other basins in the region. Sampling was also carried out to better constrain the spatial and temporal evolution of granitic rocks of the 1832–1808 Ma Sally Downs Supersuite, which are currently interpreted to have formed in an arc setting during continental collision.

Work during 2016–17 also involved the collection of geochronology and Lu–Hf isotope data for metasedimentary units within the western and central zones of the Lamboo Province to test current geodynamic models that consider these terranes to be exotic to the North Australian Craton. A study of the geochemistry and isotope compositions of granitic rocks of the Sally Downs Supersuite also commenced, which involves analysis of samples collected during the 2015 and 2016 field seasons, as well as re-analysis of samples collected during previous mapping to ensure assembly of a consistent geochemical dataset for the Halls Creek Orogen having a full suite of trace element data. Sm–Nd isotope data are also being collected as part of this study to assess the nature of the source rocks for this magmatism.

Initial U–Pb geochronology data were received as part of a program of LA-ICPMS dating of detrital zircons from several samples of previously undated basin outliers. This forms the first stage of data collection, which will conduct dating of each of the main sedimentary outliers in the region.

Products released 2016–17

Report 164: Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia
Kimberley Geological Information Series data package 2017

Planned work program and products 2017–18

A significant component of the work program for 2017–18 will focus on the production of the LANSLOWNE Second Edition 1:250 000 Geological Series map, incorporating the results of GSWA mapping over the past several years.

A report on the Kimberley Basin (redefined to include both the Speewah and Kimberley Groups) is also being prepared for publication in 2017–18. This will document the results of recent GSWA mapping and geochronology and the implications for the development and geodynamic setting of the basin. As part of this work, the ENS database will be updated with detailed descriptions of the stratigraphic units comprising the basin.

A report on the P–T–t evolution of the King Leopold Orogen is scheduled for release in 2017–18, which will present the results of thermobarometry and in situ monazite geochronology of amphibolite facies metamorphic rocks from the orogen.

LA-ICPMS dating and Lu–Hf isotope analysis will be carried out on detrital zircons from sedimentary basin outliers in order to build the geochronology dataset for regional correlations. SHRIMP zircon dating will be carried out on representative samples of the component granitic suites of the Sally Downs Supersuite to better define the spatial and temporal variations in magmatism.

Further fieldwork will be conducted in the Kimberley region with a view towards production of additional Second Edition 1:250 000 Geological Series maps.

A 2018 version of the Kimberley Geological Information Series data package is planned, which will incorporate the LANSLOWNE 1:250 000 Geological Series map and updates to the geochronology, geochemistry, ENS and WAROX databases.

Products planned for release 2017–18

LANSLOWNE Second Edition 1:250 000 Geological Series map

Report on the geology of the Kimberley Basin

Population of ENS database for units of the Kimberley Basin

Report on the P–T–t evolution of the King Leopold Orogen

Kimberley 2018 Geological Information Series data package

Planned work program, products 2018–19 and beyond

The work program for 2018–19 and beyond will include the production of Second Edition 1:250 000 Geological Series maps to ensure coverage across the Kimberley region, with CAMBRIDGE GULF a priority. A report documenting the results of LA-ICPMS dating of basin outliers will also be produced.

Future work on sedimentary basins, to the southeast of the Kimberley region is being considered as an extension of the sedimentary basin outliers study. This would aim to determine the ages of previously undated successions and to understand regional correlations with basins in the Kimberley Region and broader North Australian Craton.

Products planned for release 2018–19 and beyond

CAMBRIDGE GULF Second Edition 1:250 000 Geological Series map

Report on the ages of sedimentary basin outliers in the Kimberley region

Fieldwork and geochronology of sedimentary basins in the northern Tanami region

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 host 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 Wingelina. 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. 1300–1330 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.

<i>Products released 2016–17</i>	<i>Current status</i>
ENS update (DIORITE and GOLDEN POINT)	Released
West Musgrave GIS (includes AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON)	Released

Thermo-mechanical evolution of orogeny in the Musgrave Province (Report)	Released
Petrogenesis of the mafic–ultramafic intrusions of the Mesoproterozoic Giles Event, Musgrave Province, central Australia (Report)	Released
The volcanology, petrogenesis, and economic potential of the Mesoproterozoic shallow-water, intra-caldera, lava-like rheomorphic Kathleen Ignimbrite, west Musgrave Province, central Australia (Report)	Released
The deep seismic reflection profile 11GA-Y01 in the west Musgrave Province: an updated view (Record)	Submitted

Planned work program and products 2017–18 and beyond

The fieldwork and map compilation components for the project have been completed and compilation of the remaining Reports will continue. Explanatory notes for AGNES, DEERING, REBECCA, MOUNT BUTTFIELD, and RAWLINSON will be released in the West Musgrave GIS update.

Products planned for release 2017–18 and beyond

West Musgrave GIS with ENS update (for AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON)

Neoproterozoic evolution of the west Musgrave Province; integrating deep seismic data with thermochronology (Record)

500 Ma of amagmatic tectonic reactivation of a continental interior: a case study from the west Musgrave Province, central Australia (Record)

GS58 Youanmi Terrane

Manager: Hugh Smithies

Team members: Tim Ivanic, Ivan Zibra, Sandra Romano, Stephen Wyche

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.

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 with associated structural studies in the Narryer Terrane with Dr Tony Kemp from UWA and Prof. Cees Passchier from the Gutenberg University in Mainz
- structural studies in the Murchison Domain with various collaborators (Monash University, Gutenberg University)
- an ARC Linkage project with Sydney University to study the geochemistry and tectonic setting of the Murchison region
- a mineral chemistry project on the Windimurra and Narndee Igneous Complexes with the Guangzhou Institute of Geochemistry
- a metamorphic study of contrasting greenstone successions in the Yalgoo–Singleton greenstone belt with the University of Waterloo (Canada)
- a whole-rock isotopes study of granites in the Youanmi Terrane with Monash University.

Outcomes of work program 2016–17

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. Other studies are being undertaken to determine the relationship between granite intrusion and deformation history.

Field mapping has been completed in the Meekatharra region, resulting in some modifications to the published Murchison stratigraphy and upgrading of previously published GIS products.

A program of sampling granites and associated rocks in the South West Terrane to collect geochemical and isotopic data commenced.

GSWA published excursion guides and abstracts for the 13th International Ni–Cu–PGE Symposium.

Products released 2016–17

THUNDELARRA 1:100 000 Geological Series map

WOODLEY 1:100 000 Geological Series map

MEEKATHARRA 1:100 000 Geological Series map

Murchison GIS 2017 update

Explanatory Notes covering some granitic components in the Murchison GIS

Petrology and geochemistry of the Eoarchaeon Manfred Complex: origin and components (GSWA Record 2016/22)

Layered intrusions of the Youanmi Terrane, Yilgarn Craton: non-series map

External publication: The Windimurra Igneous Complex: an Archean Bushveld?: Geological Society, London

External publication: The Waroonga Shear Zone: Tectonophysics

Planned work program and products 2017–18

Field mapping and compilation will be completed on the NINGHAN 1:100 000 map sheet in the Yalgoo–Singleton greenstone belt and the map will be published. The GABANINTHA

1:100 000 map will be compiled and published. New mapping will commence on the DALGARANGA 1:100 000 sheet.

Sampling and collection of new analytical data, including geochemistry, geochronology and isotopic data, in the South West Terrane will continue.

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

Products planned for release 2017–18

NINGHAN 1:100 000 Geological Series map

GABANINTHA 1:100 000 Geological Series map

Murchison GIS 2018 update

Granite geochemistry in the southwest Yilgarn (GSWA Record)

Murchison stratigraphy and Explanatory Notes update

GSWA Records and Reports derived from collaborative projects

External publications relating to work program where appropriate

Yilgarn portal for DIMIRS website (West Yilgarn)

Planned work program, products 2018–19 and beyond

Field mapping in the Murchison Domain of the Youanmi Terrane will continue in 2018–19. Data will be compiled for release in future versions of the Murchison GIS. A Report covering 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. Data collection will continue in the South West Terrane and results will be used to augment existing regional datasets and to interpret the tectonic history of the terrane. Comprehensive GIS databases including metamorphic and non-GSWA geochronological data covering the Yilgarn Craton are also in preparation.

Products planned for release 2018–19

Murchison GIS update

Explanatory Notes update

DALGARANGA 1:100 000 map sheet

Windimurra and Narndee Igneous Complexes Report

Yilgarn metamorphism map and GIS

GSWA Records and Reports deriving from collaborative studies

GS61 Albany–Fraser Orogen and Eucla Basement Project

Manager: Catherine Spaggiari

Team members: Hugh Smithies, Raphael Quentin de Gromard, Mark Munro

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 has enabled a better understanding of the development of the southern WAC margin over time, on the prospectivity of the region, and has informed 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 operational. 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, and are challenging to explore largely because of the extensive cover.

While a handful of diamond drillholes exist in the Madura Province, no basement mineral exploration holes have been drilled in the Western Coompana Province. The EIS-funded 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 2016–17

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

- the understanding that the Madura and Coompana Provinces are dominated by Proterozoic oceanic basement
- 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
- completion of the ARC Linkage passive seismic project, the ‘ALFREX’ array, which has defined 3D crustal features including a linear section of deeper Moho between the Yilgarn Craton and the Fraser Zone. This highlights differences in 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.
- New detailed structural mapping and sampling in the east Albany–Fraser Orogen, with emphasis on the Fraser Zone, is unravelling the complex structural architecture and timing of events.
- In the Fraser Zone, ongoing collaborative work with Curtin University and industry including sulfur isotope, mineral and geochemical studies and P–T analysis of gabbroic rocks are helping determine the processes and tectonic environment of mineralization and prospectivity of the region.

Products released 2016–17

Geological interpretation of the Madura and Coompana Provinces along the Eucla–Gawler seismic and magnetotelluric line 13GA-EG1 (Non-series map)

Record 2016/2 Extended abstract Structural evolution of the S-bend region, east Albany–Fraser Orogen

Three external publications — see Appendix C

Planned work program and products 2017–18

- Work is focussed on detailed structural mapping and analysis in the Fraser Zone region and publishing significant datasets and their interpretations. These include: a

detailed comprehensive Report on the Eucla basement stratigraphic and co-funded drilling

- update and expand the contributions in the Explanatory Notes online database
- structural and metamorphic analysis of the Fraser Zone and adjoining regions; includes 1:100 000-scale series mapping, detailed structural mapping and analysis, sampling, microstructural work, P–T work, routine and non-routine geochronology).

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 GS61 program is integrated with the Minerals Research Institute of Western Australia (MRIWA) M470 project, which is a collaboration between exploration industry sponsors and Curtin University (led by Associate Professor Chris Kirkland,) 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 (Assoc. Prof. Katy Evans) and metamorphic work on the Fraser Zone (Dr Tim Johnson, Curtin University). The metamorphic work 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 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 now complete. This was set up to examine the 3D structure of the crust and lithosphere of the Albany–Fraser Orogen and adjacent Yilgarn Craton through passive seismic data acquisition and analysis. The results and interpretations have been published in two journal articles, and a GSWA Report is due to be released early in 2017–18.

Interpretations of the Eucla–Gawler seismic line 13GA-EG1, MT data along the same line, and potential field data modelling were presented at a dedicated session at the

Australian Earth Sciences Convention (AESC) in June 2016. This work will be published in a co-branded GSWA–Geological Survey of South Australia– GA Record this year. The work also links the GS61 program with GS62 3D Geoscience, which includes further interpretations of the Albany–Fraser seismic and MT lines, potential field data modelling, and construction of 3D models.

Work has commenced on understanding connections between the west and east Albany–Fraser Orogen, and a geochemical and isotopic sampling traverse is planned. This work will link to geochemical analysis in the Southwest and Youanmi Terranes of the Yilgarn Craton.

A pre-conference fieldtrip to the Albany–Fraser Orogen, as part of the Specialist Group in Tectonics and Structural Geology (SGTSG) of the Geological Society of Australia (GSA) will be led by members of the GS61 team in November 2017. Field guides for this trip and also for the mid-conference fieldtrip in the Denmark–Albany region and post-conference fieldtrip to the Leeuwin Province will be published by GSWA.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

Stratigraphic and co-funded drilling of the Eucla basement — the Proterozoic geology beneath 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 (Report)

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

Structural evolution of the S-bend region of the east Albany–Fraser Orogen (Report)

Explanatory Notes of selected units of the Albany–Fraser Orogen (database)

Fieldguide for the SGTSG pre-conference fieldtrip, Albany–Fraser Orogen (Record)

Fieldguide for the SGTSG mid-conference fieldtrip, Denmark–Albany region (Record)

Fieldguide for the SGTSG post-conference fieldtrip, Leeuwin Province (Record)

SGTSG program and abstracts (Record)

External publications — see Appendix C

Planned work program, products 2018–19 and beyond

The focus for 2018–19 will be the release of the first IBG map at 1:250 000 scale of the Eucla basement to the South Australian border, as part of a Geological Exploration Package (GEP). The IBG will use the results of the Eucla basement stratigraphic drilling, new stratigraphic drilling by the Geological Survey of South Australia, and interpretation 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 continue on linking the west and east Albany–Fraser Orogen.

Products planned for release 2018–19

1:100 000 series digital map package of the southern east Albany–Fraser Orogen

1:250 000 IBG and GEP of the Eucla basement

Explanatory Notes of selected units of the Albany–Fraser Orogen, Madura and Coompana Provinces

Structural and metamorphic evolution of the east Albany–Fraser Orogen (Record)

Geochemistry of the west Albany–Fraser Orogen (Record)

GS62 3D Geoscience

Manager: Klaus Gessner

*Team members: Ruth Murdie, Lucy Brisbout, Elle Rakich, Huaiyu Yuan
(Macquarie University), Joel Burkin (CET)*

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 2016–17

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 2016–17

Geological interpretation of the Madura and Coompana Provinces along the Eucla–Gawler seismic and magnetotelluric line 13GA-EG1 — Map

Ten external publications — see Appendix C

West Gawler 3D model

Specifications for submission of 3D Models to GSWA

Rocklea Dome 3D Model

Planned work program, products 2017–18 and beyond

The 3D Geoscience section will continue to contribute to regional mapping project teams. The team will also contribute to a number of regional 3D modelling studies, potential field interpretations of the Yilgarn Craton, the Capricorn Orogen, the Albany–Fraser Orogen, and the Canning Basin.

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 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

COPA passive seismic array (Report)

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)

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, 10GA-CP1, 10GA-CP2, 10GA-CP3 (Geophysical Modelling Reports)

Geophysical Modelling Reports for GSWA map sheets ATLEY, BADJA, BUNGAR, DIORITE, DRYSDALE, GOLDEN POINT, LAKE PERCY, MEEKATHARRA, RICHENDA, SANDSTONE/GUM CREEK, THUNDELARRA, WARBURTON RANGE, WEBB, YALGOO, YOUANMI

3D index for geophysical modelling reports
Hamersley Basin and Merlinleigh 3D models
Nine external publications — see Appendix C

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, a total of 581 km of deep seismic reflection data were 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 2017–18 and beyond

The main objective of the project, which started in 2017–18, 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):
 - establish which of the mafic intrusive rocks of the region are related to the Fortescue and Hamersley Groups
 - establish the geochemical relationship between felsic igneous rocks of the Fortescue and Hamersley Groups and the associated mafic and ultramafic rocks
 - use litho-geochemistry 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 data collection, including the collation of available legacy data from the Fortescue and Hamersley Groups and HyLogger scanning of selected drillcore from the Hamersley Basin. These data will be used in a study of hydrothermal alteration. The initial fieldwork has been aimed primarily at validating existing mapping and identifying areas for detailed future work. Systematic outcrop and drillcore 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

Compilation of legacy data (aerial photographs, field notebooks, and samples), imagery for the project area and reinterpretation of the bedrock geology of the southwestern Hamersley Province at 1:250 000 scale (Geological Information Series)

Products planned for release 2018–19 and beyond

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)

YARRALoola 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), Darren Wallace, Bhumita Fadadu, Marie Ferland, Kiran Gavni, Kay Greenberg, Gary Hartley, Bec Hitchings, Arthur Hoffman (Manager GS85), Joe Hogen-Esch, Stewart Jefferys, Jean Johnston, Annick Francois, John Kirk, Tom Lenane, Irena Lesiak, Frank Matera, Tuyen McDonald, Sue Mulligan, Margie Nash, Mittal Patel, Joyce Peng, Michael Prause (Manager GS82), Bernd Striewski, Adam Symonds, Daniel Then (Manager GS83), Brad Tapping, 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 and GIS specialists.

These program areas reside in the Geoscience Information Branch (GIB), which 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 2016–17

There was continued focus on the management and delivery of geoscience data. Major outcomes of the work program included:

- promotion of Western Australia’s prospectivity at international and national conferences, and trade shows
- Release of a number of digital data layers downloadable from Data and Software Centre and through GeoVIEW.WA
- Continued to provide GSWA online systems training in Kalgoorlie and Perth
- Ongoing updates to a number of web-based applications

Products released 2016–17

Products released in 2016–17 were:

- 38 manuscripts
- 5 Geological Series maps (1:100 000 and 1:250 000 scale)
- 10 geological maps at other scales
- 16 digital products
- completed Native Title South West Settlement final assessment system tool across the Department of Lands and DMIRS
- First release of the digital 1:10 million tectonic map as a data layer and through GeoVIEW.WA
- Release of two virtual tours — the mafic–ultramafic intrusions of the Youanmi Terrane and Meteorite impact structures of Western Australia
- Release of a new version of WA Geology application
- Released a spatial tool for MRIWA website
- Release of a new version of GeoVIEW.WA
- The launch of a new Data and Software Centre web site.

Planned work program and products 2017–18

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

- 40 manuscripts
- 6 Geological Series maps (1:100 000 and 1:250 000 scale)
- 18 geological maps at other scales
- 18 digital products
- MINEDEX2018 redevelopment
- further develop ENS to include regolith, geochronology and mineral systems.
- WAPIMS CO2 enhancements

GS91 Mineral Exploration Information Management

Acting manager: Ann Fitton

Team members: Monique Brouxhon, Subashni De Biran, Joyce Edmonds (retired December 2016), Fiona MacCorquodale, Robert Pizzi, Christine Suchodolski, Julia Thom

The department has a statutory obligation to manage the collection, storage, and release of company exploration reports containing geoscience information on mining tenements in Western Australia — and this function is performed by GSWA. 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, which minimizes duplication of exploration effort and enables more efficient exploration.

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

Outcomes of work program 2016–17

The online report-writing application for mineral exploration reports was launched in February 2015. It has been available for just over two years during which time companies have had an opportunity to use it for the compilation of their annual reports. Its use is still optional and at end June 2017, more than 2363 reports had been submitted online representing 81% of the reports submitted. Current plans are for use of the online report-writing application to be mandatory from mid-2018.

The tenth annual release of exploration reports, after an advertising and objection period on the website in early 2017, was completed in May 2017 — and 1079 reports were released. This consisted of reports submitted to the department in 2011 and released under the provisions of the Mining Regulation 96(4), commonly known as the ‘sunset clause’. In addition, 1826 reports were released to open file as part of the normal cancellation process of dead tenements. At the end of June 2017, more than 86 000 reports were accessible to the public on the department’s website.

The mineral drillhole and surface geochemistry database was maintained. It now contains around 2.7 million drillholes and 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 2016 and March 2017. Charts illustrating the annual number of drillholes, amount of metres drilled, and number of surface geochemistry samples analysed are included as Figures 30–31, respectively.

<i>Outcomes 2016–17</i>	<i>Current status</i>
The online report-writing application for mineral exploration reports has been available for two years	It has generally been well received. At the end of June 2017 more than 2363 reports had been submitted via the system
Bi-annual updates of mineral drillhole and surface geochemistry database	Updates were released in August 2016 and March 2017
Annual release of reports under the ‘sunset clause’ legislation	The tenth annual release of exploration reports under the ‘sunset clause’ was successfully completed in May 2016, with release of 1079 reports
Release of reports on dead tenements	A total of 1826 reports was released under the normal cancellation process. At end of June 2016, more than 86 000 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 2016, March 2017, and June 2017)
Identification of mineral exploration core suitable for inclusion in the Perth and Kalgoorlie core libraries	Donations of mineral core continued in 2016–17 with the extended downturn in the industry. Under the circumstances, company geologists were very keen to find a good home for their valuable core.

Planned work program and products 2017–18

Planned activities and outcomes are to:

- formalize the online report-writing application for mineral exploration reports to become mandatory by mid-2018
- review and release surrender reports and their associated annual reports as they are received, together with the 11th 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
- amend the Guidelines for Mineral Exploration Reports on Mining Tenements to include:-program of works number (POW) and whether a drillhole has been rehabilitated in the collar table of drillholes, adopt a unique sample ID for mineralogical samples and make digital submission of reports mandatory by mid-2018
- continue bi-annual releases 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 to enable better searching of the drillcore
- continue to identify and collect historical drillcore suitable for the Perth and Kalgoorlie core libraries. It was successful in 2016–17 and, under the continued industry downturn, is likely to continue to be successful during 2017–18
- 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, the department 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 department is also assisting NOPTA and GA develop and maintain NOPIMS, with very close links to WAPIMS and the Core Library database (CIMS).

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 2016–17

Outcomes 2016–17

Implemented Petroleum Online data submission module through PGR interface

New functionalities and enhancement added to the WAPIMS (e.g. historical permits layer on the GIS Map)

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

Work in collaboration to NOPTA and GA on the successful release of the new NOPIMS based on WA system (WAPIMS)

Catalogue and archive petroleum data collections donated to DMIRS from industry and academia

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 2017–18

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.

Planned activities and outcomes are to:

- continue the testing and create enhancements to the new WAPIMS in collaboration with NOPTA and GA
- create forms and public reports to release online all the public geoscientific data captured in WAPIMS (State and Commonwealth)
- assist Petroleum Division in capturing data submitted for Gorgon CO₂ injection project and Tubridgi gas storage project
- assist the Basin and Energy Geoscience section in creating Digital Core Atlas for Theia 1 and other projects as required (geochemical data capture, reprocessing)
- publish a new 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
 - For State surveys, start planning and transcribing the 3480/3590 seismic data cartridges into a new media (3592 cartridges)
 - 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

Manager: Paul Stephenson

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

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, petroleum industry onshore and offshore 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 from around Australia. 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.

The core libraries at Carlisle (Perth) and Kalgoorlie also house the extensive core generated since 2009 from the EIS co-funded drilling program. This core, after a short 6-month confidentiality period, is a great boost to explorers and academia, providing new core from greenfield areas and allowing testing of new ideas and concepts.

Outcomes of work program 2016–17

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 steady during 2016–2017 relative to 2015–16— this continues the decade-long trend (Figs 33, 34). 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 — a total of 96 km of core was laid out and 2005 pallets accessed at Carlisle during 2016–17 (Figs. 33, 34).

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 led by DMP’s Facilities Services group.

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.

All works have now been completed, and the core library extensions were officially opened in November 2016.

Planned work program and products 2017–18

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

- Upgrade the Carlisle site security with new swipe entrance gates for May–June 2018.

- Install a crash barrier at the corner of Harris and Briggs Street by May 2018.
- Place Nodding Donkey acquired from AWE Ltd erected at the Harris St entrance by June 2018.
- Exxon Mobil is in discussions with us at present about donating its core and cuttings from Victoria and Tasmania (around 250–300 pallets worth).

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Team members: Edward Rogers, Michael Wawryk

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. The 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. Full datasets are also available upon request.

Outcomes of work program 2016–17

For the year ending 30 June 2017, the GSWA HyLogger facility collected and processed VNIR–SWIR–TIR spectral data for 42 692 m of core from 155 drillholes. These comprised 69 EIS co-funded holes, 72 historical and donated mineral holes, and 14 petroleum wells. The amount of core scanned is the second largest in the facility’s eight years of operation (Fig. 35).

For 2016–17, about 55% of the scanned core was derived from EIS co-funded drilling, whereas ‘other’ scanned core was mostly legacy mineral exploration core in GSWA archives in both Kalgoorlie and Perth Core Libraries, plus a small amount of from petroleum exploration projects. During the year, more of the historical core and EIS core from Kalgoorlie Core Library was freighted to Perth for re-scanning using upgraded technology and data interpretation methodology. The project is partly funded by AuScope as part of an NCRIS grant scheme.

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

- regional stratigraphy and hydrothermal alteration assemblages of the Fortescue Group, Hamersley Basin 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)
- Hyperspectral characterization of Li mineralization in Londonderry pegmatite deposit, Yilgarn Craton REE mineralization identified by hyperspectral and XRF methods (MSc, Curtin University) depositional history of several regions in Northern Carnarvon Basin (BSc Honours, UWA) sedimentology and geochemistry of source rocks in Perth Basin (PhD, UWA)

Other activities that involved HyLogger staff included:

- provision of a first batch of five new GSWA HyLogger Record that summarizes drillhole metadata and basic mineralogical interpretations
- provision of a two-day GSWA–CSIRO workshop showcasing the utility of the HyLogger for understanding mineral systems to industry clients and users of the data. This followed successful workshops delivered in May 2014, April 2015, and May 2016
- upgraded the drillhole database ‘HyMeta’ with options to have links to additional HyLogging publications, levels of data processing, and release dates
- upgraded the ‘HyLogger’ layer within GSWA’s GeoVIEW.WA map-based interface showing colour-code for different levels of data interpretation and the links to the HyLogging summary reports
- commissioning of a new portable/desktop SEM instrument for mineral validation work
- collaboration with CSIRO staff at the Earth Sciences Centre in Sydney and the Australian Resources Research Centre in Perth 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 facility in the extended Perth Core Library.

Products released 2016–17

Five new GSWA HyLogger records of summary drillhole metadata and basic mineralogical interpretation. Links to the summary records are available through the HyLogger layer in GeoVIEW.WA

Record 2016/16: Mapping iron ore alteration patterns: Beebyn deposit, Yilgarn Craton

Record 2016/17: Mapping iron ore alteration patterns: Windarling iron camp, Yilgarn Craton

Record 2016/18: Mapping iron ore alteration patterns: Drillhole PK11DD001, Mt Richardson, Yilgarn Craton

Record 2016/19: Mapping iron ore alteration patterns: Drillhole PK12DD001, Mt Richardson, Yilgarn Craton

AJES, 2016, v. 63: Reflectance spectroscopic characterisation of mineral alteration footprints associated with sediment-hosted gold mineralization at Mt Olympus, Ashburton Basin, Western Australia

Planned work program and products 2017–18

The facility will continue to collect and interpret spectral data from drillcore that contributes directly to increasing the knowledge of Western Australian geology and mineral/petroleum systems. 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 in order to balance the competing objectives, demands and priorities of users.

Other regular activities for 2017–18 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 department's GeoVIEW.WA 'HyLogger' layer. Short GSWA reports of data processing and interpretation will be included in the final products. In addition, links to other related publications will be available through GeoVIEW.WA HyLogging layer.

HyLogger staff will collaborate lead several special projects in 2017–18 to:

- develop procedures for using the portable/desktop XRD and SEM 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 2017–18

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

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

Planned work program, products 2018–19 and beyond

Maintenance of the HyLogging facility, 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

ES20 Government Co-funded Exploration Drilling

Manager: Margaret Ellis

Team member: Jane Forsey, Monique Brouxholm**

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 geoscience information and discoveries.

The program is preferentially funding high-quality, technical and soundly 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.

A formal advisory committee, chaired by the Director General or Deputy Director General of the department and consisting of representatives from the main industry representative groups and research sector, provides advice to the department 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 capped at \$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 completed (Fig. 36). 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

* Part year

the department before payment of the refunds, and the final report and core are released to open file after a six-month confidentiality period.

Outcomes of work program 2016–17

During 2016–17 drilling from three rounds was undertaken by exploration companies. As can be seen highlighted by the red rectangle in Figure 37, three rounds overlapped the reporting year. Round 12 projects covered the 2016 calendar year, with a number of projects drilled between July and December 2015. Round 13 projects were drilled between July 2016 and June 2017, and Round 14 covered projects drilled during the 2017 calendar year. There a number of Round 14 projects drilled in the first six months of 2017.

Successful drilling projects usually cannot be deemed to be so after just one drilling campaign. The successes listed below are some of those announced for drilling projects that have received co-funding in 2016–17 or in previous years.

Highlights of the 2016–17 program include:

- Breaker Resources orientated EIS diamond drill holes, the first into the 2.2 km-long Bombora gold discovery provided important information on the mineralised structures, host rock geochemistry and has reinforced the continuance of in-fill aircore and reverse circulation drilling to provide a maiden JORC Resource in late 2017. Assay results from diamond drilling has included 21.3 m at 5.10 g/t (BBDD0006), 3.55 m at 7.77 g/t and 2.55 m at 10.65 g/t (BBDD008).
- Drilling at Lake Wells by Australian Potash (formerly Goldphyre Resources) has continued and has now identified a deeper Tertiary paleochannel aquifer. A successful scoping study released in March 2017 indicated a possible mine life of 20 years, with premium-priced sulphate of potash in years 1–5 at a production rate of 150 000 tpa (stage 1) and years 6–20 at a production rate of 300 000 tpa (stage 2).
- Sipa Resources 4500 metre plus aircore program extended a previous one-hole copper–gold anomaly to a strike-length of >4km at its Paterson North Project. Multi-element results indicated the presence of significant copper–gold–silver–molybdenum–tungsten over a strike of 1.5 km, with gold values of up to 1.26 g/t. A co-incident magnetic and gravity anomaly along the mineralised strike referred to as

'Obelisk' has been the focus of deep RC drilling and early assay results returned 46 m at 0.12% Cu, 0.4 ppm Ag, 16 ppm Mo and 178 ppm W within a broader 62 m anomalous zone.

- Panoramic Resources announced a maiden Ore Reserve of 6.65 million tonnes at 1.42% Ni, 0.61% Cu and 0.10% Co for 94 500 t nickel, 40 900 t copper and 6700 t cobalt for its Savannah North deposit. A mine life of 10 years has been estimated.
- Sirius' Nova nickel mine, which was a discovery using GSWA precompetitive data and support from co-funded drilling, and subsequent mine development by Independence Group has resulted in the production of nickel and copper concentrate and export. From discovery (2012) to mine start-up (2015) was achieved in record time of only three years.

The following outcomes were also achieved during the year:

- completion of 49 exploration drilling projects by successful recipients between July 2016 and June 2017
- drilling of 27 919 m of diamond drilling and 54 380 m of non-cored drilling
- call for applications for the 2017 round of drilling, and evaluation of applications for co-funding
- announcement of successful applications, including from prospectors, for Round 14 of Government Co-funded Exploration Drilling to be undertaken during the 2017 calendar year, and distribution of those agreements (Fig. 38); Table 15)
- call for applications for the 2017–18 round of drilling (Round 15), and evaluation of applications for co-funding
- announcement of successful applications for Round 15 of Government Co-funded Exploration Drilling for projects to be drilled during the 2017–18 financial year (Fig. 39); Table 16). The distribution of those agreements was slightly delayed because of the State election, change of government, and delay in delivery of the State Budget.

Figure 40 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 2017. A total of 732 projects have been offered co-funding up until 30 June 2017, and drilling has been completed on 371 projects. Another 42 projects have

until the end of December 2017, and 43 projects have until the end of June 2018 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 41.

Planned work program 2017–18 and beyond

The drilling projects that were successful in gaining co-funding in Round 15 will be undertaken during the 2017–18 financial year. All relevant data and core will be submitted and subsequently released to open file.

Round 16 of the Co-funded Drilling program will be advertised, with an application period between September and early October 2017. This round is offering about \$5 million to support drilling projects undertaken during the 2018 calendar year.

Round 17 will be open for applications in late February 2018 for applications for drilling projects to be drilled during the 2018–19 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 2016–17

In 2016 –17, the project planned and coordinated the Director General's promotional visit (July 2016) to Beijing, China. Key activities during this trip were:

- Attending China International Gold Conference, with presentation of a keynote address at the Conference reaffirming relationships with major investors and potential investors; promoting Western Australia's track record in resource development and

investment attractiveness; and meeting major resource investors and key industry leaders

- visit China SOEs and potential major investors — meeting with the China National Administration of Coal Geology (CNACG), China National Nuclear Co (CNNC), and Beijing Research Institute of Uranium Geology

In 2016–17, 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
- the 13th International Mining & Machinery Exhibition (IMME), India
- 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 2017–18

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 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. The objective of the initial phase 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 (Fig. 23).

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). The Capricorn Orogen survey was flown and this complements the earlier reconnaissance AEM surveys undertaken by GA (Fig. 24).

Airborne gravity surveys are included and described 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 2016–17

No airborne magnetic, radiometric or electromagnetic surveys were planned for 2016–17 with funds and efforts being concentrated on the airborne gravity program reported under ES32 Regional Gravity Surveys.

No surveys are currently 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 and program priorities. Currently no airborne surveys other than gravity (see ES32 for details) are under consideration.

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 this project (i.e., 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.

Passive seismic studies have commenced with UWA to investigate the feasibility of using the ambient noise and receiver function techniques in the Perth Basin, including a novel project that explores how the Metropolitan Fibre Optic Network can be utilised to achieve this. These projects aim to detect both the shallow and deep velocity structure beneath the Perth Basin.

Outcomes of work program 2016–17

During 2016–17 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. 42). Two targeted passive seismic arrays continued to be deployed in 2016–17 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.

Products released 2016–17

West Gawler 3D model

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)
11 external publications — see Appendix C

Planned work program and products 2017–18

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 also continue to support the deployment of the COPA passive seismic array in the Capricorn Orogen. 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 resolving seismic anisotropy structure for long-operating stations.

Local ambient noise and receiver function studies with UWA will continue to investigate the shallow and deep velocity structure beneath the Perth Basin.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

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

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)

Albany–Fraser Orogen 3D Model

Perth Basin passive seismic study (Report)

Geophysical Modelling Reports for Seismic Surveys 10GA-YU1, 10GA-YU2, 10GA-YU3, 11GA-SC1 , 10GA-CP1, 10GA-CP2, 10GA-CP3

Four external publications — see Appendix C

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 2016–17

Data from the 2.5 km grid survey that was completed between May and June 2015 in the Wiluna area were processed and released (4 454 new stations) (Fig. 25).

GSWA's first airborne gravity survey was completed in the East Kimberley and the data released (38 000 line-km) (Fig. 25).

Two Requests for Tender were issued and contracts awarded for additional airborne gravity surveys in the NE Canning – Tanami and Kidson areas (Fig. 25) for completion by the end of 2017 and publication of data anticipated for the first quarter of 2018.

<i>Products planned for release 2016–17</i>	<i>Current status</i>
Completion of the Wiluna survey in areas cleared for access.	Complete; data published
Completion of the East Kimberley airborne gravity survey.	Complete; data published

Planned work program and products 2017–18

Completion of the NE Canning – Tanami and Kidson area airborne gravity surveys.

Planned work program, products 2018–19 and beyond

Area prioritization for new surveys will be determined over the course of 2017–18.

ES33 Yilgarn Margin Geochemistry

Manager: Paul Morris

Team members: Nadir de Souza Kovacs, Sara Jakica

This program was originally formulated to generate regolith–landform maps and regolith geochemical data on the margins of the Yilgarn Craton, which has a well-established mineral endowment. The approaches taken at the inception of the program have been extended to areas with similar cover characteristics: that is variably thick, usually transported regolith in areas where there are little available data related to its mineral potential. Recently, this program has included the Ngururrpa area in the northeast part of the State, covering parts of the Murraba and Canning Basins. Over 600 regolith samples were collected at a density of one sample every 12.5 km². Regolith and spinifex samples were collected across two regional faults to test whether changes in chemistry of both media indicated that faults had acted as conduits to bedrock-derived fluids. Passive seismic data were collected along one transect to determine the thickness of regolith. Apart from providing a complement to regolith chemistry, the regolith–landform mapping carried out as part of the Ngururrpa program forms part of an update to the West Arunta geological information package (GIP). Additional regolith–landform mapping has now extended the coverage of this package south to include the Macdonald (SF52-14) 1:250 000 map sheet.

GSWA recognises that federal government agencies and tertiary institutions can make a valuable contribution to geoscience programs through collaboration. Regolith-related programs involve GSWA funding of and external co-operation with staff from CSIRO and Curtin University.

- GSWA has contributed to the funding of biogeochemical work carried out by CSIRO in the northwestern Yilgarn Craton – Gascoyne area. This work was completed in 2016–17, and will be published in 2017–18 as a GSWA record.
- GSWA has contributed to the further investigation of regolith fine-fraction chemistry to explore for buried mineralization through an industry–government–MRIWA project based at CSIRO. A development in this program is the potential use of

archived regolith material held in GSWA's core library for further testing of sample preparation and analytical approaches developed earlier in the program

- GSWA has been instrumental in developing the application of the single-station passive seismic approach to estimating regolith thickness. An important part of this approach is to determine the level of agreement between data generated by passive seismic, and those resulting from drilling or other techniques such as airborne electromagnetics (AEM). To test the effectiveness of different methods, GSWA is working with CSIRO scientists to evaluate data from the Gascoyne area, where passive seismic data have been acquired close to AEM flight lines, and drilling data are available. The passive seismic data program has been expanded by the purchase of four single-station devices, and entering an agreement with Curtin University to generate improved approaches to data reduction.
- Radiometric dating of ferruginous duricrust at Curtin University using the (U–Th)/He method has been undertaken on GSWA samples collected in the Kimberley and southwest Yilgarn Craton areas. Apart from providing valuable geochronological data, dating of these samples has contributed to further evaluation of developing an in situ approach to dating using this technique. The availability of these types of data will contribute to better regolith–landform maps, and an improved understanding of the more recent geological evolution of the State. Sample collection from the Gascoyne and Goldfields areas in 2016–17 will be used to expand this program.

Outcomes of work program 2016–17

- Co-sponsor and contribute a researcher to a CSIRO–MRIWA–industry project to examine the application of fine-fraction chemistry of regolith for mineral exploration in areas of transported regolith
- Contribution to the funding of a biogeochemical study carried out by CSIRO in the northwestern Yilgarn Craton and Gascoyne area.
- Extension of the west Arunta GIP regolith layer to include the Macdonald 1:250 000 map sheet (SF52-14)
- Dating of ferruginous duricrust from the Kimberley and Boddington areas
- Collection of ferruginous duricrust from the Gascoyne and Goldfields areas for further (U–Th)/He dating.

Planned work program and products 2017–18

- Carry out regional regolith-oriented programs in underexplored parts of the State, conditional on funding
- Collect representative samples of duricrust suitable for radiometric dating
- Dating of ferruginous duricrust from the Gascoyne and Goldfields areas by the (U–Th)/He dating method
- Acquire passive seismic data in areas of variable cover as a complement to regolith geochemical data, and with an aim to generate a third dimension for regolith–landform maps.

Products planned for release 2017–18

Regolith geochemistry of the Ngurrupa area (Record)

NW biogeochemistry and beyond project (GSWA Record)

(U–Th)/He dating of ferruginous duricrust (GSWA record)

Macdonald 1:250 000 geological map sheet (SF52-14)

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 2016–17

<i>Outcomes 2016–17</i>	<i>Status</i>
Implement an online search tool that interrogates the field observation database (WAROX)	Ongoing – USB released
Enhance ENS to include regolith and mineral systems	Ongoing
Redevelop the department's Data and Software Centre	Complete
Enhance geochemistry database (WACHEM)	Stage 1 complete
Develop methodology and application for Mining Act Section 16(3) and administrative referrals to/from Department of Lands	Complete

Planned products and outcomes 2017–18

<i>Planned outcomes 2017–18</i>
Implement an online search tool that integrates with the field observation database (WAROX)
Develop a new user interface for WAMEX
Enhance ENS to include regolith and mineral systems
Enhance geochemistry database (WACHEM) Stage 2

ES42 3D Geoscience

Manager: Klaus Gessner

Team members: Lucy Brisbout, Ruth Murdie, Elle Rakich, Huaiyu Yuan (Macquarie University), Joel Burkin (CET)

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 2016–17

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) investigated the lithosphere structure of the Albany–Fraser Orogen using a passive seismic array. Lucy Brisbout, Ruth Murdie and Klaus Gessner collaborated with Catherine Spaggiari (see also GS61) ANU seismologists Christian Sippl, Hrvoje Tkalčić and Brian Kennett on the geological interpretation, resulting in a GSWA Record (scheduled for publication in 2017–18) and two external publications.

Ruth Murdie and Huaiyu Yuan worked with Michael Dentith at UWA in installing a trial passive seismic array in the Perth Basin to investigate the feasibility of such studies in this area.

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'.

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 manuscript is scheduled for publication in 2017–18 in a Geological Society (London) Special Publication

Elle Rakich has worked with 3D Geoscience as part of her departmental Graduate Rotation from February to April 2017. During that time Elle worked in close collaboration with Mark Jessell and Vitaliy Ogarko (CET) on the application of graph theory algorithms to find a linear representation of the topology of geological networks and stratigraphy.

Joel Burkin (UWA) has worked on transforming external 3D models to GSWA standards.

Products released 2016–17

Record 2016/3: Integrated Exploration Platform v2.5

Record 2015/13: Saying goodbye to a 2D Earth

Record 2015/16: Second Lithosphere Workshop Abstracts

West Gawler 3D model

Record: Specifications for submission of 3D Models to GSWA

Ten external publications — see Appendix C

Planned work program, products 2017–18 and beyond

A key focus for 2017–18 will be on the collaboration with the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS) in Beijing, China, to carry out the first stage of passive seismic deployment in the coastal region of northern Western Australia (Fig. 42).

3D Geoscience staff will also contribute to a collaborative project with UWA on the crustal structure of the southwest Yilgarn Craton. 3D models and publications are also planned for the Albany–Fraser and further modelling work will be carried out on the Hamersley, Merlinleigh and Perth Basins.

Within the ARC CCFS Huaiyu Yuan (supported by an exchange student and a visiting Postdoctoral Research Fellow from the Chinese Academy of Sciences) will continue work on the architecture of the lithospheric mantle of the West and North Australian Cratons. A suite of passive source methods will be applied in conjunction with the COPA to develop a technical template for resolving both the isotropic and anisotropic seismic velocity models for both long-operating and the COPA stations. A 3D lithosphere-scale P-wave velocity model targeting the Capricorn region will be worked on by the exchange student, and a Yilgarn-wide crustal shear velocity model will be developed by the visiting postdoc using the data from both the Albany–Fraser and the COPA deployments and the GA permanent stations. Results of the seismic modelling will be published in peer-reviewed journals and as GSWA Records.

Local passive seismic studies with UWA will continue to investigate the feasibility of using the techniques in the Perth Basin and also against the Metropolitan Fibre Optic Network.

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 2017 Goldschmidt meeting in Paris, the 2017 conference of the Structural Geology and Tectonics Specialist Group of the Geological Society of Australia (SGTSG) in Denmark (WA), the 2018 ASEG meeting in Sydney, the 2018 AOGS Meeting in Singapore, the 2018 EGU Meeting in Vienna, the 18th Annual Conference of the International Association for Mathematical Geosciences (IAMG) in Fremantle, and the Third CCFS Lithosphere Dynamics Workshop at UWA.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

A magnetotelluric survey across the Albany–Fraser Orogen and adjacent Yilgarn Craton (Report)
Imaging the structure of Archean fault rocks with synchrotron X-ray microtomography (Record)
The Precious Earth – Understanding Hydrothermal Ore Forming Systems (Book)
Third Lithosphere Dynamic Workshop (Abstract volume)
SGTSG (Abstract volume)
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, 10GA-CP1, 10GA-CP2,
10GA-CP3 (Geophysical Modelling Reports)
3D index for Geophysical Modelling Reports
Merlinleigh and Hamersley Basin 3D models
Twelve external publications — see Appendix C

ES43 Mineral Systems Atlas

Managers: David Maidment, Trevor Beardsmore

Team members: Lauren Burley, Paul Duuring, Josh Guilliamse, Sidy Morin-Ka, Mark Hutchison, Wally Witt, CET UWA, CODES, CSIRO

Under this program, GSWA has entered 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. Many of these projects are managed or monitored by GSWA's Mineral Systems group, and in some instances have received in-kind funding from the GS20 recurrent budget, but the majority of these minerals-oriented research projects have been partly to fully funded by the Exploration Incentive Scheme (EIS). Some of the EIS-funded collaborative research projects have been or will soon be completed. Uncertainty on the long-term continuity of EIS has put a brake on initiating new research projects.

Significant projects recently coming to a conclusion 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
- diamond prospectivity of Western Australia

Outcomes of work program 2016–17

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 released early in 2016–17 (Report 158).

The EIS-funded collaborative study of the VMS fertility of Yilgarn volcano-sedimentary successions was completed in late 2015. The results of the analysis of then-existing public domain data were published in GSWA Report 165 and in the journal *Precambrian Research* during 2016–17. Studies of the litho-geochemistry and geochronology of a number of under-represented terranes using newly collected data have also been compiled and are to be published in another GSWA Report in the coming year; some of the new work on the Nimbus, Teutonic Bore and King VMS deposits has also been published in *Precambrian Research* and presented at a variety of international conferences (see Appendix C).

The EIS-funded government–academia–industry collaborative study of BIF-hosted iron ore metallogeny in the Yilgarn Craton (part of Project ES43) was 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 published in 2016–17 some of the results of mapping iron ore and associated alteration using HyLogging as a series of GSWA Records. An overall synthesis is to be published as a GSWA Report and series of external publications.

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 published as a co-branded GSWA Report 163 in early 2016–17 (at the expiry of the confidentiality period), and a presentation made at GSWA’s Annual Open Day (Record 2017/02).

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, together with the earlier-submitted interim Report and database, are being prepared for release as GSWA publications in 2017–18.

The mineral prospectivity analysis of the southeastern Capricorn Orogen by UWA’s Centre for Exploration Targeting was near completion at the end of 2016–17. The final

report documenting the study is being prepared for release in 2017–18. Three GIS datasets with prospectivity models and toolboxes will also be released, as well as a new time–space correlation chart for the Capricorn Orogen.

Dr Mark Hutchison neared completion of a database 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). Release of the Western Australian ‘diamond’ database and associated reports is scheduled for August 2017, at the 10th International Kimberlite Conference.

In a significant new initiative, the Mineral Systems Studies section commenced work to create an interactive, GIS-based Mineral Systems Atlas, which will deliver ‘mappable geological proxies’ for critical metallogenic processes, that are derived from systematic ‘mineral systems analyses’ of known or probable mineral systems in Western Australia (see Project GS20 for more details).

GSWA also began developing in-house knowledge and technological capacity to undertake multi-scale prospectivity studies. Staff from the Mineral Systems Studies section, the Mapping section, and the GIS section attended two training workshops provided by UWA–CET staff.

Product released 2016–17

Report 158: Yilgarn Gold Exploration Targeting Atlas – Volume 3

Report 163: MRIWA Report Project M426: exploration targeting for BIF-hosted Fe deposits in the Pilbara Craton, Western Australia

Report 165: VMS mineralization in the Yilgarn Craton, Western Australia: A review of known deposits and prospectivity analysis of felsic volcanic rocks

Record 2016/16: Mapping iron ore and alteration patterns BIF using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia

Record 2016/17: Mapping iron ore and alteration patterns in BIF using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia

Record 2016/18: Mapping iron ore and alteration patterns in BIF using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia

Record 2016/19: Mapping iron ore and alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia

Planned work program and products 2017–18

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:

- a series of Reports and Records detailing the results of mineralogical and metallogenic studies of Archean BIF-hosted iron ore deposits in the Yilgarn Cratons
- final Report and three GIS datasets for the mineral prospectivity targeting work in the 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.

The development and funding of new collaborative research projects will depend on continuation of the Exploration Incentive Scheme.

Products planned for release 2017–18

Report and database — Diamond and diamond-indicator mineral occurrences, and diamond prospectivity, in Western Australia (provisional title)

Mineral systems analysis of the Capricorn Orogen (provisional title) (Report)

Three GIS datasets with prospectivity models and toolboxes (Capricorn southern basins, Edmund-Collier basins and Ashburton Basin)

Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (Report and external publications)

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 2018–19 and beyond

GSWA will negotiate new, relevant collaborative research projects that may be funded from the EIS — if EIS is funded beyond mid-2017.

ES45 Geological Mapping and Interpretation

Manager: David Maidment

Team members: Olga Blay, Nadir De Souza-Kovacs

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 several remote greenfields areas of Western Australia, including the Kimberley, Capricorn, west Arunta, west Tanami and Paterson regions. Large parts of these areas are underexplored due to remoteness, land access issues, and the lack of up-to-date pre-competitive geoscience datasets. This program is providing new mapping and interpretations, as well as making existing legacy data available in digital format.

Capricorn Orogen

In the Capricorn Orogen, the project has contributed to mapping of late Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins, which contain Abra, Western Australia's largest stratabound Pb–Ag–Cu–Au deposit (see Project GS49). As part of this work, the WONYULGUNNA 1:100 000 Geological Series map was produced in 2016–17, completing 1:100 000 Geological Series mapping of these basins. Mapping in the region is now transitioning to the basins of the Eastern Capricorn Orogen, which include the Bryah, Earahedy, Padbury and Yerrida Basins. Reports detailing the results of focussed studies are also in preparation, including the geochemistry and geochronology of a newly identified dolerite suite and other dolerite suites within the basins.

West Arunta region

The West Arunta region incorporates poorly exposed metasedimentary and meta-igneous rocks of the Paleoproterozoic Arunta Orogen, which is overlain by Neoproterozoic sedimentary rocks of the Murraba and Amadeus Basins. The Arunta Orogen in Western Australia is underexplored, owing to the paucity of outcrop and remoteness, but several base metal prospects have been identified in areas of outcrops (e.g. Enceladus and Iapetus Zn–Pb), as well as a field of kimberlitic intrusions (Webb diamonds) under shallow cover.

The provision of new geological data for this geologically complex, but understudied region will assist mineral exploration targeting and reduce exploration risk in this greenfields domain.

Recent EIS-funded work by GSWA in the region has focused on the production of two Second Edition 1:250 000 Geological Series maps: WEBB (released in 2015–16) and MACDONALD (to be released in 2017–18). A Tanami–Arunta Geological Information Series digital product was released 2016, and will be updated in 2017–18 with the most recent mapping.

Paterson Orogen

The Paterson Orogen to the east of the Pilbara Craton includes polydeformed and metamorphosed Neoproterozoic to Paleoproterozoic rocks of the Rudall Province as well as overlying Neoproterozoic sedimentary rocks of the Yeneena Basin. These rocks are in turn overlain by Paleozoic sedimentary rocks of the Canning Basin and widespread surficial sediments that largely mask the Proterozoic units. The Yeneena Basin hosts several major mineral deposits and occurrences, including the Telfer Au–Cu, Nifty Cu, Kintyre U and O’Callaghans W (Zn–Cu–Pb) deposits. Most mineralization in the region formed during one of two major metallogenic events: 840–810 Ma (e.g. Nifty, Kintyre, Warrabarty); and coeval with deformation and granite emplacement at 655–605 Ma (e.g. Telfer, Magnum, O’Callaghans).

Recent EIS-funded work in the Paterson Orogen has included the publication of a Report in 2017 on the geochronology and evolution of the Rudall Province, in conjunction with Geoscience Australia. A collaborative study with Curtin University on the oxygen and Lu–Hf isotope compositions of zircon from Mesoproterozoic to Neoproterozoic magmatic rocks has recently completed the data acquisition phase.

Kimberley Region

In the Kimberley region, the project is contributing to the collection of geochronology, geochemistry and isotope data for metasedimentary and igneous rocks of the 1912–1788 Ma Lamboo Province to better constrain the timing and nature of tectonism and geodynamic models for the region (see Project GS56). SHRIMP U–Pb dating of detrital

zircons from 1880–1845 Ma metasedimentary successions is complete, which provides constraints on the nature of the western and central zones prior to their inferred collision with the North Australian Craton. Collection of Lu–Hf isotope data for these rocks is ongoing. The results of this study will be produced as a Record assessing the geodynamic setting of the region prior to the deposition of the Kimberley Basin. Geochemistry, geochronology and Sm–Nd data are also being collected for granitic rocks of the 1832–1808 Ma Sally Downs Supersuite to better understand the spatial and temporal variations in magmatism during the Halls Creek Orogeny.

West Tanami region

The West Tanami region incorporates the western part of the Granites–Tanami Orogen, a poorly exposed domain of Neoproterozoic to Paleoproterozoic metasedimentary and igneous rocks that host significant orogenic gold (e.g. Callie, Tanami Goldfield, Groundrush and Coyote) and REE deposits (Browns Range). The Granites–Tanami Orogen is overlain by Mesoproterozoic to Neoproterozoic sedimentary successions, including the Birrindudu and Murraba Basins, as well as widespread surficial cover that has hampered mineral exploration.

Recent work by GSWA in the West Tanami region has included production of several 1:100 000 geological series maps (SLATEY CREEK, BALWINA, WATTS, KEARNEY AND LEWIS), as part of an EIS-funded project compiling previous GSWA and GA mapping data. These maps, as well as recent regolith mapping, regolith geochemistry and gravity data in the Ngururrpa area between the Tanami and Arunta regions, have been released as part of the Tanami–Arunta Geological Information Series 2016 data package. A report on the results of SHRIMP U–Pb dating of zircon from the western Granites–Tanami Orogen is also in preparation, in collaboration with Geoscience Australia.

Outcomes of work program 2016–17

In the Capricorn Orogen, the 2016–17 work program focused on compilation and publication of the WONYULGUNNA 1:100 000 Geological Series map, under EIS funding. A 2016 update of the West Capricorn Geological Information Series data package incorporated data for the LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps, which were released in 2015–16. Geochemical and geochronology studies

have identified a previously unrecognized 1517–1505 Ma dolerite suite, which provides a minimum age constraint for Depositional Package 1 of the Edmund Group.

A Report on the geochronology and geochemistry of the Rudall Province of the Paterson Orogen was released in 2017. This study revealed the presence of possible Neoproterozoic metasedimentary rocks, widespread 1589–1549 Ma granitic magmatism in the eastern part of the Province and suggests that amalgamation of the West and North Australian Cratons might have occurred significantly later than previously thought. A collaborative study with Curtin University of Lu–Hf and O isotopes of Meso- to Neoproterozoic granitic rocks from the Paterson Orogen completed its data acquisition phase. The results reveal a range of isotopically evolved and primitive magma sources that provide insights into the geodynamic setting and crustal structure of multiple magmatic events.

Work in the West Arunta region focused on compilation of the MACDONALD 1:250 000 Geological Series Map. This has involved generation of a new regolith layer for the sheet as well as revision of the interpreted basement geology based on recent fieldwork.

In the Kimberley region, EIS-funded work in 2016–17 focused on acquisition of detrital zircon geochronology for 1880–1845 Ma metasedimentary units of the Lamboo Province. The results of this dating suggest that terranes previously thought to be exotic might instead have been part of the North Australian Craton and that geodynamic models might require revision. Lu–Hf isotope data for these rocks are currently being collected to test regional correlations. Geochemistry and Sm–Nd isotope data for the 1832–1808 Ma Sally Downs Supersuite were also collected during 2016–17 and incorporated into GSWA databases.

Products released 2016–17

WONYULGUNNA 1:100 000 Geological Series map

West Capricorn Geological Information Series update 2016 (including the LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps)

Report 161: Geochronology of the Rudall Province, Western Australia: implications for the amalgamation of the West and North Australian Cratons

Planned work program and products 2017–18

In the Capricorn Orogen, EIS-funded work in 2017–18 will continue the compilation of legacy data for the basins in the eastern Capricorn Orogen project. Work will commence on the construction of seamless 1:250 000-scale digital geology layers with the progressive release of 1:250 000 mapping tiles each year as digital layers in the East Capricorn Geological Information Series data package.

In the west Arunta region, the MACDONALD 1:250 000 Geological Series Map will be published, with data incorporated into a 2018 update for the Tanami–Arunta Geological Information Series digital data package. This will complete Second Edition mapping of the Arunta Orogen in Western Australia.

A report on the volcanology and geochemistry of the c. 1795 Ma Hart–Carson large igneous province will also be released. This report will present the results of a collaborative study with the University of Tasmania examining the volcanology and geochemistry of this extensive mafic magmatism within the Kimberley Basin. Work will also include preparation of a report documenting the results of detrital zircon dating of the Lamboo Province. EIS-funded work will also contribute to the compilation of the LANSLOWNE 1:250 000 Geological Series map, scheduled for release in 2017–18.

Products planned for release 2017–18

Recognition of a new Mesoproterozoic mafic intrusive event in the Capricorn Orogen (Record)

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

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

MACDONALD 1:250 000 Geological Series map

LANSLOWNE 1:250 000 Geological Series map

Mineral prospectivity of the Southern Basin of the Capricorn Orogen (Yerrida, Bryah, Earraheedy and Padbury Basins) (GIS digital data package)

Volcanology and geochemistry of the Hart–Carson large igneous province (Report)

Detrital zircon geochronology and Lu–Hf isotope study of the Lamboo Province (Report)

Geochronology of the western Granites–Tanami Orogen (Report)

Oxygen and Lu–Hf isotope study of magmatic events in the Paterson Orogen (Report)

Planned work program, products 2018–19 and beyond

Work in the Capricorn Orogen will continue to focus on the compilation of legacy data for the basins in the eastern Capricorn Orogen and the progressive release of 1:2 500 000-scale mapping tiles as digital layers for the Eastern Capricorn Geological Information Series digital product. Work will also focus on the writing and update of explanatory notes for the Eastern Capricorn Basins.

Work in the Kimberley region will include evaluation of geochemical and isotope data of the Sally Downs Supersuite to produce a report on the implications for geodynamic models and mineral prospectivity.

Products planned for release 2018–19 and beyond

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

Eastern Capricorn Geological Information Series 2019 (including a digital compilation of the 250 000 IBG and associated digital layers, and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earraheedy Basins)

Geochemistry and isotope study of Sally Downs Supersuite (Report)

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 continues to extend and enhance 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 additional isotope-related techniques (such as whole-rock Lu–Hf and Pb–Pb isotopes) conducted in collaboration with university research groups. These techniques enable construction of a range of isotopic maps at different scales, which are powerful in imaging lithospheric and crustal architecture, identifying metallogenic terranes and favourable geodynamic environments, and constraining the 4D evolution of the lithosphere. The resulting knowledge will greatly help focus exploration in prospective areas.

Variations of radiogenic isotope compositions (mainly Sm–Nd and Lu–Hf) provide information on the nature of the sources of magmatic rocks, allowing magmas derived from the mantle to be distinguished from those derived by reworking of older crust. Stable isotopes, mainly oxygen, are used to distinguish material derived from near-surface or supracrustal environments from mantle-derived material.

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 in controlling the fertility of a magma for ore formation. 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 2016–17

About 900 previously dated zircons from 24 samples were analysed for Lu–Hf isotopes during 2016–17. Following significant delays in the return of Lu–Hf data during 2016–17, we are expecting results for another 900 zircon analyses from 40 samples in the near future. The samples represent igneous, metamorphic, and sedimentary rocks selected from the Murchison Domain of the Yilgarn Craton, the Gascoyne Province, and the Kimberley

region. More than 100 samples were submitted in 2016–17 for Sm–Nd whole-rock analysis, mainly from the Eastern Goldfields Superterrane, the Murchison Domain, and the South West Terrane of the Yilgarn Craton, as well as the Kimberley region. About 830 previously dated zircons from 50 samples were analysed for oxygen isotopes during 2016–17, mainly from basement rocks beneath the Eucla Basin, and granites of the Pilbara and Yilgarn Cratons and the Capricorn Orogen (Fig. 43).

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, the GSWA Geochemistry (GeoChem Extract) web page, and within the annual compilation of geochronology information released on USB. 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 are described below.

Over 200 new samples have been collected for geochronology, geochemistry, and isotope analysis from igneous rocks in the South West Terrane of the Yilgarn Craton, a region with little pre-existing information. Geochemical (e.g. Eu/Eu*) and Nd isotope mapping using these new data, together with previously available data across the Yilgarn Craton, suggest the existence of east-trending basement structures that cut across current north-trending terrane boundaries. This discovery questions existing models of the structure of the Yilgarn Craton, and forces a rethinking of processes of craton formation and modification and crust amalgamation through time.

Zircons from about 40 previously dated samples from across the Yilgarn Craton have been analysed for trace element compositions. These new data indicate that Archean granites were mainly formed through lower crustal or infracrustal partial melting of mafic crust within the garnet stability field, whereas Phanerozoic Cu-fertile suites were formed by intracrustal amphibole-dominated fractionation of mafic magmas. This in turn suggests that Archean granite magmas are typically relatively dry compared to Phanerozoic Cu-fertile granite magmas. Granites formed by the first process have lower potential for porphyry Cu mineralization due to insufficient water and the lack of increasing copper and sulfur in the melt. Additional data are needed from mineralized Archean granites to determine whether they have different genesis from non-mineralized Archean granites.

The 2013–16 ARC Linkage project ‘Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: constructing a geological framework for understanding mineral systems’, which involved collaboration between GSWA and Curtin University, was completed at the end of 2016. This project used 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 close to completion. One result from this project is the discovery of c. 2400 Ma mineralization and hydrothermal alteration at the Paulsens mine, southern Pilbara Craton. This age does not correspond with any known deformation event in the region, and suggests a significantly different and more complicated low-temperature tectonothermal evolution for the southern Pilbara region than previously recognized.

A three-year research project commenced in 2015 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 presents Hf isotope data from the East Pilbara Terrane that indicate increased reworking of existing crust during the Paleoproterozoic and Mesoproterozoic. Another article in review uses Lu–Hf and oxygen isotope data for Proterozoic granites in the Rudall Province to understand the genesis of Archean TTGs in a non-subduction setting. Finalising the interpretation of Lu–Hf and oxygen isotope data for basement rocks beneath the Eucla Basin is still underway.

Two MRIWA-administered projects continued in 2016–17. The first project, ‘M448: Rutile – Pathfinder to Ores’ 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. Rutile U–Pb ages from previously dated GSWA sandstone samples in some cases show very different age spectra compared to those based on zircon U–Pb ages, indicating that detrital zircon, monazite, xenotime, and rutile may have originated from different sources, and in combination provide the best constraints on maximum deposition ages. In addition, the chemistry of coarse rutile grains can preserve a gold ‘fingerprint’ that may be used to point towards another Tropicana or Big Bell gold deposit.

MRIWA project ‘M446: Re–Os sulphide geochronology’ uses the Re–Os isochron dating of sulfide minerals to determine precise ages for two classes of metal deposits in Western Australia: VMS Zn–Pb–Cu deposits and orogenic gold deposits. For each class of deposit, reviews of geology and geochronology were used to guide sulfide sampling. Minerals such as molybdenite, arsenopyrite, and pyrite are the best minerals for Re–Os geochronology given their high-Re and high Re/Os.

A three-year MRIWA project, ‘M470: Mineral systems on the margin of cratons: Albany–Fraser Orogen / Eucla basement case study’, commenced in May 2016. This project integrates Lu–Hf, Sm–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 to highlight areas of enhanced mantle input within the eastern Albany–Fraser Orogen and adjacent Eucla basement rocks. Three PhD projects at Curtin University are focusing on crustal evolution, petrochronology, and sulfide sources and budgets, respectively.

Products released 2016–17

Lu–Hf data released as part of the Compilation of geochronology information 2017

Lu–Hf and Sm–Nd datasets released to online applications (GeoVIEW.WA and GeoChem Extract)

Ten external journal articles and two conference abstracts (see Appendix C)

Planned work program and products 2017–18

Analyses of Lu–Hf, Sm–Nd, and oxygen isotopes will continue in 2017–18. 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. Existing and new zircon oxygen isotope data will be released for the first time in tabular form via GeoVIEW.WA and in the annual compilation of geochronology information. 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.

MRIWA project ‘M448: Rutile – Pathfinder to Ores’ will continue to develop and test the “small spot” LA-ICPMS method for analysing small rutile grains, to build the geochemistry database on rutiles from ore environments, and to better understand how rutile geochemistry and age are preserved and modified by secondary events. MRIWA project ‘M446: Re–Os sulfide geochronology’ will continue acquisition of sulfide Re–Os and sericite Ar–Ar geochronology at the Nimbus VMS deposit and the Boddington and Big Bell gold deposits. Sulfide Os–Pb isotopes will also be conducted to fingerprint metal sources at these deposits. MRIWA project ‘M470: Mineral systems on the margin of cratons’ will continue to acquire new Hf–Nd–O–S isotope data, and LA-ICPMS trace element and U–Pb data from TIMA mounts and drillcore samples from the Albany–Fraser Orogen and Eucla basement.

Planned work program and products 2018–19 and beyond

The planned work program for 2018–19 and beyond will be similar to that for 2017–18. New samples will be collected during the normal course of GSWA fieldwork to address specific geological problems.

ES47 Petroleum, Coal and CO₂ Geosequestration

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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 gas fields 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; the agency estimated that the Canning Basin 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 possible viable future addition to the State's domestic gas market.

During the last decade, shale has become an important supply of natural gas and oil in the US. Interest in exploring shale 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 tight and shale hydrocarbon potential of the Canning and northern Perth Basin. The results of the Canning Basin project to date include recognition of a new potential petroleum source rock in the Ordovician Nambett Formation; improved correlation of conodont age dating with international time scales using new geochronology (CA-IDTIMS) and chemostratigraphy (carbon isotope curves) results; better estimation of thermal maturity combining geochemistry and several methods of converting organic petrology of bitumen, graptolites and other bioclasts to an equivalent vitrinite reflectance; and the development of a new digital product (called the Digital Core Atlas) to interactively display large data sets from

core analysis results. The first Digital Core Atlas was for the well Olympic 1 and has received wide acclaim from industry, academia and international geological surveys.

Geophysical projects being undertaken that will provide new pre-competitive data and aim to improve the structural and stratigraphic definition of the Canning, Carnarvon and Perth Basins include:

- contribution to a project involving the acquisition of new passive seismic data in the Perth Basin (ES31) with results expected in 2017–18
- reprocessing of selected 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and northwestern Canning Basin
- reprocessing of selected 2D seismic lines in the southern Carnarvon Basin and the Coolcalalaya Sub-basin of the northern Perth Basin
- completion of a revised SEEBASE (depth to basement) product over the Canning Basin by FrogTech Geoscience
- new regional deep crustal seismic survey of almost 900 km in the Kidson Sub-basin of the Canning Basin is currently being planned to be undertaken in winter 2018, jointly funded by GA and GSWA. Following on from the seismic acquisition, stratigraphic drilling is planned for mid-2019 on a location along the new seismic line, to improve understanding of the stratigraphy and petroleum potential of the Kidson Sub-basin and the underlying basement. The stratigraphic hole will be largely funded by GA through its 4-year *Exploring for the Future* project in Northern Australia.

A project to document the coal resources of Western Australia is underway. The first two records to be released in 2017–18 review the exploration history and estimated lignite resource volumes in the southwestern Western Australia including the Eucla Basin; and the Mesozoic coal seams of the northern Perth Basin. Work has commenced on the next two Records which focus on the coal resources of the Canning Basin and the Permian coal resources of the Carnarvon and Perth Basins.

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, with the Canning Basin project 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, DMIRS.

Outcomes of work program 2016–17

Canning Basin

Some of the main outcomes from studies in the Canning Basin in 2016–17 were:

- completion and publication of an interpretation of the Canning Basin deep crustal seismic survey (data acquisition funded by EIS and data processing by GA)
- GSWA continued participation in core analyses of the Lower Ordovician cored in Olympic 1 and Senagi 1, drilled by Buru Energy Ltd; and Theia 1, drilled by Finder Exploration Pty Ltd in 2015. The core analysis is now complete and work on interpreting the results and incorporating the implications into the regional prospectivity assessment and geological framework of the Canning Basin is continuing into 2017–18
- a new interactive digital product has been developed during the last two years, 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. The first atlas covered the core in Olympic 1 and was published during 2016–17. Work continues into 2017–18 on compiling a core atlas for each of Theia 1 and Senagi 1.
- publication of GSWA Report 169 on petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1
- publication of GSWA Report 170 on assessment of thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Olympic 1, Canning Basin
- publication of GSWA Digital Core Atlas: Olympic 1
- publication of GSWA Record 2017/05 on Canning Coastal seismic survey — an overview of the Canning Basin
- Work commenced on a Record assessing the coal resources of the Canning Basin.

- A project to update the SEEBASE product over the Canning Basin and the Western Australia portion of the Amadeus Basin commenced, with a draft of the product completed at the end of 2016–17.

Eucla Basin

The main outcome from studies in the Eucla Basin in 2016–17 was an assessment of the lignite resources of the Eucla Basin and southwest Western Australia, which was completed and will be published as a Record in 2017–18.

Perth Basin

Some of the main outcomes from studies in the Perth Basin in 2016–17 were:

- An assessment of the Mesozoic coal resources of the Perth Basin was completed and Record of the results will be published in 2017–18
- Work commenced in an assessment of the Permian coal resources of the Perth Basin, with a Record of the results expected to be published in 2017–18
- A collaborative core analysis project commenced with AWE Ltd on cores from the northern Perth Basin.

Products released 2016–17

Record 2017/05: Canning Coastal seismic survey — an overview of the Canning Basin

Report 169: Petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1

Report 170: Assessment of the thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Canning Basin

Digital Core Atlas: Olympic 1

Planned work program, products 2017–18 and beyond

Continue regional geological, geophysical and petroleum geochemical studies for the Canning, Perth and Carnarvon Basins during 2017–18 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 includes collaboration on core analysis with AWE Ltd of the core from the Waitsia 3 petroleum well, which was drilled in June 2017 in the north Perth Basin
- 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
- Interpretation of the new reprocessed seismic data
- completion of the SEEBASE product for the Canning Basin and the Western Australian portion of the Amadeus Basin.

Canning Basin

The planned outcomes from studies in the Canning Basin in 2017–18 are to:

- complete seismic reprocessing of vintage 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and the NW portion of the Canning Basin
- complete and release the revised SEEBASE product over the Canning Basin
- continue collaborative core analysis from recent and future wells drilled by petroleum companies in the Canning Basin including cooperative studies with CSIRO
- completion of digital core atlases for the Canning Basin petroleum wells Theia 1 and Senagi 1, which were included in the collaborative core analysis projects
- continue to investigate regional correlations and hydrocarbon potential of the lower to middle Ordovician Goldwyer and Nambeet formations
- define the Goldwyer Formation Reference Section
- complete and assessment of the CO₂ sequestration potential of the Ordovician in the Canning Basin based on the results from the collaborative core analysis project.

Perth Basin

The planned outcomes from studies in the Perth Basin in 2017–18 are to:

- undertake collaborative core analysis projects with AWE Ltd who have acquired core in

Waitsia 3 within 2016–17, with results feeding into regional studies

- release two GSWA Records on the coal resources of the Perth Basin; the first focusing on the Mesozoic and the second Record will document the Permian
- review results obtained from a passive seismic traverse

Southern Carnarvon Basin

The planned outcomes from studies in the Carnarvon Basin in 2017–18 are to:

- complete seismic reprocessing of vintage 2D seismic lines in the Southern Carnarvon Basin and the Coolcalalaya Sub-basin of the northern Perth Basin
- commence interpretation of the newly reprocessed 2D seismic lines and incorporate the results into a wider interpretation project to improve the definition of the stratigraphy and structure of the onshore portion of the basin.

Products planned for release 2017–18

Reference Section: Nambeet Formation, Canning Basin (Report)

Reference Section: Goldwyer Formation, Canning Basin (Report)

Digital Core Atlas, Theia 1, Canning Basin (interactive digital product)

Digital Core Atlas, Senagi 1, Canning Basin (interactive digital product)

Canning Basin Coal Resources (Record)

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

Mesozoic coal resources of Northern Perth Basin (Record)

Lignite resources of the Eucla/Bremer Basin (Record)

Permian coal resources of the Perth and Carnarvon Basins (Record)

Revised SEEBASE model for the Canning and western Amadeus Basins (digital product)

Reprocessed vintage 2D seismic data in the Canning and Southern Carnarvon Basins and the Coolcalalaya sub-basin of the Perth Basin

ES50 Strategic Industry Research Program

Manager: Margaret Ellis

This program has encompassed the following two activities:

- the expansion of research into greenfields exploration with funding support by EIS to the Minerals Research Institute of Western Australia (MRIWA) of \$350 000 per annum since 2009–10
- the Western Australia Regional Researcher Initiative.

This latter activity was 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 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, with the final report published in early 2017.

Outcomes of work program 2016–17

Several new MRIWA projects, which are supported directly or indirectly by GSWA, received approval by the MRIWA Board this year. They were:

- **M493** – Don't bury Western Australia's geophysical data: uncovering prospective mineral terrains with regional potential field, seismic and MT transects through cooperative inversion
- **M494** – Mapping chemical architecture of gold camps
- **M509** – MinEx CRC

In addition, seven more EIS-and GSWA-supported projects were already in progress:

- **M462** Multiscaled 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
- **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 is due for publication next year:

- **M424** Multiscale dynamics of hydrothermal mineral systems

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 first two Reports listed below were published prior to 2016–17, whereas the third (Report 165) was published during 2016–17.

- GSWA Report 144: Greenfields geochemical exploration in a regolith-dominated terrain: the Albany–Fraser Orogeny/Yilgarn Craton margin
- GSWA Report 145: High-grade gold deposits: processes to prediction
- GSWA Report 165: VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks.

Planned work program and products 2017–18

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 2019. The situation after that is subject to review and is dependent on future funding arrangements of EIS. Currently, EIS funding is forecast to terminate in June 2019.

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Appendices

Appendix A: 2017 WA Labor Platform

The following is a partial extract from the 2017 WA Labor Platform (<https://www.walabor.org.au/platform>) . The WA Labor State Platform is set and revised by each State Conference and it outlines WA Labor’s core beliefs and policy priorities. The Platform does not contain specific election promises or commitments. For ease of reference to the original document, headings and reference numbers below are as per the original Platform document. All of the wording below is directly quoted from the original document.

CHAPTER 3: CONSERVATION, THE ENVIRONMENT AND CLIMATE CHANGE

ENVIRONMENT

1. WA Labor believes that:

- a) A strong economy and environmental sustainability are mutually compatible;
- b) The Western Australian Government’s responsibility is to ensure that the present needs of everyone in our community are met without compromising the ability of future generations to meet their needs;
- c) Committing to sustainability will create jobs, improve living standards, support regional development and encourage growth in new industries;
- d) Environmental sustainability requires a whole of government approach and that all government decision-making should consider the need for a sustainable future;
- e) Biodiversity is crucial to environmental sustainability and must therefore be protected; and
- f) Aboriginal people have a relationship with the land that gives them the right to determine and implement environmental policy for that land, subject to the determinations of the Environmental Protection Authority.

CLIMATE CHANGE & CLEAN ENERGY

2 WA Labor recognises the science demonstrating that Human induced climate change is real and Western Australia's natural environment, public health infrastructure and economy are all vulnerable to its impacts.

3 WA Labor supports the need for Western Australia to develop strong mitigation and adaptation plans to deal with the consequences of climate change.

4 WA Labor supports the need for a comprehensive Energy, Jobs and Community Transition Plan to smoothly and fairly transition WA's energy sector from fossil fuel based energy production to renewable based energy production.

5 WA Labor believes that:

- a) Responding to climate change presents Western Australia with an opportunity to diversify our economy, create jobs and enhance our social fabric;
- b) Reducing energy use and improving energy efficiency is the most economically viable and cost effective way to reduce greenhouse emissions;
- c) A market-based mechanism is a highly effective method to reduce carbon emissions on a large scale; and
- d) The Western Australia Government must establish and work towards renewable energy targets for Western Australia, consistent with target commitments made by Federal Labor.
- e) The WA Government should have a dedicated office tasked with implementing and monitoring climate change policies.

6 In Government, WA Labor will:

- a) Consider legislation that includes:
 - i. Implementing a mandatory energy efficiency scheme for large and medium electricity users;

- ii. Supporting mandatory renewable energy targets; and
- iii. Continuing to develop ways to reduce waste to landfill and increase recycling.

b) Monitor the effects of greenhouse offsets in reducing the carbon footprint of major projects;

6 q) Develop the legislation, policy and science necessary for the establishment of a commercial carbon sequestration industry in Western Australia's Rangelands, ensuring that a royalty is paid to government for use of this publicly owned resource.

9 c) Explore the relative costs and benefits of Pumped Hydro Storage at sites in the Collie Region, near the Perth Metro area, namely the Darling Range, population centres in the South West, namely the Stirling Range, and relevant sites in the North of the State, namely the Super Pits.

FRACKING

WA Labor acknowledges that communities have expressed opposition to gas fracking development throughout the State, and that the previous Government failed to protect communities and the environment from the harmful effects of this industry.

WA Labor will immediately ban fracking in the SouthWest, Perth, Peel and Swan Valley Regions.

WA Labor supports a scientific approach to the regulation of fracking, and will conduct a public inquiry to examine environment, health, agriculture, heritage and community impacts prior to any fracking activity.

WA Labor will place a moratorium on the use of fracking until such an inquiry can demonstrate that fracking will not compromise the environment, groundwater, public health or contribute adversely to climate change.

Following the public inquiry into fracking and where supported by Traditional Owners, WA Labor will consider a permanent ban on fracking in any water reserves or

groundwater areas, productive farmlands, or areas with environmental, cultural heritage or tourism values which could be compromised by fracking.

WA Labor supports strong, enforceable measures to protect groundwater aquifers from pollution, contamination or depletion by industrial activities including the oil and gas industry.

WA Labor will target renewable energies in order to combat climate change and diversify regional economies to create employment opportunities.

REGULATION

18 b) WA Labor believes that: The long term legacy issues associated with the closure and rehabilitation of mining and other industrial sites in Western Australia must be addressed as a matter of urgency to ensure that proponents, and not taxpayers, pay the costs of closure and rehabilitation.

19 In government, WA Labor will:

b) Insist that mine closure plans and the capacity to finance and progressively implement those plans will be built into the assessment processes for mining proposals and developments;

c) Review and, where necessary, modify existing mine closure plans where the proponent's capacity to finance and progressively implement those plans is in doubt;

URANIUM AND THORIUM

20 WA Labor believes that:

a) Enriching uranium poses significant risks to human health, the natural environment and is not a solution to climate change; and

b) Thorium also poses significant risks to human health and the environment.

21 In Government, WA Labor will:

- a) Oppose the mining and export of uranium;
- b) Oppose nuclear enrichment, nuclear power and otherwise the production of dangerous radioactive waste;
- c) Oppose the storage of nuclear energy waste in Western Australia;
- d) Oppose the testing or use of nuclear weapons in Western Australia or near our coastline;
- e) Encourage local governments to declare themselves ‘Nuclear Free Zones’; and
- f) Ensure that the mining of thorium in Western Australia only occurs under the most stringent environmental conditions and oppose thorium exports to countries that do not observe the Nuclear Non-Proliferation Treaty.

RESOLUTIONS

29

WA Labor notes and congratulates the McGowan Government’s delivery of a core election promise to ban all future uranium mining applications in Western Australia.

WA Labor reaffirms its long and principled opposition to the mining and use of uranium due to the devastating effect it and its byproducts have on workers, the environment and communities.

WA Labor, in particular, notes that due to the location of uranium deposits in WA, any potential mining of uranium would likely have a disproportionate effect on Indigenous communities.

WA Labor also reaffirms its pre-election commitments to investing in renewable energy and leading the industry in the development and implementation of sustainable energy technology.

This Conference condemns the previous Liberal Government for its reckless approval of uranium mining projects within Western Australia.

WA Labor State Conference notes the legal advice that these approvals cannot be overturned without serious legal and financial ramifications for the State.

WA Labor cannot and will not use taxpayers' money to pay out projects which are not financially viable.

WA Labor commits to supporting and resourcing the Environmental Protection Authority, the Department of Mines and Petroleum, WorkSafe and any other relevant departments to ensure they have the capacity to guarantee strict compliance from any potential uranium mines to best practice in the environmental, industrial and community spheres.

CHAPTER 4: ECONOMICS, INDUSTRY AND REGIONAL DEVELOPMENT

PUBLIC SECTOR EMPLOYMENT

250: WA Labor will, in consultation with relevant unions of government employees, review the use of labour hire, independent contractors and consultants to ensure that such employment or contract arrangements are used only where necessary and in accordance with ALP policy on government and determine the need for amendments to the Public Sector Management Act or other relevant legislation.

MINERALS AND ENERGY

The Responsible Development of Western Australia's Resources

INTRODUCTION

266 Western Australia owns a rich and varied world class mineral endowment. The mining and energy industries developed around the extraction of these minerals are a major source of export earnings, direct and indirect employment. Labor recognises that Australia's minerals and energy industries are vital to the strength of our economy.

267 WA Labor believes that there is further potential for development of these industries. The greatest economic and social benefits from further development-will come from leveraging this development into high skills jobs.

268 WA Labor will ensure that any development or expansion of the mining and energy industries will only proceed in an environmentally sustainable way, with the highest standards for the health and safety of workers and their communities, and with protection for the native title rights of traditional owners.

PROMOTING DEVELOPMENT

269 WA Labor will:

- a) Maintain and encourage sound relations with our trading partners, between governments, and where appropriate, between government statutory authorities;
- b) Work to ensure that WA remains a desirable option for investment in minerals and energy exploration and development;
- c) Encourage mining companies and State and Commonwealth Governments to cooperate in international negotiations;
- d) Support efforts to provide a positive framework for the exchange of information and a forum for discussion on the industry, involving all industry players;
- e) Introduce changes to the Mining Act directed at harmonising its process with those of the Native Title Act with a view to ensuring mining titles are processed in the shortest practical time; and
- f) Investigate ways to increase ‘green fields’ exploration undertaken in the State.

BALANCING DEVELOPMENT

270 To ensure a proper balance between economic, social and environmental concerns in all developments WA Labor will:

Economic

- a) Encourage exploration and development of mineral and energy deposits;

- b) Promote Western Australia as an international centre for the mining industry and create a long term plan for the development of the industry;
- c) Promote the development of products and technologies which reduce pollution and greenhouse emissions and add to environmental sustainability;
- d) Promote research to improve the efficiency, safety and environmental performance of the minerals and energy sector;
- e) Promote the sourcing and purchase of locally manufactured and fabricated products and local services where possible, for use in every stage of a project;
- f) Promote downstream processing projects in Western Australia, including by ensuring there is adequate infrastructure and suitable sites for projects;
- g) Ensure that new developments optimise the use of existing infrastructure;
- h) Ensure that infrastructure agreements serve the financial interests of the State and that major projects entailing State Government or statutory authority infrastructure expenditure are subject to social impact, energy audits, economic and environmental cost/benefit analysis and public scrutiny;
- i) Ensure the industry contributes adequately to the cost of infrastructure requirements;
- j) Recognise that Western Australia's mineral resources are an important non-renewable asset which should only be exploited in a manner that maximises benefits to Western Australia;
- k) Ensure that the levels of royalties in minerals are at levels that ensure project economic viability while maximising returns to the community;
- l) Work to ensure that mining companies active in Western Australia do not use their place in the global market to drop the price of commodities in order to drive out other local mining companies, thus reducing employment, community and taxation returns;

- m) Insist that all existing and new mineral and energy developments enforce the highest possible standard of safe working practices;
- n) Ensure the mining and extractive industries adequately fund education and training for its workforce through an Industry Training Council involving key representatives from all levels of industry;

Social

- o) Ensure that all minerals and energy sector development proposals and plans are accessible to the public and subject to social and environmental impact assessments;
- p) Such assessments will include public review and community consultation;
- q) Ensure the protection of Aboriginal sacred sites and cultural heritage and that all reasonable demands by the local Aboriginal community for compensation, and participation in the benefits of developments, are met with a view to facilitating Aboriginal participation in the broader economy;
- r) Ensure that companies accept their financial and social responsibility towards:
 - i) People moving into an area of development;
 - ii) Development of independent communities; and
 - iii) Local governments, including ensuring costs incurred by local government as a consequence of development are met through appropriate mechanisms.

Environmental

- s) Ensure that mining has minimal adverse impact on water resources and that the public are informed and consulted about any changes that affect the quality of water;
- t) Ensure that emissions from refining and processing of mineral products are subject to rigorous environmental and epidemiological reviews.

- u) Ensure that occupational health and safety standards (where workplace radiation levels occur above background levels) are pegged to those of the International Commission on Radiological Protection (ICRP); and
- v) Continue to monitor the performance of all areas of the industry where any possible radiation risk to the public, or workers, exists, and ensure that industry complies with the stricter of the Australian Codes of Practice, or international standards for the separation, storage, transport and processing of these minerals and disposal of any waste products.

ENERGY

271 WA Labor recognises the importance of the provision of energy for economic development and householders. The provision of energy needs to balance a range of interests such as sustainability, affordability, available resources and latest technology. WA Labor will develop and implement a plan to generate 20% of Western Australia's energy production from renewable energy resources by 2020.

272 To achieve this goal, WA Labor will:

- a) Maintain a renewable energy buy-back scheme to require electricity suppliers to purchase from individuals;
- b) Promote fuel switching, energy efficiency and green power purchases among domestic and commercial users;
- c) Continue community service obligations by the utilities;
- d) Ensure that government policy incorporates the principles of energy efficiency particularly in respect of commercial and domestic construction, urban planning and transport;
- e) Promote Western Australia as an international centre for research and development in energy technologies in both conventional and renewable sectors;

- f) Labor is committed to the long term future of the Collie coalfields as a source for base load electricity, until viable alternative base load energy sources become available. In this framework, Labor will ensure that the future of coal is developed within a framework using clean coal technology; and
- g) Maintain the Domestic Gas Reservation policy so that there is an oversupply of gas into the Western Australian domestic market. An oversupply of gas will lead to lower gas prices in the domestic market, and innovative uses of the gas, as has occurred in the United States in response to their domestic gas reservation policy.

ENERGY UTILITIES

273 WA Labor is committed to the public ownership of energy utilities, but will ensure that energy generation, transmission and distribution industries, whether publicly or privately owned, are independently regulated to provide a competitive market. WA Labor recognises the importance of reducing energy costs for business and householders as well as the need to retain natural monopolies as a publicly owned utility.

URANIUM MINING & NUCLEAR ENERGY

274 Recognising the problems, hazards and dangers of nuclear power, especially relating to:

- a) The safety of the nuclear fuel cycle;
- b) The unsolved problems pertaining to the reprocessing and storage of radioactive wastes and spent plant;
- c) The growing concern about the biomedical effects of even low radiation;
- d) The coupling of nuclear energy and nuclear weapon development;
- e) The added danger of a future plutonium economy and the threats to civil liberties involved in a nuclear economy; and
- f) The fact that Labor policy contained herein on fossil fuels, energy conservation and renewable resources will ensure Western Australian energy self sufficiency.

275 WA Labor will:

- a) Reject nuclear power as an option for electricity generation in Western Australia;
- b) Oppose the establishment of a nuclear enrichment facility in the State;
- c) Reject the establishment of nuclear processing plants or the storage of nuclear wastes in the State;
- d) Allow no uranium mining or development in Western Australia; and
- e) Place thorium under the restrictions and conditions applicable to the mining, processing, sale and transportation of uranium currently mined in Australia as outlined in the Resources and Energy section of the National Platform, so far as they relate to nuclear non-proliferation.

276 The platform recognises WA Labor's long and continuous opposition to Uranium Mining. The commencement and continuation of any uranium project is inconsistent with WA Labor Policy. WA Labor will accept no obligation to complete approval processes or honour contractual arrangements entered into by a previous government where such approvals or contracts are directed towards an outcome inconsistent with WA Labor's platform.

SUSTAINABLE RESOURCE AND INDUSTRIAL DEVELOPMENT IN OUR REGIONS

300 WA Labor recognises both the existing and potential contribution of the resources sector to the development of our regions and will work to attract new investment in major resource and industrial development projects.

301 WA Labor recognises that periods of rapid industrial expansion place strain on regional communities and is committed to minimising the negative impacts of such periods, for the benefit of local communities and all Western Australians.

302 WA Labor will undertake strategic planning for major resource and industrial development sites on a regional basis. Such planning should be undertaken within a sustainability framework that assesses potential sites according to:

303 Economic factors, including the direct and indirect economic and employment benefits to both the State and Regional economies and the cost of economic infrastructure required:

- a) Social factors, including the capacity of government agencies to deliver services, the potential of regional communities to meet employment and skill demand, the availability of residential housing, community attitudes to development and Aboriginal heritage issues;
- b) Environmental factors, using strategic level EPA assessments that identify all environmental issues and the appropriate industrial capacity of locations; and
- c) Labor will encourage major resource and industrial development projects to locate where there is the optimum balance of economic, social and environmental factors, as identified in the strategic planning process.

304 WA Labor will examine local government, environment, planning, regional development and other relevant legislation to assess the extent to which these permit forward strategic environmental assessment and planning for major resource and industrial development projects within our regions. Where possible, WA Labor will amend legislation to facilitate strategic plans, thereby facilitating efficient assessment processes for major resource and industrial development proposals that comply with these plans.

305 WA Labor will establish or commit to economic infrastructure required in designated development locations and industrial sites as early as is consistent with sound financial management.

306 WA Labor recognises that existing Commonwealth / State financial relations result in a disproportionate amount of direct financial benefits from resources projects accruing to the Commonwealth Government and the limitation this places on the State in providing

the economic infrastructure required to attract investment to our regions. WA Labor will campaign for a new deal on Commonwealth / State financial relations to enable greater investment by the State in economic infrastructure and the attraction of increased levels of investment in major resource and industrial development projects within our regions.

307 WA Labor will make all available data on environmental values (ranging from endangered species' habitats to the management plans for maintaining the ambient quality of air, land and water) from formal strategic environmental plans, regional surveys and regional environmental management plans publicly available, so that project proponents can develop their proposals consistent with achieving government sustainability objectives.

308 WA Labor will investigate the establishment of a fund to assist regional communities to participate in the environmental impact assessment of major projects.

309 As part of a major project proponent's development application, WA Labor will require the proponent to develop a sustainability statement that addresses the economic, social and environmental impacts of the project during the construction and operations phases and following site rehabilitation, in a manner that enables the government to assess the overall cost benefit to both the region and the State from a sustainability perspective. This statement should be released in parallel with any formal document released for public review under the Environmental Protection Act.

CHAPTER 9: INTERNATIONAL RELATIONS

ASIAN ENGAGEMENT: A WHOLE OF GOVERNMENT APPROACH

1 WA Labor will appoint a Minister for Asian Engagement, charged with overseeing the implementation of an Asian Engagement Strategy

2 Develop a whole of government Asian Engagement Strategy to guide economic diversification and create jobs. The strategy will address the following issues and initiatives:

- a) Support WA small and medium-sized businesses engage Asia to attract capital investment and exploit export opportunities;

- b) Subsidise Asian language training to public servants and consider a small allowance to those who achieve a recognised standard;
- c) Help to establish a dedicated centre for Asian Engagement by competitive tender at a WA university;
- d) Commit to sending WA government delegations to at least one Asian country every year aligned with the Asian Engagement Strategy priorities and ensure gender equity of these delegations;
- e) Require every government department to develop a “Supporting Asian Engagement Plan” and manage its implementation;
- f) Host an annual ASEAN Dialogue, concurrently with a trade and investment show, and Asian Arts Festival. In similar vein a WA Labor government will conduct an annual high-level dialogue with the Indian Ocean Rim Association (IORA) as well as pursue other numerous opportunities to hold regional trade, political, cultural and social forums in Perth and encourage other similar forums to take place across Western Australia;
- g) Establish an Asian exchange program that will assist with members of the government, not-for-profit, and private sector to engage with our Asian neighbours; and
- h) Fund leading arts companies to tour Asian cities; and support Asian arts companies in touring Western Australia.

Appendix B: GSWA maps, books and datasets released 2016–17

Geological maps

1:100 000 Geological Series maps

MEEKATHARRA, WA Sheet 2544 by *Romano, SS, Ivanic, TJ and Chen, SF*

THUNDELARRA, WA Sheet 2340 by *Zibra, I, Chen, SF, Ivanic, TJ, Li, J and Gu, P*

UAROO, WA Sheet 1952 by *Cutten, HN, Johnson, SP and de Souza Kovacs, N*

WONYULGUNNA, WA Sheet 2848 by *Thorne, AM and Blay, OA*

WOODLEY, WA Sheet 2642 by *Ivanic, TJ*

Non-series maps

Aboriginal land, conservation areas, mineral and petroleum titles and geology,
Western Australia — 2017 by *Ridge, KJ*

Iron ore deposits of the Pilbara region 2017 by *Cooper, RW*

Layered intrusions of the Youanmi Terrane, Yilgarn Craton by *Ivanic, TJ*

Major resource projects, Western Australia — 2017 by *Cooper, RW, Wyche, NL,
Strong, C, Day, LJ, Jones, JA and Irimies, F*

Mineral deposits and petroleum fields 2017 by *Cooper, RW, Wyche, NL, Strong, CA,
Day, LJ and Jones, JA*

Mines — operating and under development, Western Australia — 2017 by *Cooper,
RW, Strong, CA, Wyche, NL, Day, LJ and Jones, JA*

Plates

Geological interpretation of the Canning Basin along Canning Coastal seismic lines
14GA-CC1 and 14GA-CC2 by *Zhan, Y*

Geological interpretation of the Madura and Coompana Provinces along the Eucla–
Gawler seismic and magnetotelluric line 13GA-EG1 by *Spaggiari, CV, Dutch,
RA, Doublier, MP, Pawley, MJ and Thiel, S*

Interpreted regolith–landform geology of the Dambimangari area, west Kimberley by
de Souza Kovacs, N

Publications

Bulletins

Mineral Resources Bulletin 25 Gemstones of Western Australia second edition by
Fetherston, JM, Stockmayer, SM and Stockmayer, VC

Reports

- Report 158 Deposit-scale targeting for gold in the Yilgarn Craton: Part 3 of the Yilgarn Gold Exploration Targeting Atlas *by Witt, WK*
- Report 161 Geochronology from the Rudall Province, Western Australia: implications for the amalgamation of the West and North Australian Cratons *by Maidment, DW*
- Report 163 MRIWA Report Project M426: exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia *by Duuring, P, Teitler, Y, Hagemann, S and Angerer, T*
- Report 164 Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia *by Phillips, C, Orth, K, Hollis, JA, Kirkland, CL and Bodorkos, S*
- Report 165 VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks *by Hollis, S, Yeats, CJ, Wyche, S, Barnes, SJ and Ivanic, TJ*
- Report 166 Thermo-mechanical evolution of orogeny in the Musgrave Province *by Walsh, A*
- Report 167 The geology, tectonic evolution and gold mineralization of the Lawlers region: a synopsis to 2001 *by Beardsmore, T*
- Report 169 Petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1 *by Normore, LS and Dent, LM*
- Report 170 Assessment of thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Olympic 1, Canning Basin *by Dent, LM and Normore, LS*
- Report 171 The volcanology, petrogenesis, and economic potential of the Mesoproterozoic shallow-water, intra-caldera, lava-like rheomorphic Kathleen Ignimbrite, west Musgrave Province, central Australia *by Medlin, CC*
- Report 172 Petrogenesis of the mafic–ultramafic intrusions of the Mesoproterozoic Giles Event, Musgrave Province, central Australia *by Seubert, REB*

Records

- Records 2016/1 Geological Survey work program for 2016–17 and beyond
- Record 2016/12 Komatiites and associated rocks of the Kalgoorlie–Leonora region *by Barnes, SJ, Mole, D, Wyche, S and Dering, G*
- Record 2016/13 13th International Ni–Cu–PGE Symposium, Fremantle, Australia: Abstracts *by Godel, B, Barnes, SJ, Gonzalez-Alvarez, I, Fiorentini, ML and Le Vaillant, M*
- Record 2016/14 Mineralogy of gold from the Paulsens and Mount Olympus deposits, northern Capricorn Orogen, Western Australia *by Hancock, EA and Thorne, AM*
- Record 2016/15 Regolith chemistry of the Dambimangari area, west Kimberley *by Morris, PA, Scheib, AJ and de Souza Kovacs, N*

- Record 2016/16 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/17 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/18 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/19 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/22 Petrology and geochemistry of the Eoarchean Manfred Complex: origin and components *by Rowe, ML*
- Record 2017/2 GSWA 2017 Extended abstracts: promoting the prospectivity of Western Australia
- Record 2017/3 Provenance, depositional setting and regional correlations of the Ordovician Carranya Formation, Canning Basin *by Normore, LS*
- Record 2017/4 Geological reconnaissance of the southern Murraba Basin, WA *by Haines, PW and Allen, HJ*
- Record 2017/5 Canning Coastal seismic survey — an overview of the Canning Basin *by Zhan, Y*
- Record 2017/6 TARGET 2017, Perth, Australia: abstracts *by Wyche, S and Witt, WK*
- Non-series books*
- An Early Devonian fish fauna from an unnamed sandstone in petroleum exploration well Wendy 1, northern Perth Basin *by Martin, SK*
- Calendar 2017: Geological Survey of Western Australia
- Fieldnotes: A Geological Survey of Western Australia newsletter 2017 January issue 81
- Fieldnotes: A Geological Survey of Western Australia newsletter 2017 April issue 82
- Fieldnotes: A Geological Survey of Western Australia newsletter July 2016 number 79
- Fieldnotes: A Geological Survey of Western Australia newsletter October 2016 number 80
- GSWA guide to editing digital products 2017–18
- Petroleum prospectivity of State Acreage Release Areas L17-1, L17-2, L17-3, L17-4 and L17-5, Canning Basin, Western Australia
- Specifications for 3D models submitted to GSWA *by Murdie, RE and Lindsay, MD*
- WA unearthed series: A Paleozoic perspective of Western Australia *by Mory, AJ*

Western Australia atlas of mineral deposits and petroleum fields 2017

Datasets

Geological Information Series

East Yilgarn Geological Information Series 2017

Kimberley Geological Information Series 2017

Murchison Geological Information Series 2017

Western Capricorn Geological Information Series 2016

Data packages

Compilation of geochronology information, 2017

Compilation of WAROX data, 2017

GSWA Open Day 2017

Iron ore deposits of the Pilbara, 2017

Manganese deposits of the Pilbara and Capricorn regions, 2016

NAPE 2017

Olympic 1, 2017: Digital Core Atlas Series

Rocklea Inlier, 2016: 3D Geomodel Series

State Acreage Release May 2017

Virtual tour of the mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton

West Musgrave GIS 2017

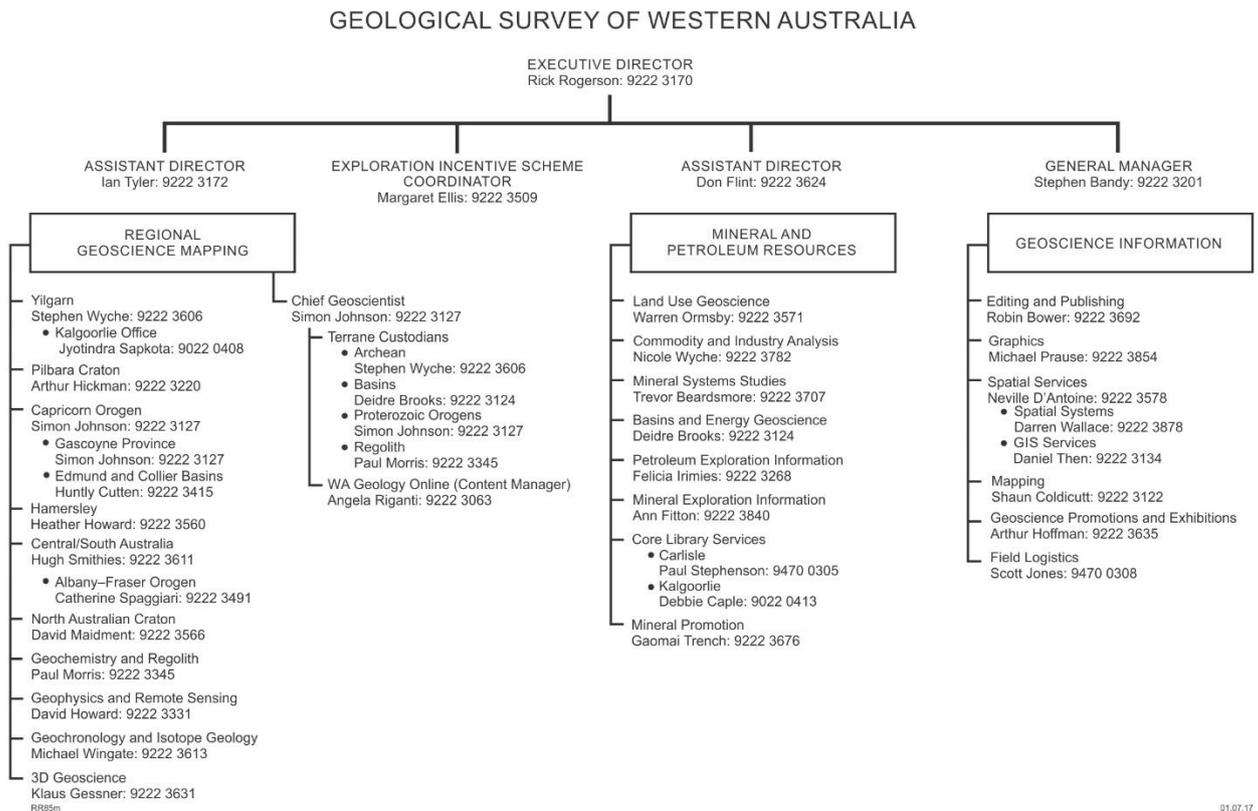
Explanatory Notes System

Murchison Explanatory Notes System 2017 (which is delivered online via ENS)

Posters

58 scientific posters

Appendix C: Organisational structure — 30 June 2017



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Appendix D: GSWA external publications on Western Australian geoscience 2016–17

- Allen, H-J**, Grey, K and **Haines, PW** 2016, Stromatolite biostratigraphy of the western Amadeus Basin supporting Neoproterozoic-Cambrian stratigraphic revisions: Geological Society of Australia Abstracts 117 *edited by* JR Laurie, PD Kruse, DC Garcia-Bellido and JD Holmes, p. 16–17.
- Barham, M, Kirkland, CL, Reynolds, S, O'Leary, MJU, Evans, NUJ, **Allen, H**, **Haines, PW**, Hocking, RM, McDonald, BJ, Belousova, E and Goodall, J 2016, The answers are blowin' in the wind: ultra-distal ashfall zircons, indicators of Cretaceous super-eruptions in eastern Gondwana: *Geology*, v. 44, p. 643–646.
- Burley, L**, Barnes, S, Mole, D, Fiorentini, M and Belbin, W 2016, The Fisher East nickel sulfide prospects: 13th International Nickel–Copper–PGE Symposium abstracts, Perth, Western Australia, September 2016.
- Burley, LL**, Barnes, SJ, Laukamp, C, Mole, DR, Le Vaillant, M and Fiorentini, ML 2017, Rapid mineralogical and geochemical characterisation of the Fisher East nickel sulphide prospects, Western Australia, using hyperspectral and pXRF data: *Ore Geology Reviews*, doi: [org/10.1016/j.oregeorev.2017.04.032](https://doi.org/10.1016/j.oregeorev.2017.04.032).
- Donskaya, TV, Gladkochub, DP, Ernst, RE, Pisarevsky, SA, Mazukabzov, AM, Soderlund, U, **Wingate, MTD**, Hamilton, MA and Demonterova, EI 2016, Age and geochemical characteristics of major mafic dyke swarms in the southern part of the Siberian craton: *Acta Geologica Sinica (English Edition)*, v. 90 (supp. 1), p. 125–126.
- Donskaya, TV, Gladkochub, DP, Ernst, RE, Pisarevsky, SA, Mazukabzov, AM, Soderlund, U, **Wingate, MTD**, Hamilton, MA, and Demonterova, EI 2016, Age and geochemical characteristics of major mafic dyke swarms in the southern part of the Siberian craton: *Acta Geologica Sinica*, v. 90, p. 6–7.
- Duuring, P**, Hassan, L, Zelic, M and **Gessner, K** 2016, Geochemical and spectral vectors for metamorphosed and deformed VMS-style mineralisation in the Quinns district, Yilgarn Craton, Western Australia: 2016 TIGeR Conference — rock alteration in the upper crust: element mobility and concentration: Curtin University, Perth, Western Australia, p. 17.
- Fielding, I**, **Johnson, SP**, Rasmussen, B, Muhling, JR, Dunkley, DJ, Zi, J, Sheppard, S and **Wingate, MTD** 2016, In situ SHRIMP geochronology to reduce the search area for orogenic gold exploration: 35th International Geological Congress, Capetown, South Africa.
- Gessner, K**, **Murdie, R**, Yuan, H, **Brisbout, L**, Sippl, C, **Tyler, I**, Kirkland, C, **Wingate, MTD**, **Johnson, S**, **Spaggiari, C**, **Smithies, RH**, **Lu, Y**, Gonzalez, C, Jessell, M, Holden, EJ, Gorczyk, W, and Occhipinti, S 2017, Continental geodynamics and mineral exploration — the Western Australian perspective: *Geophysical Research*

Abstracts, v. 19.

- Ghori, KAR** 2016, Shale petroleum resources of Western Australia: Australian Organic Geochemistry Conference, Fremantle, Western Australia, 4 December 2016.
- Ghori, KAR** 2017, Petroleum system modelling of the Perth Basin, Western Australia: AAPG Datapages/Search and Discovery Article #90217.
- Ghori, KAR** 2017, Petroleum systems modelling of the Perth Basin, Western Australia: American Association of Petroleum Geologists.
- Gladkochub, DP, Donskaya, TV, Ernst, RE, Pisarevsky, SA, **Wingate, MTD** and Soderlund, U 2016, Proterozoic Dyke Swarms of the Siberian Craton and Their Geodynamic Implications: *Acta Geologica Sinica (English Edition)*, v. 90 (supp. 1), p. 6–7.
- Guilliamse, JN** and **Beardsmore, TJ** 2017, Is there an unrecognised c. 1800 Ma mineral system in the northern Capricorn Orogen, Western Australia, *in* Future Understanding of Tectonics, Ores, Resources, Environment and Sustainability *edited by* JM Huizenga et al.: Economic Geology Research Unit, James Cook University, p. 50.
- Haig, DW and **Mory, AJ** 2017, Middle Permian (Roadian) Foraminifera from mudstone facies of the type Baker Formation, Southern Carnarvon Basin, Western Australia: *Journal of the Royal Society of Western Australia*.
- Haig, DW, **Mory, AJ**, McCartain, E, Backhouse, J, Håkansson, E, Ernst, A, Nicoll, RS, Shi, GR, Bevan, JC, Davydov, VI, Hunt, A, Keep, M, **Martin, SK**, Peyrot, D, Kossavaya, O and Dos Santos, Z 2016, Late Artinskian–Early Kungurian (Early Permian) warming and maximum marine flooding in the East Gondwana interior rift, Timor and Western Australia, and comparisons across East Gondwana: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 468, p. 88–121.
- Haines, PW** 2017, Drilling to basement at Hickman Crater, Western Australia: 2017 International workshop on: shock metamorphism in terrestrial and extra-terrestrial rocks, The Institute for Geoscience Research, Curtin University, Perth, 26–29 June 2017.
- Haines, PW**, Kirkland, CL, **Wingate, MTD**, **Allen, HJ**, Belousova, EA and Gréau, Y 2016, Tracking sediment dispersal during orogenesis: A zircon age and Hf isotope study from the Amadeus Basin, Australia: *Gondwana Research*, v. 37, p. 324–347.
- Hancock, EA**, Thorne, AM, Roche, LK and **Beardsmore, TJ** 2016, Gold provenance fingerprinting and prospectivity in Western Australia: 35th International Geological Congress, Cape Town, South Africa.
- Hartnady, M, Kirkland, CL, Clark, C, **Spaggiari, C** and **Smithies, RH** 2017, Peering into the deep: Illuminating the crustal evolution of the Eucla basement and its relationship to the Albany-Fraser Orogen of southwest Australia: EGU General Assembly 2017, v. 19.
- Hassan, LY and Roberts, MP 2016, Tellurides associated with volcanogenic massive

sulfide (VMS) mineralization at Yuinmery and Austin, Western Australia: *Ore Geology Reviews*, v. 80, p. 352–362, doi: 10.1016/j.oregeorev.2016.07.005.

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Johnson, TE, Brown, M, Gardiner, NJ, Kirkland, CL and **Smithies, RH** 2017, Earth's first stable continents did not form by subduction: *Nature*, v. 543, p. 239–242.

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**Appendix E: Current collaborative research projects at 1 July
2017**

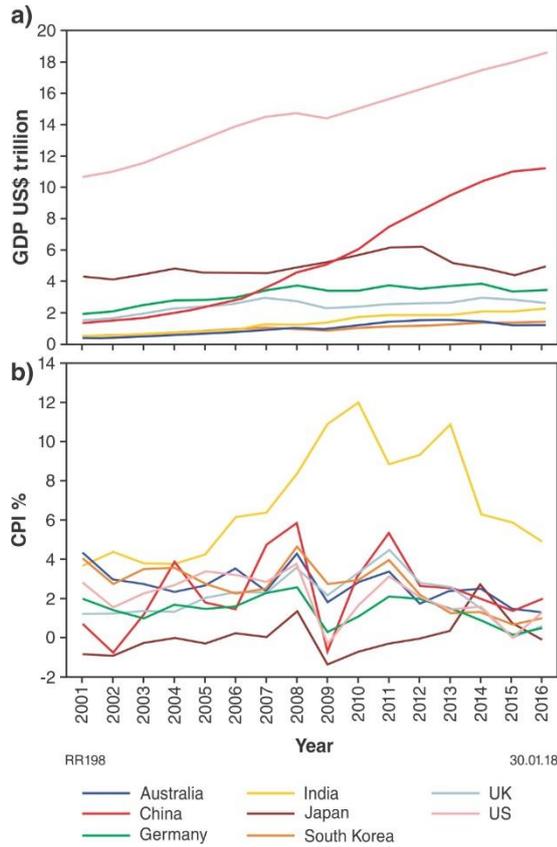
<i>Project cost centre</i>	<i>Collaborating entity</i>	<i>Project title</i>
ES31	ANU	ARC Linkage Project LP130100413: Craton modification and growth: The East Albany–Fraser Orogen in 3D
ES31	Centre for Exploration Targeting UWA	Fraser magnetotelluric survey
ES31	Geoscience Australia, Geological Survey of South Australia, AuScope Earth Imaging	Eucla–Gawler seismic, gravity and MT survey
ES31	MRIWA	M476: An integrated multi-scale study of crustal structure and prospectivity of the eastern Yilgarn Craton and adjacent Albany–Fraser Orogen
ES33	CSIRO	Eucla hydrogeochemistry of WA
ES33	MRIWA, CSIRO	MRIWA M462: Ultrafine fraction geochemistry
ES42	AMIRA – DET CRC	Deep Exploration Technologies Cooperative Research Centre
ES42	Centre for Exploration Targeting UWA, MRIWA	ARC Linkage Project LP100200785: Multiscale dynamics of ore-body formation - project extension through the MRIWA Project M424, multiscale dynamics of hydrothermal mineral systems
ES42 & ES46	Macquarie University, Curtin University and UWA	ARC Centre of Excellence CE11E0070: Core-to-crust fluid systems
ES43	Centre for Exploration Targeting UWA	Mapping sulfur sources in selected Precambrian terranes of Western Australia to enhance predictive targeting for gold and base metal mineralization
ES43	Centre for Exploration Targeting UWA	Predictive exploration for BIF-hosted Fe deposits in the Yilgarn Craton, Western Australia
ES43	Centre for Exploration Targeting UWA	ARC Linkage Project LP140100267: Reducing 3D geological uncertainty via improved data interpretation methods
ES43	CSIRO	Integrated spectral mapping of Au-hosted mineralisation, Nanjilgardy Fault
ES43	CSIRO, CET, Curtin	The distal footprints of giant ore systems: UNCOVER Australia project RP04-063
ES43	Northern Minerals Ltd, Curtin University	Geological studies of the Browns Range HREE mineralization
ES43 & ES31	Centre for Exploration Targeting UWA	Second generation regional targeting products: data generation and integration

ES43 & GS20	CRC for Metals Discovery – University of Tasmania	Yilgarn pyrite fingerprint database
ES43 & GS20	KalNorth Gold Mine	Provenance fingerprinting of gold from Kurnalpi Goldfield
ES43 & GS20	Northern Star Resources Ltd, Curtin University, UWA	Determining the age of gold mineralisation at the Paulsens mine, northern Capricorn Orogen, using monazite and xenotime geochronology
ES45	Centre for Exploration Targeting UWA	Stratigraphic contact analysis tool
ES45	Macquarie University (Sandra Piazzolo)	Yalgoo Dome structural project
ES45	MRIWA, Curtin University, CET (Chris Kirkland)	MRIWA M470: Mineral systems of the margin of cratons: Albany–Fraser Orogen/Eucla Basement case study
ES45	Uni of Sydney (Associate Professor Derek Wyman)	ARC Linkage Project: LP130100722: Earth's best-preserved Archean boninites: do they finally resolve the Archean mantle plume – plate tectonics controversy?
ES45	Johannes Gutenberg University Mainz, Germany (Prof Cees Passchier)	Narryer Terrane structural project
ES45	UWA (Tony Kemp)	Narryer Terrane isotopes project
ES46	Curtin University	ARC Linkage Project LP130100922: Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: providing a framework for understanding mineralizing systems
ES46	Curtin University (Chris Kirkland)	Crustal evolution of Western Australia
ES46	Curtin, MRIWA, Thermo Fisher Scientific	MRIWA M446: 4D Evolution of WA ore systems: Re-Os sulfide geochronology
ES46	Curtin, MRIWA, Thermo Fisher Scientific	MRIWA M448: 4D evolution of WA Ore systems: rutile pathfinder to ores
ES46	John de Laeter Centre	Contribution to funding for Centre Directorate
ES47	Frogtech Geoscience	SEEBASE project — Canning Basin
ES47	Geoscience Australia	Seismic reprocessing project — Canning, Carnarvon and North Perth Basins
ES50	AMIRA	AMIRA UNCOVER stage 2: Unlocking Australia's hidden mineral potential, Stage 2: Implementing the roadmap findings. AMIRA P1162A
ES50	CSIRO (Steve Hollis)	Volcanic hosted massive sulphide (VHMS) exploration in the Yilgarn Craton
GS20	Centre for Exploration Targeting UWA	Yilgarn gold exploration targeting atlas
GS53	National Geographic Society, Cambridge Uni	First footfall - the colonization of land

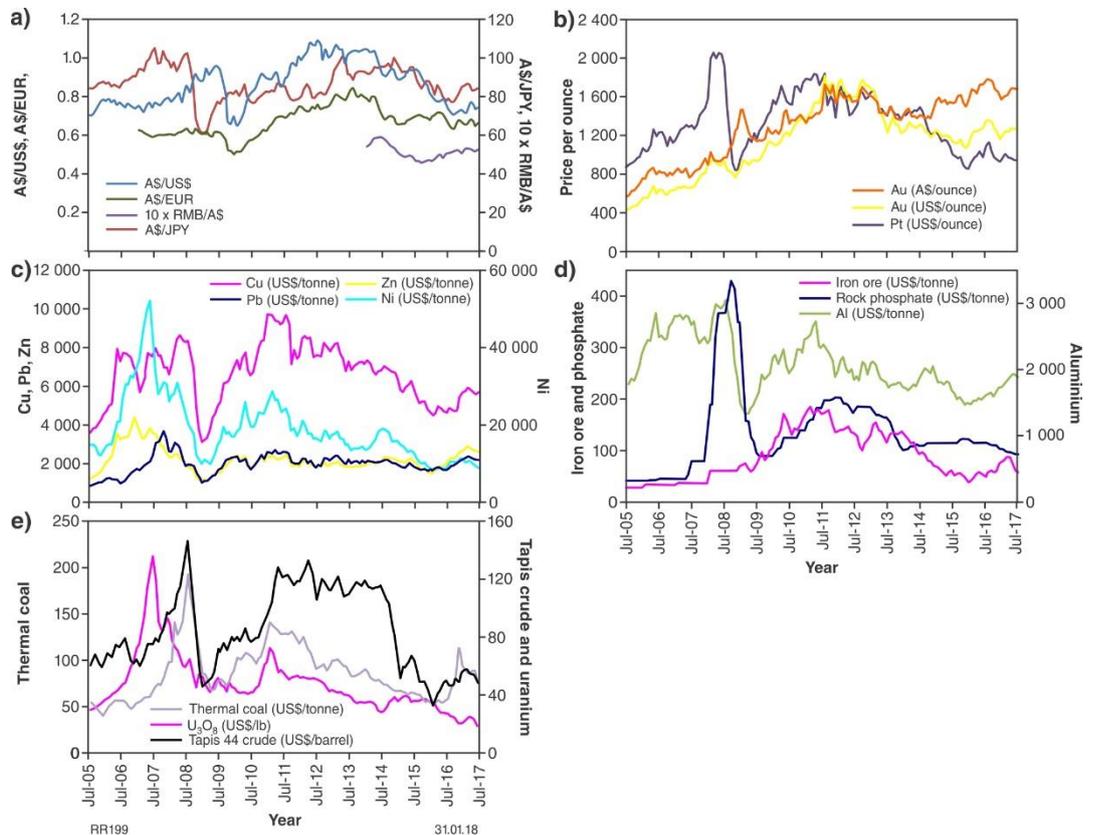
GS61	Curtin University	Geological studies of gabbroic rocks intruding the Arid Basin
GS95	Auscope with NCRIS funding, CSIRO	Virtual Core Library project - Auscope Agreement
KS02	UTAS (Dr. K Orth)	Paleoproterozoic mafic magmatism of the Kimberley Basin, Western Australia

Figures

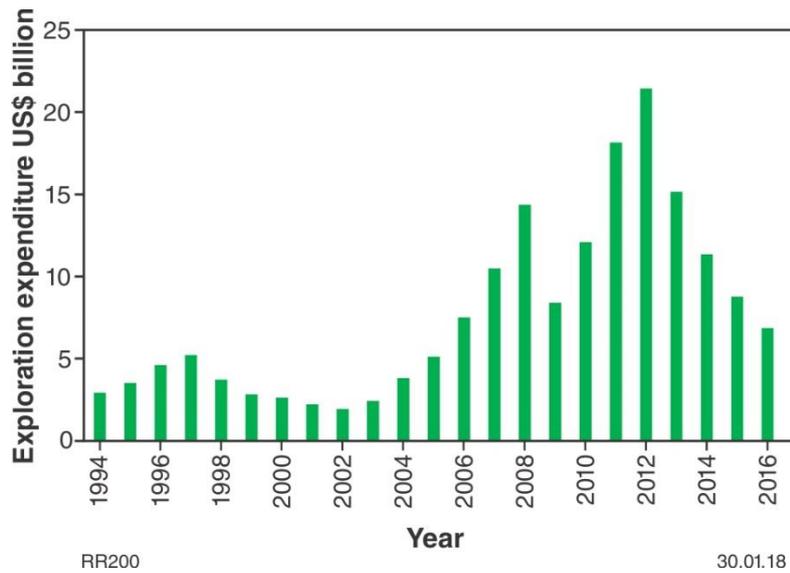
1. World economic volatility



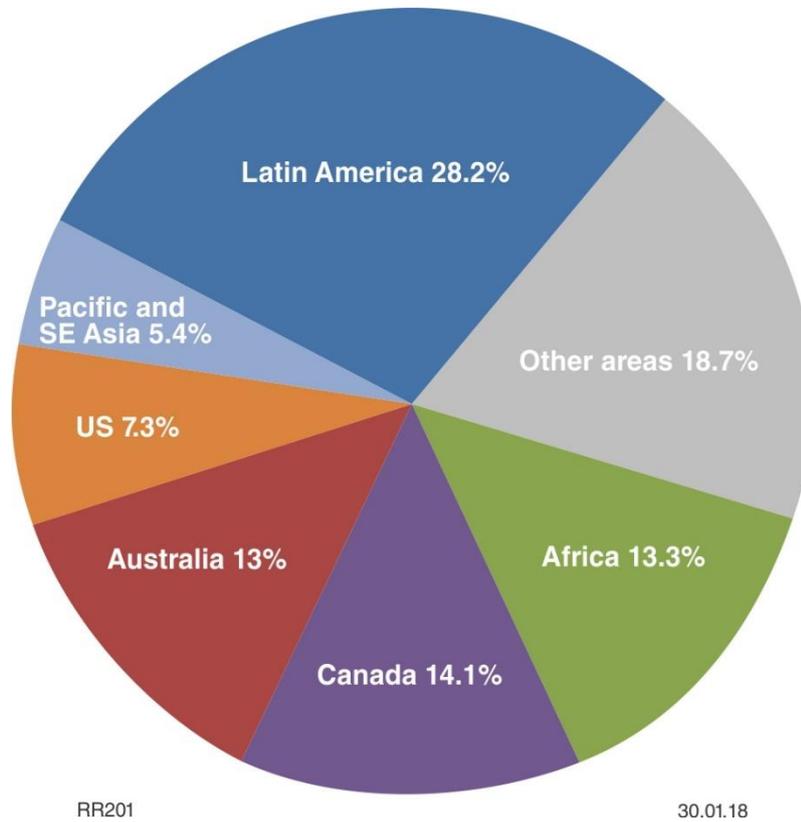
2. Average monthly commodity prices — July 2004 to June 2017 (dollars of the day)



3. Global exploration budgets 1994–2016

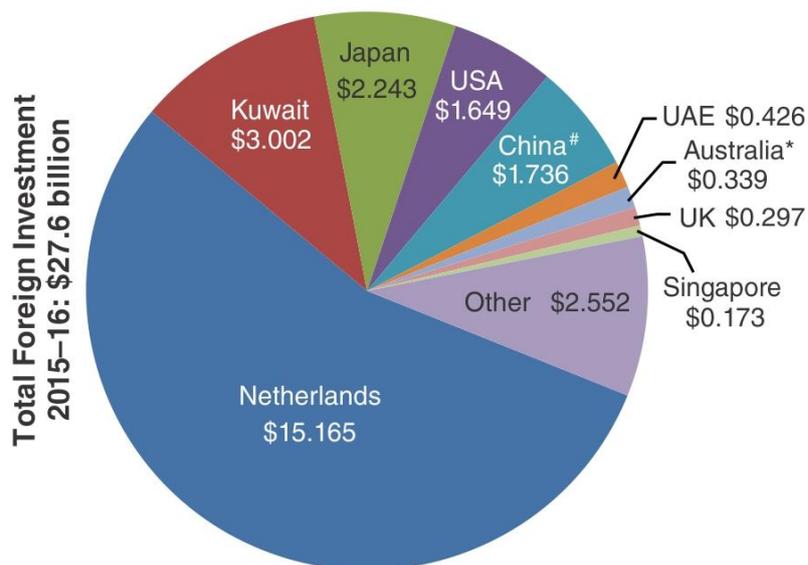


4. Worldwide non-ferrous exploration budgets by country or region for 2016



5. Sources of foreign investment into Australia's resource sector for 2015–16

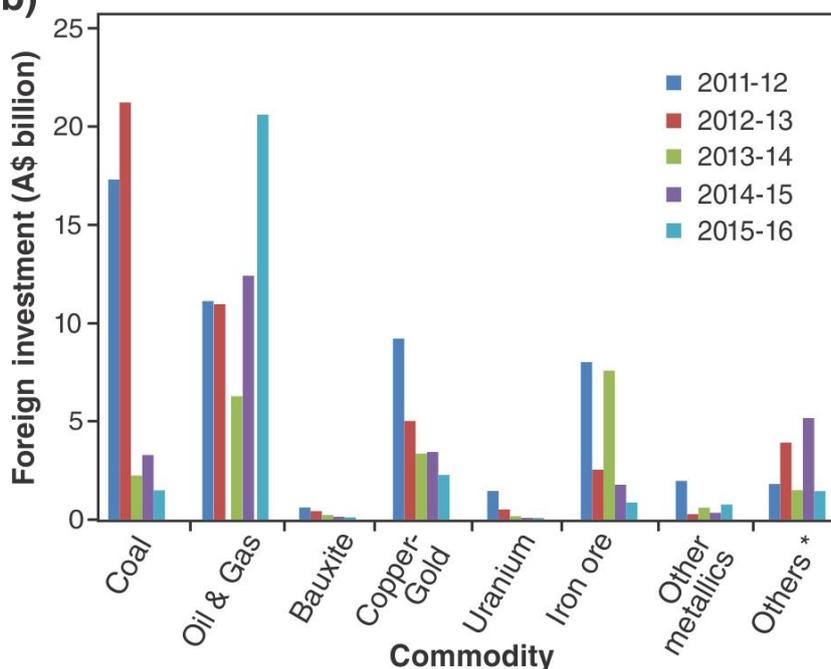
a)



* Investment by Australian investor with overseas partner or existing Chinese investor in Australia making additional investment.

[#] Includes Hong Kong

b)

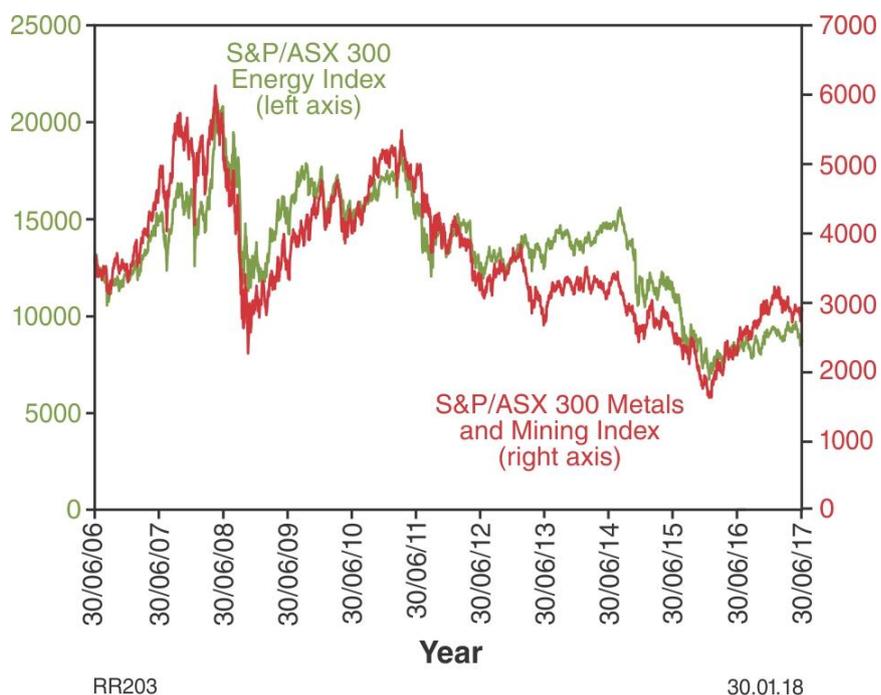


* Exploration and other support services; and other non-metallic minerals mining and quarrying

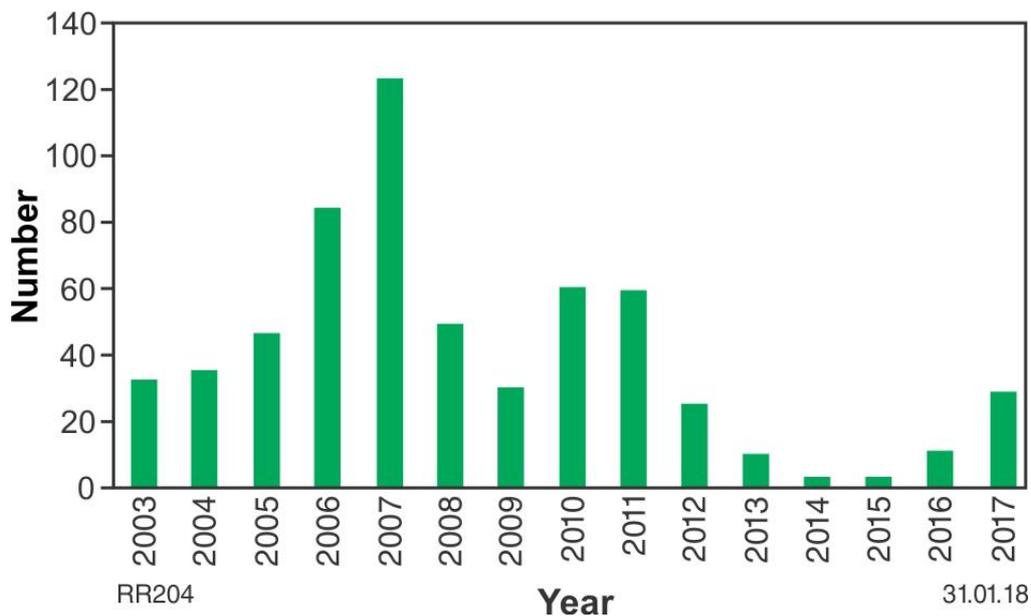
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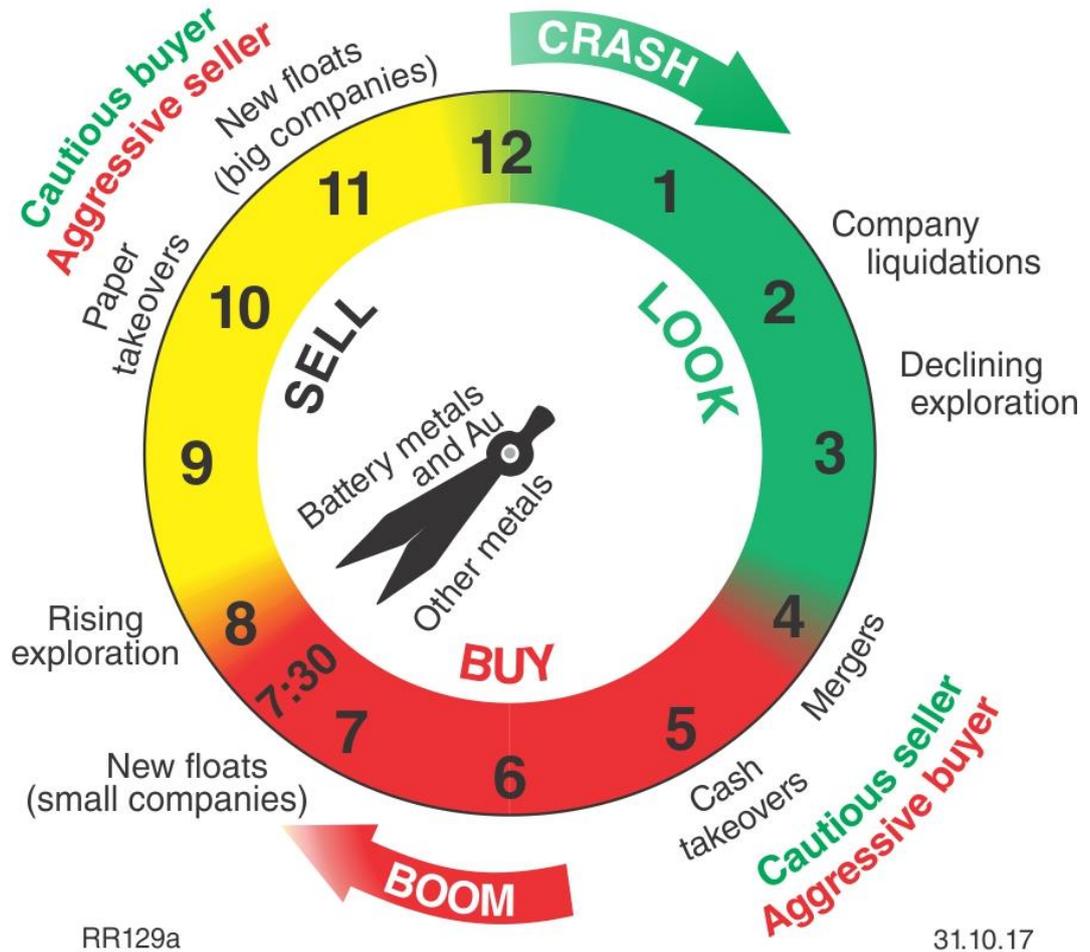
6. Metals and Mining Index and Energy Index — July 2006 to June 2017



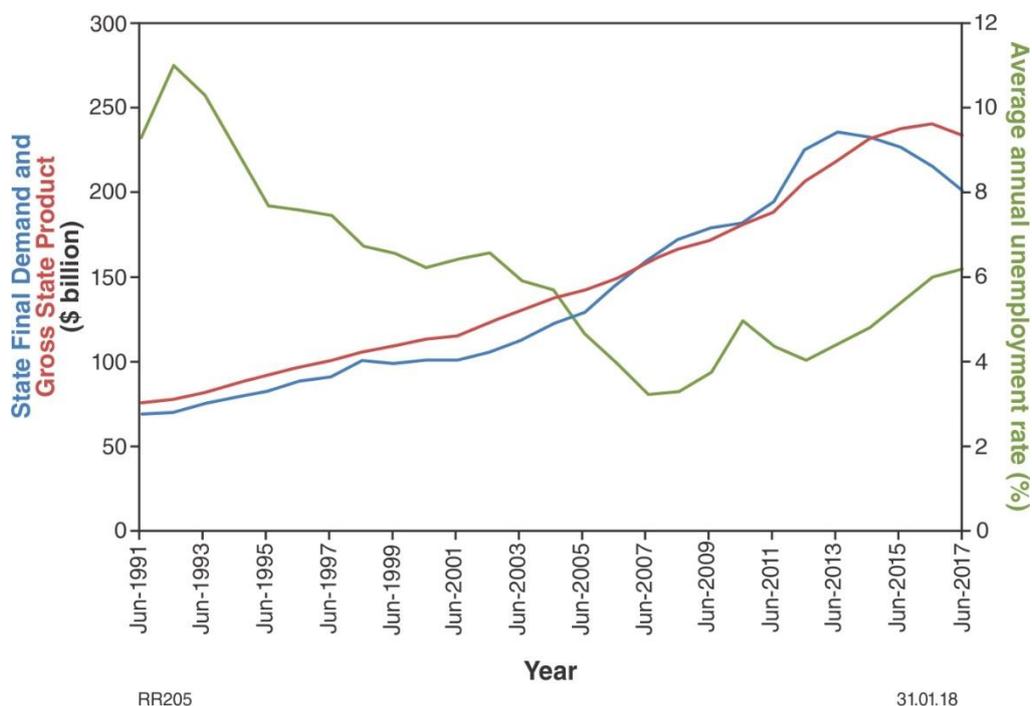
7. Mineral IPO (including coal) on the ASX by calendar year



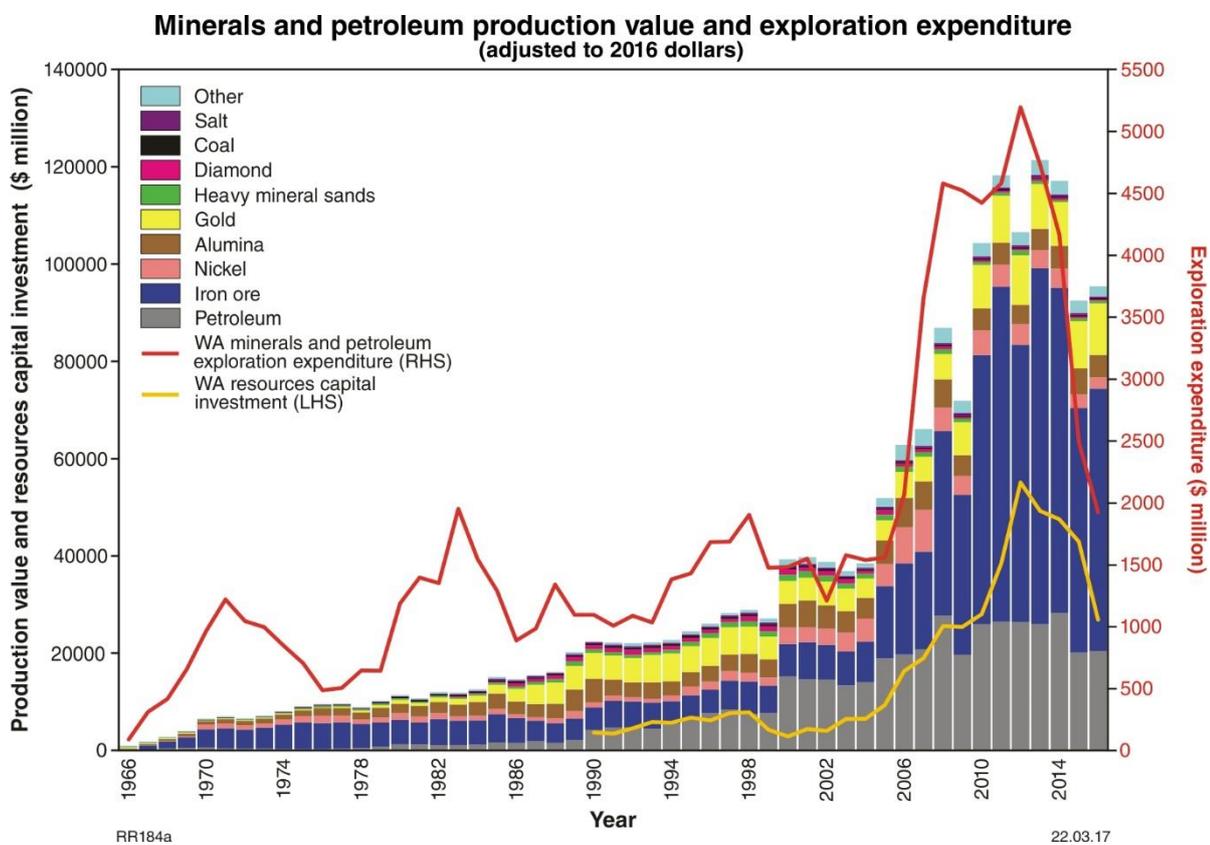
8. Lion Selection Group's well-known Widdup Cycle



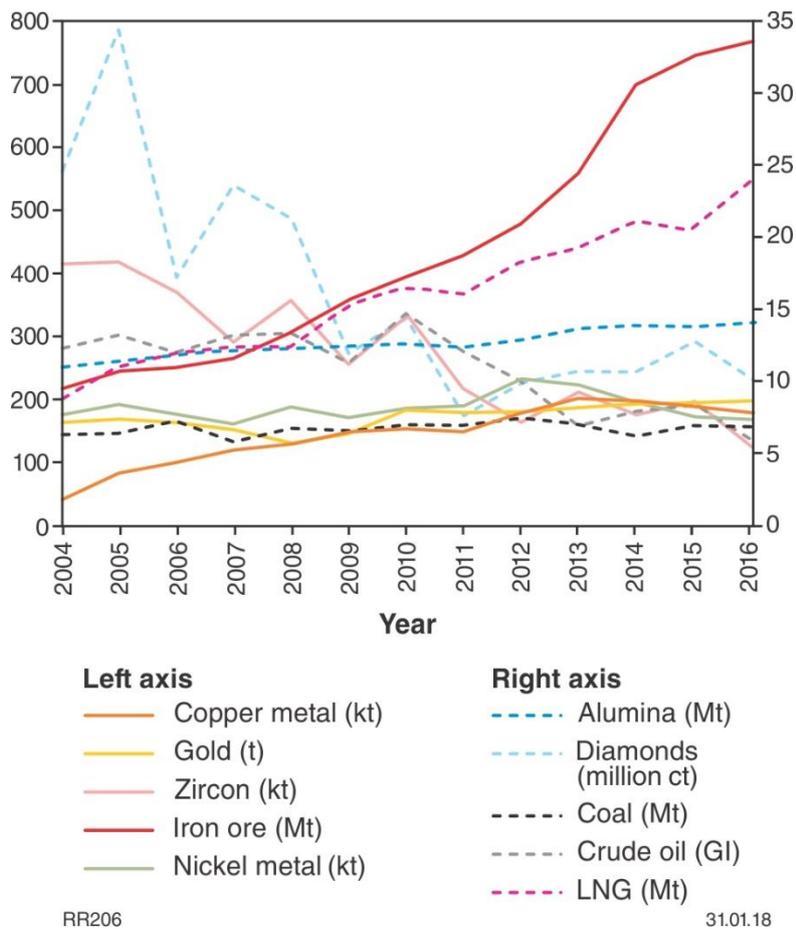
9. Macro-economic indicators and unemployment statistics for WA — June 1990 to June 2017 financial years



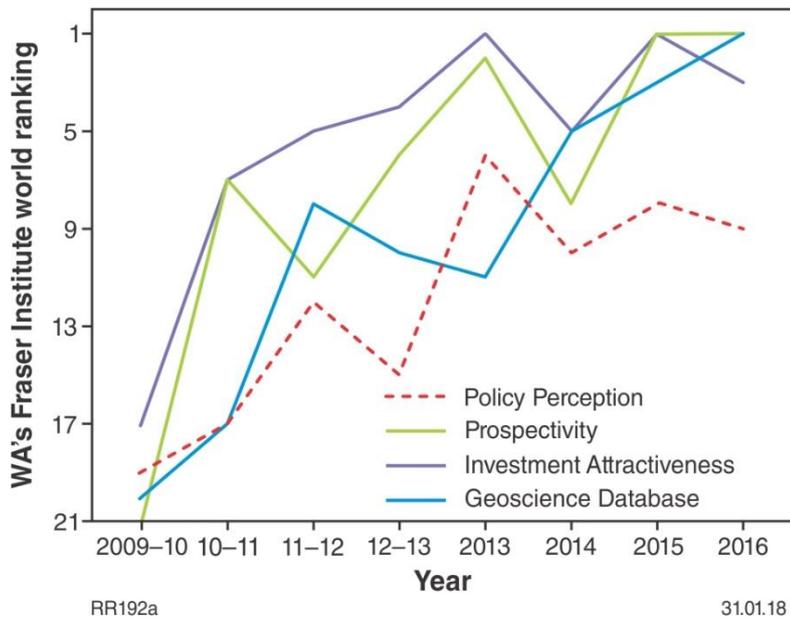
10. The three resources cycles in WA (2016)



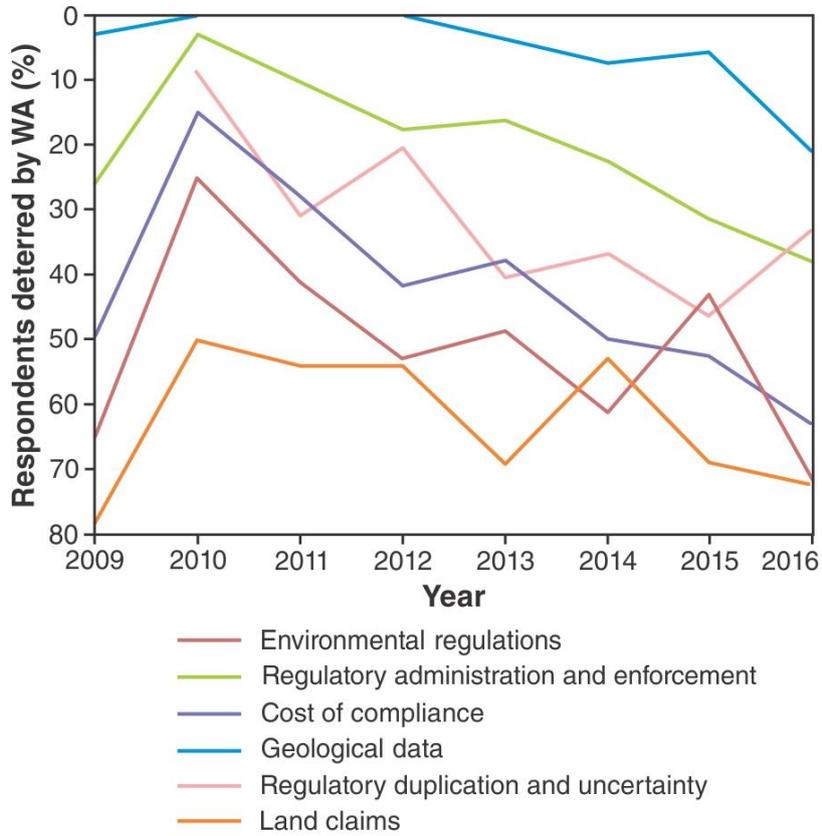
11. WA production quantity for major commodities 2015–16



12. WA's trend in the Fraser Institute's three critical mineral investor perceptions categories



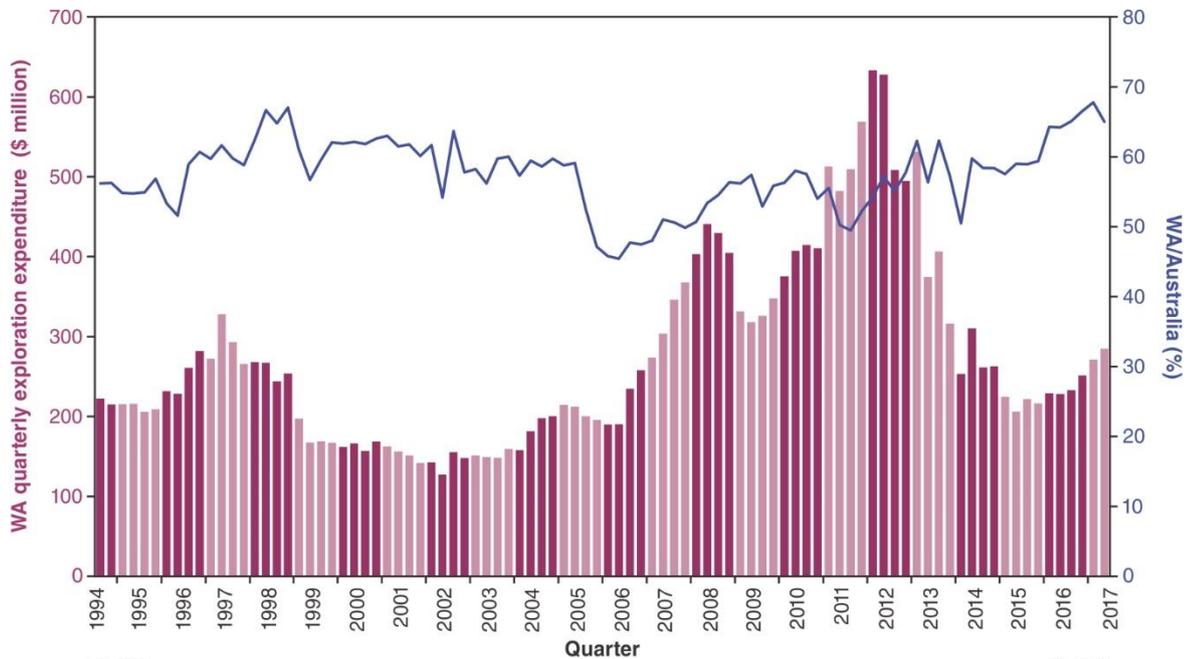
13. Selected factors contributing to Fraser Institute's petroleum PPI for WA



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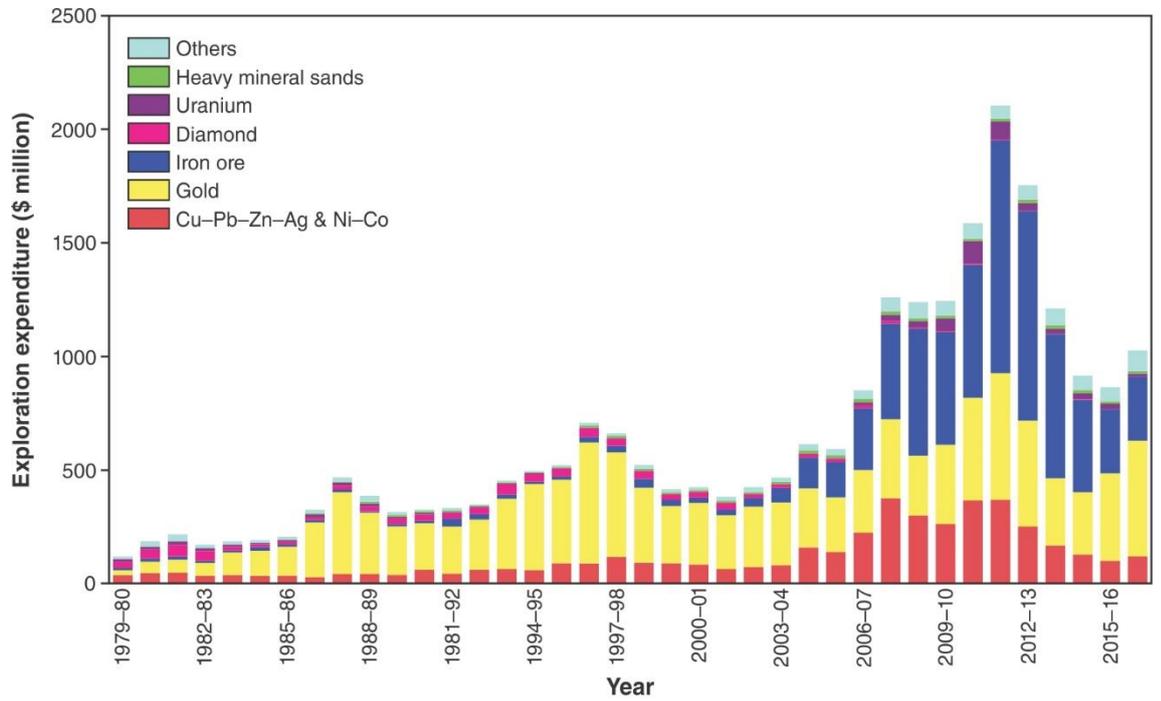
14. Quarterly mineral exploration expenditure in WA



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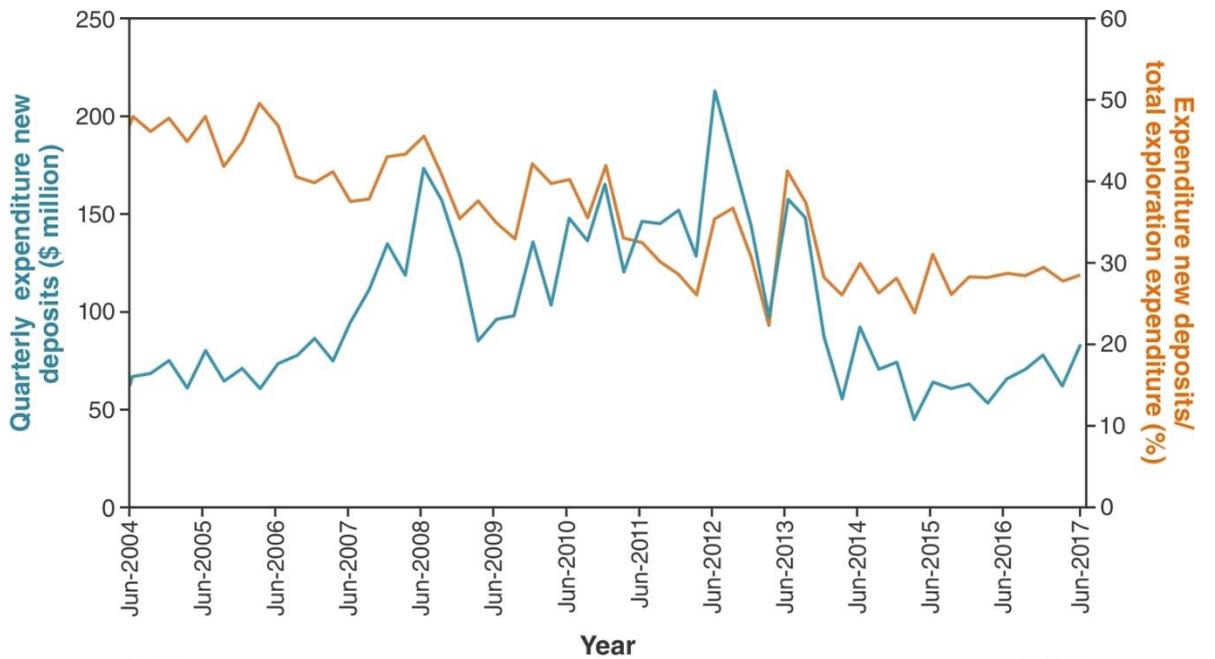
15. Exploration expenditure in WA by financial year by commodity



RR194a

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16. Greenfields mineral exploration expenditure in WA

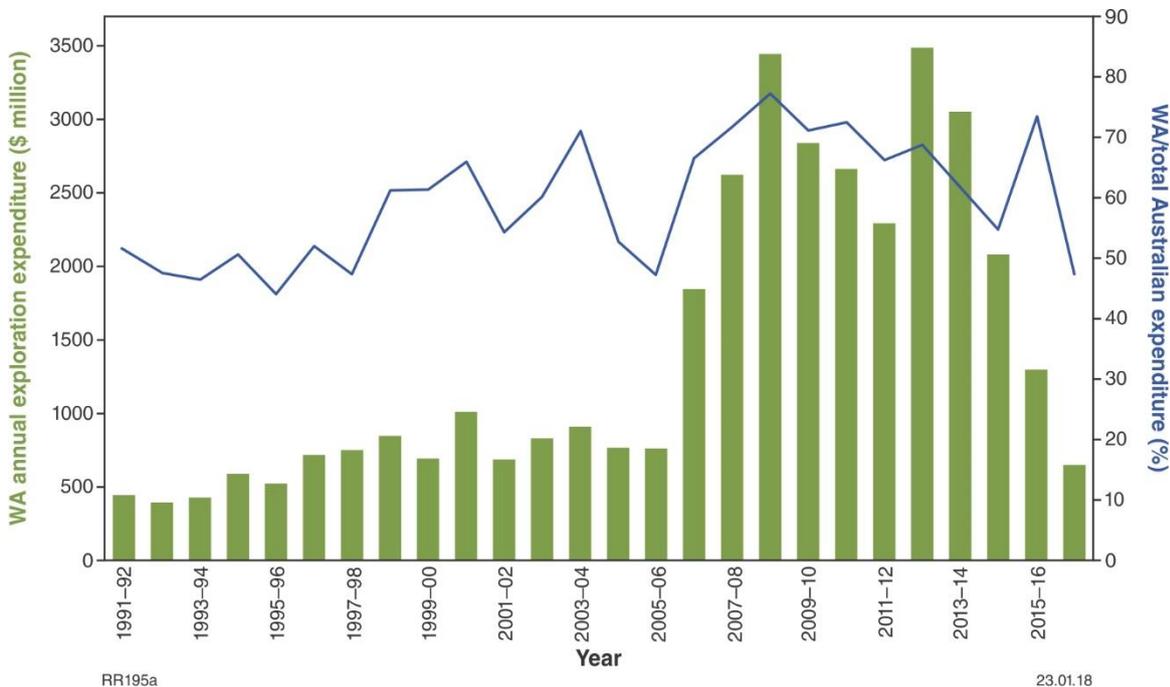


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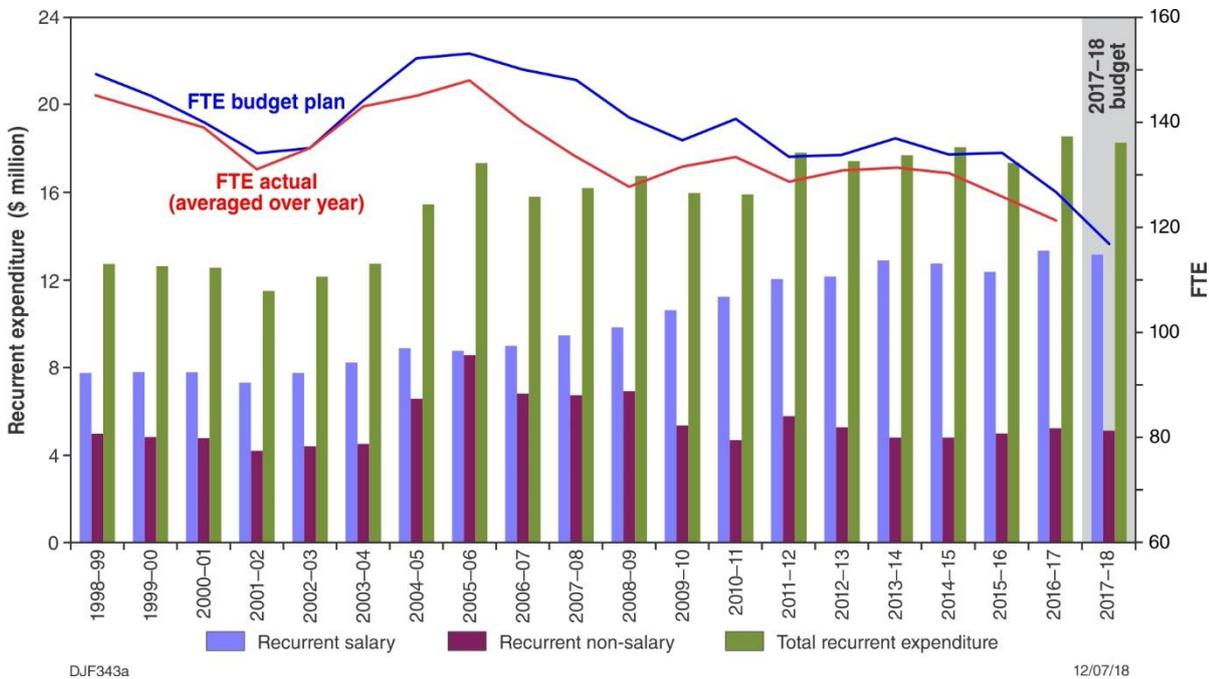
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17. Annual petroleum exploration expenditure in WA and adjacent

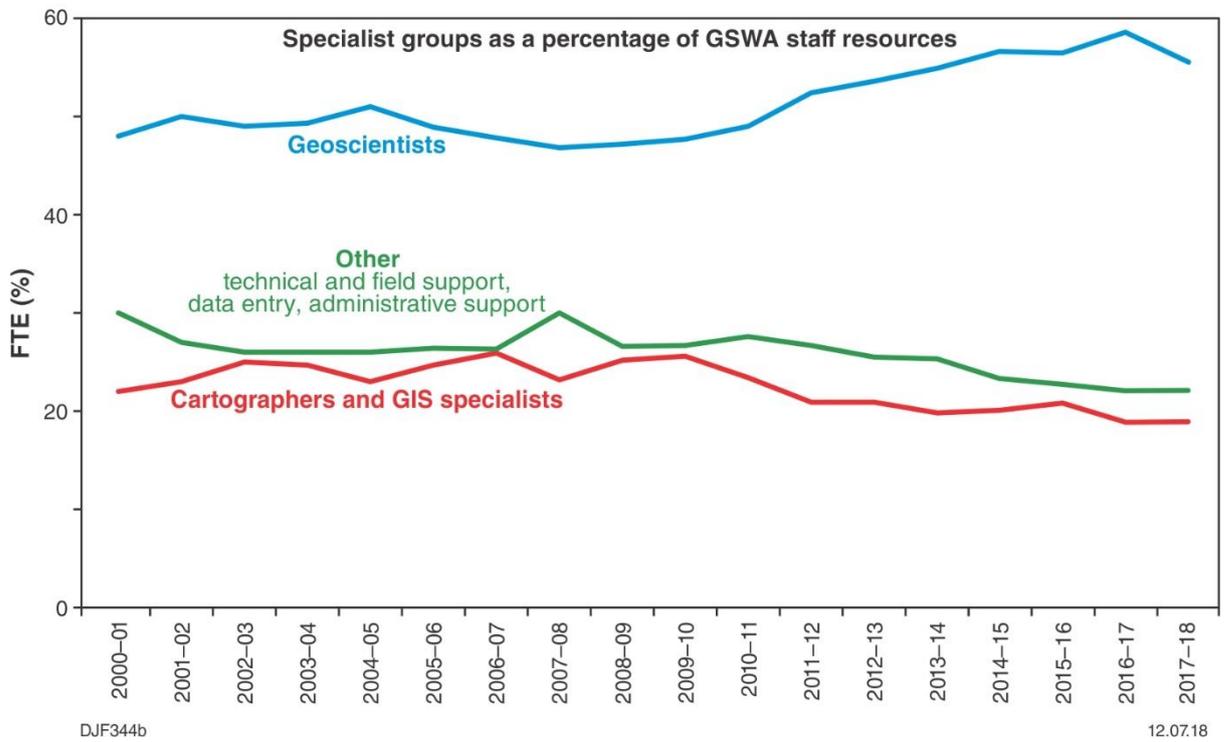
Commonwealth Waters



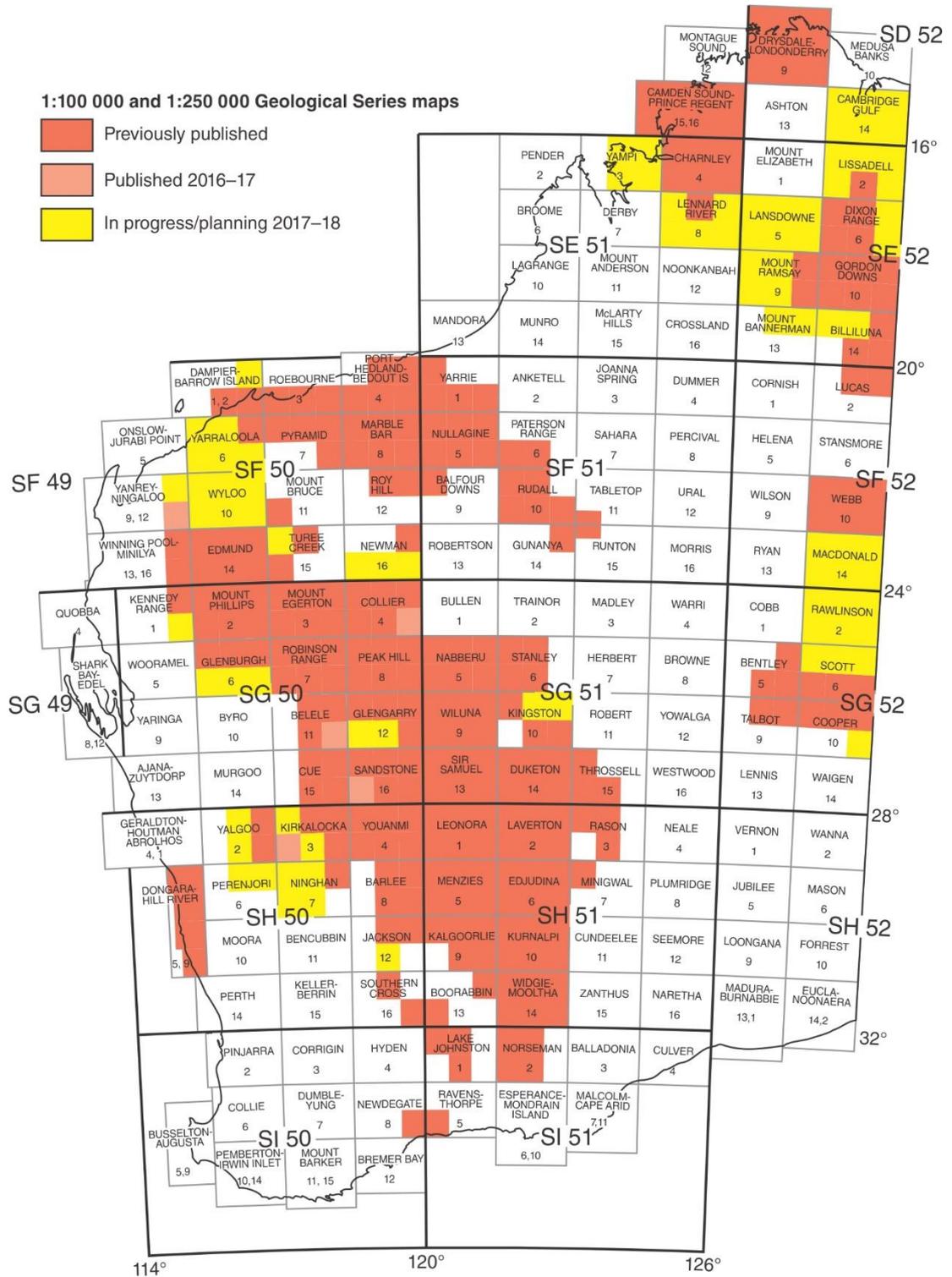
18. Long-term trends in GSWA's recurrent salary and non-salary expenditure



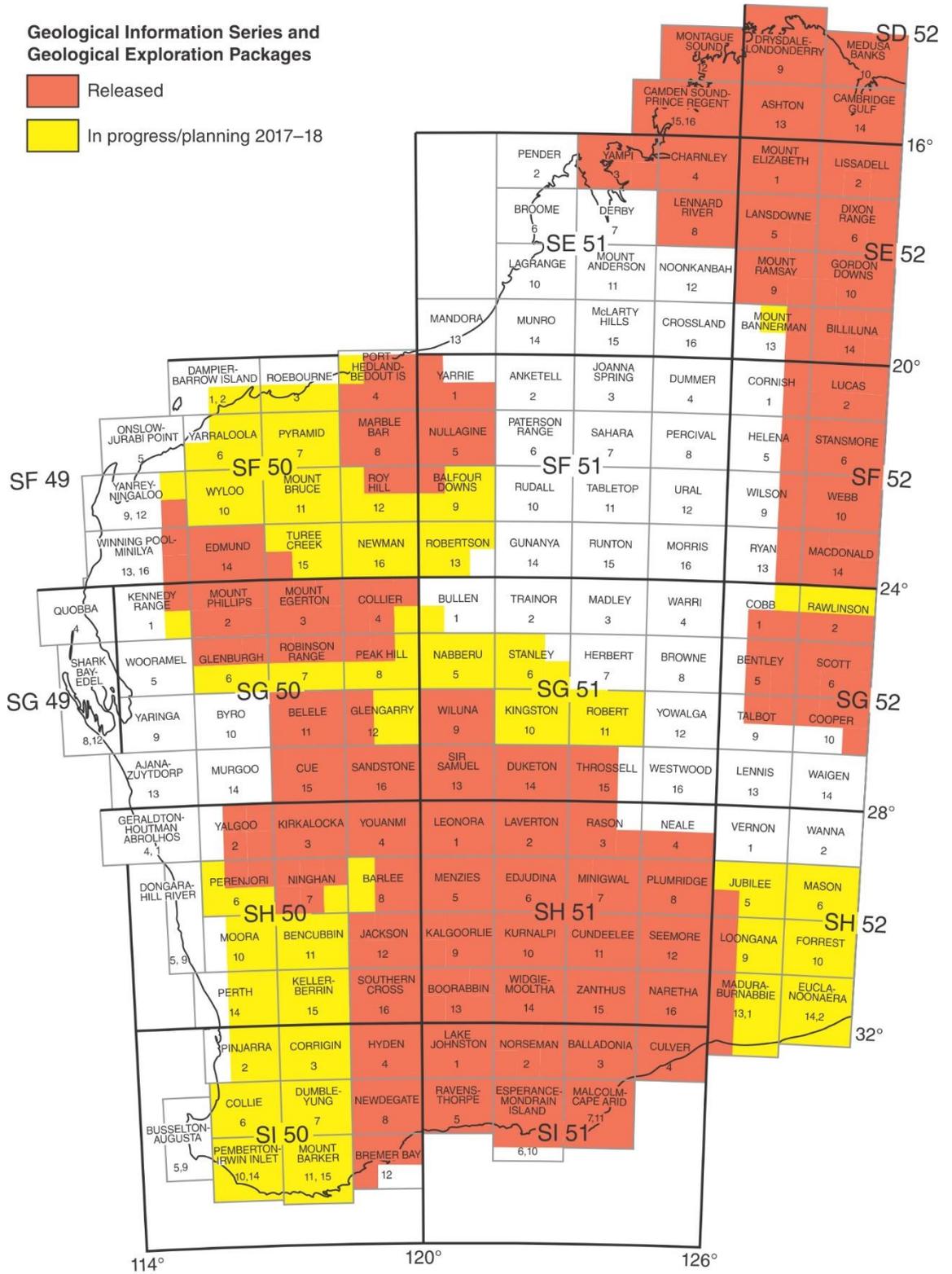
19. Specialist groups as a percentage of GSWA staff resources



20. Index map showing 2017–18 planned achievements — 1:100 000 Geological Series maps



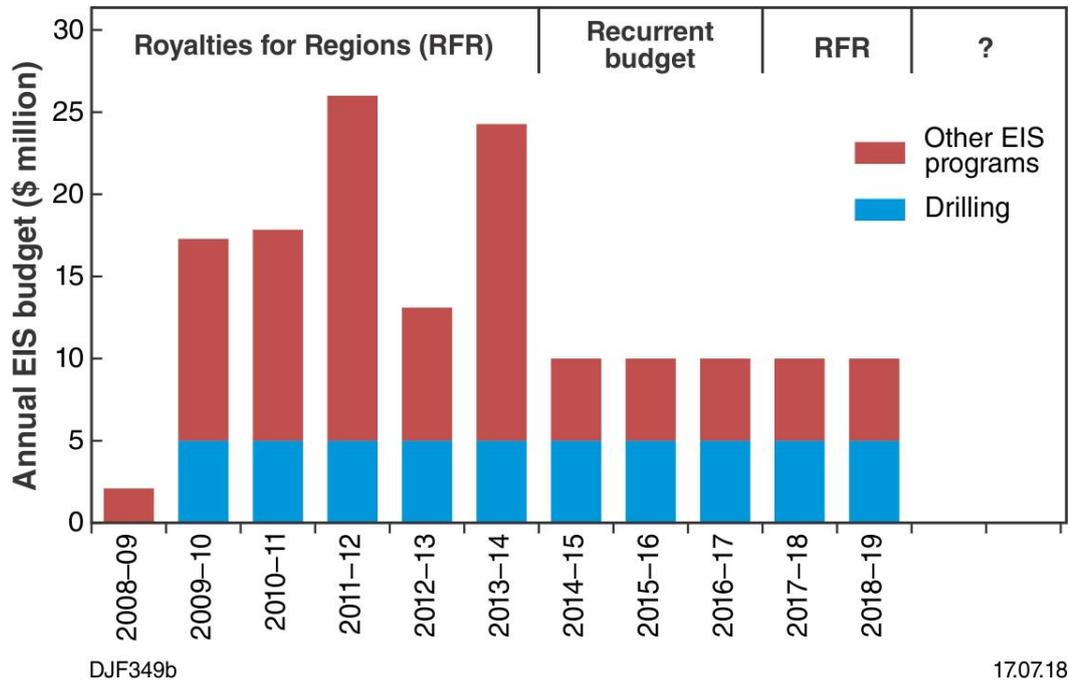
21. Index map showing 2017–18 planned achievements — 1:100 000 Geological Information Series (GIS) and Geological Exploration Packages (GEP)



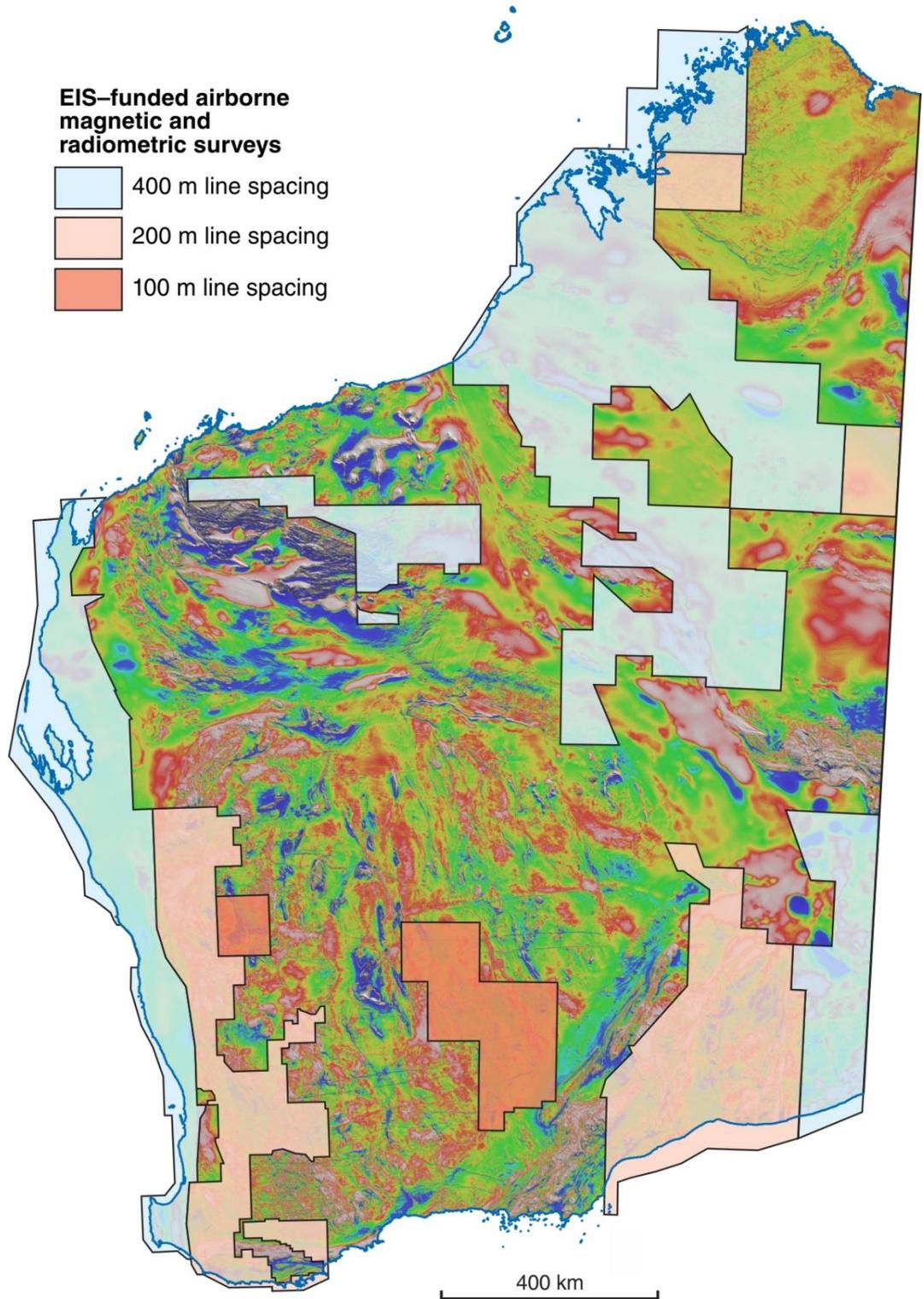
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22. EIS budgets since 2008–09



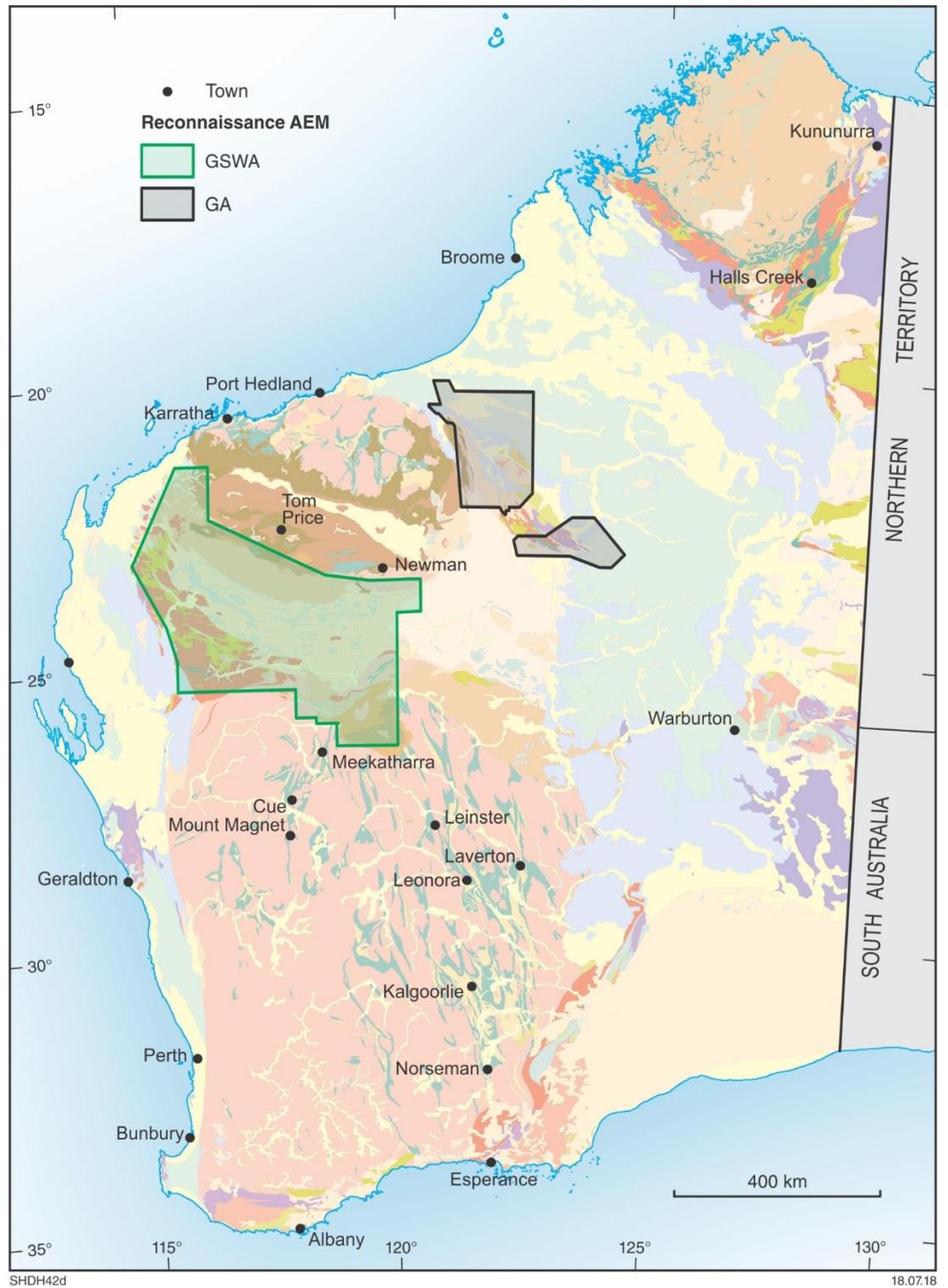
23. EIS-funded airborne magnetic and radiometric surveys



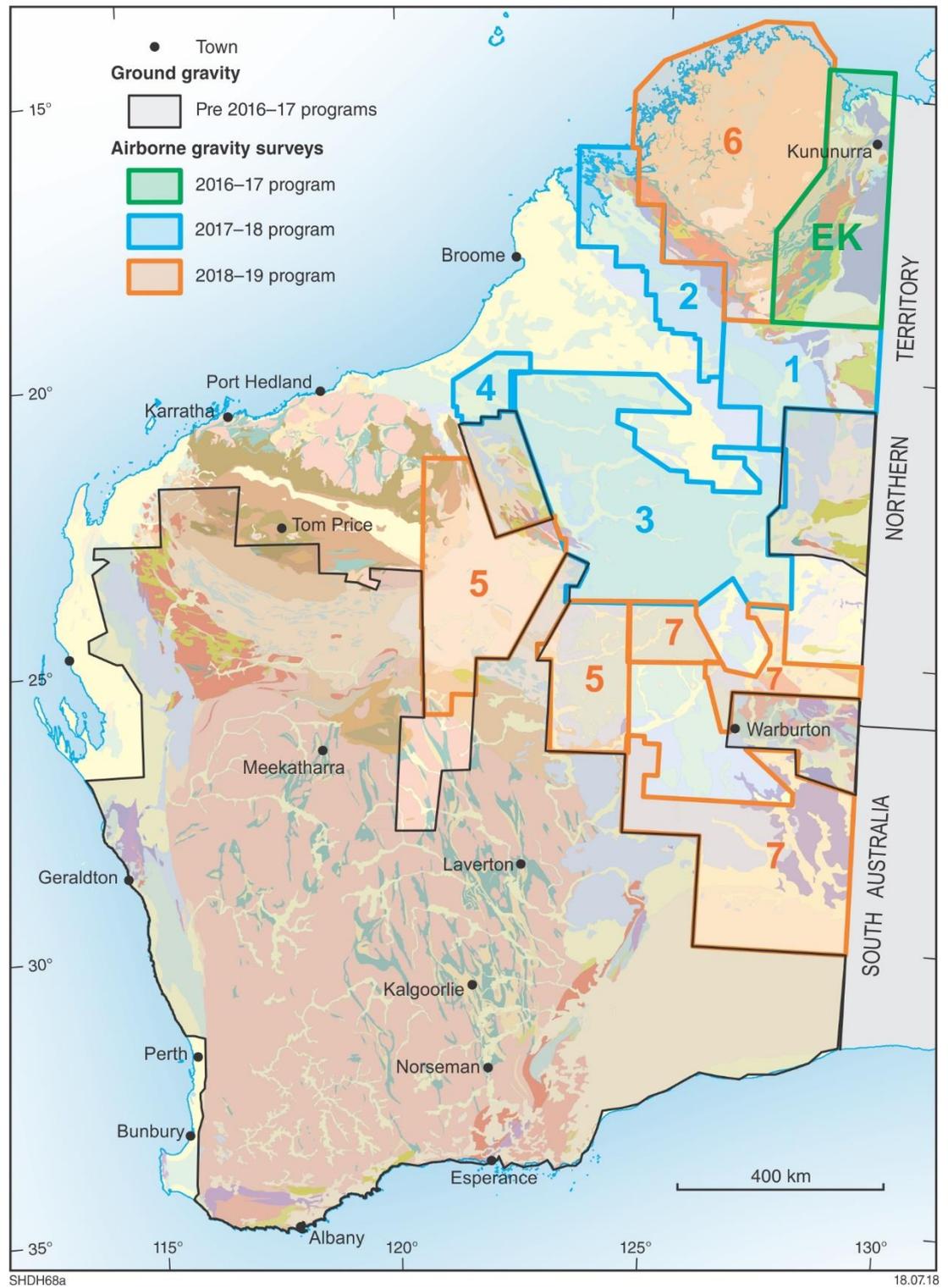
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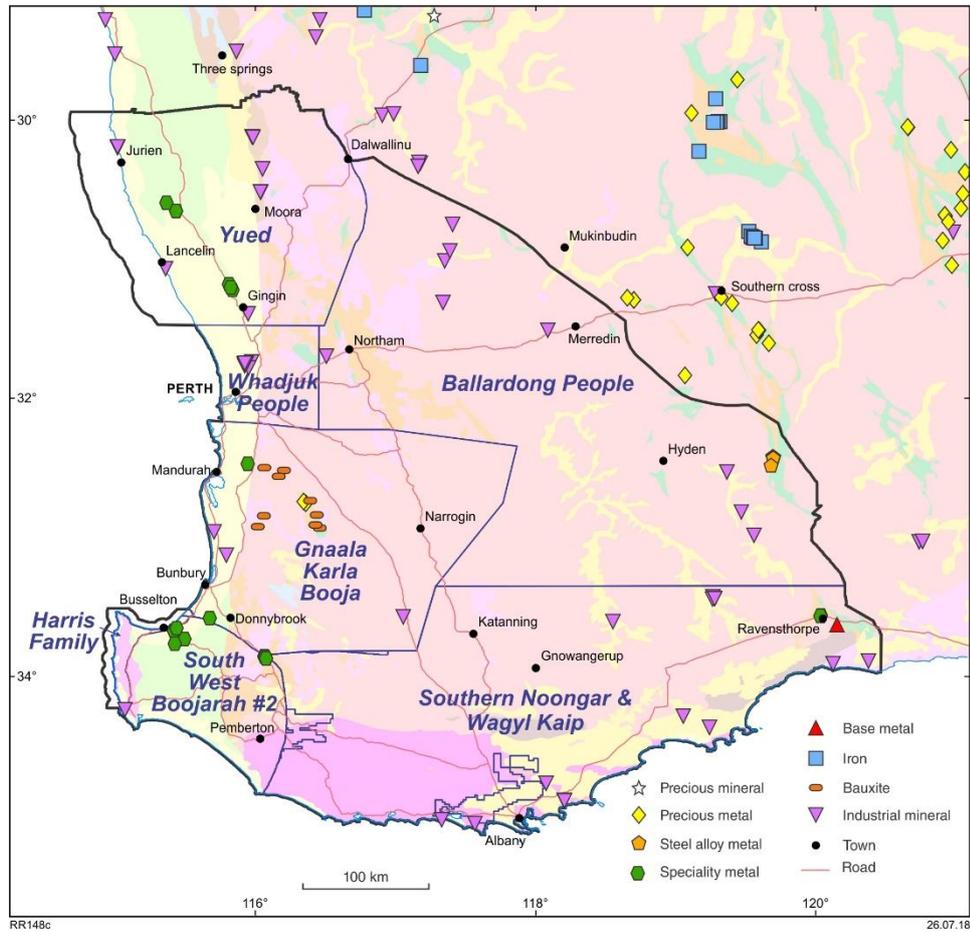
24. EIS-funded airborne electromagnetic surveys



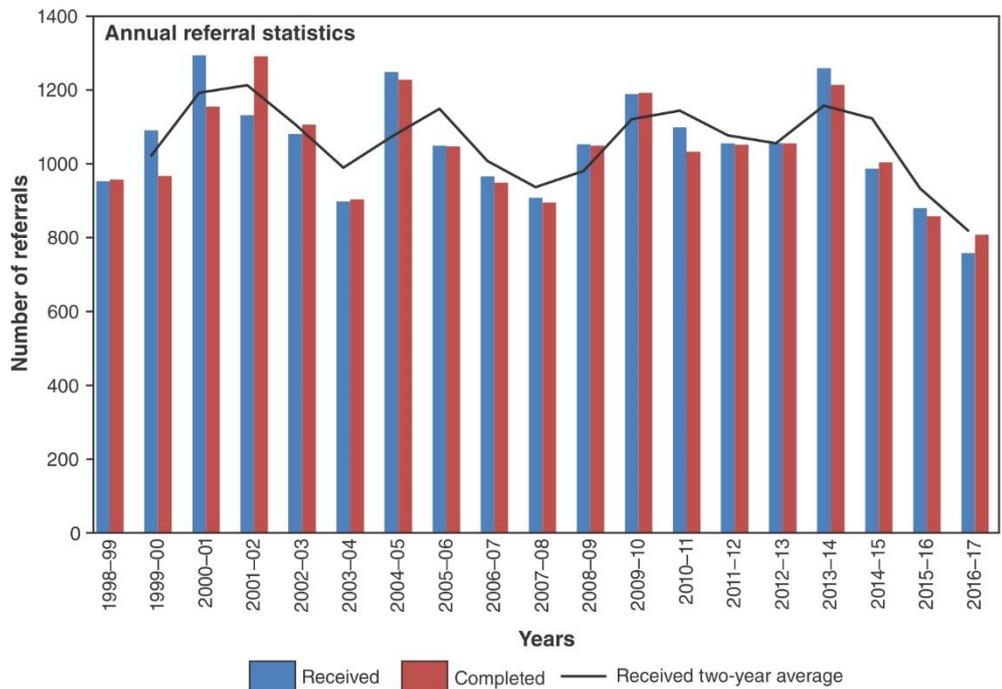
25. EIS-funded ground and airborne gravity surveys



26. South West Settlement project — location map



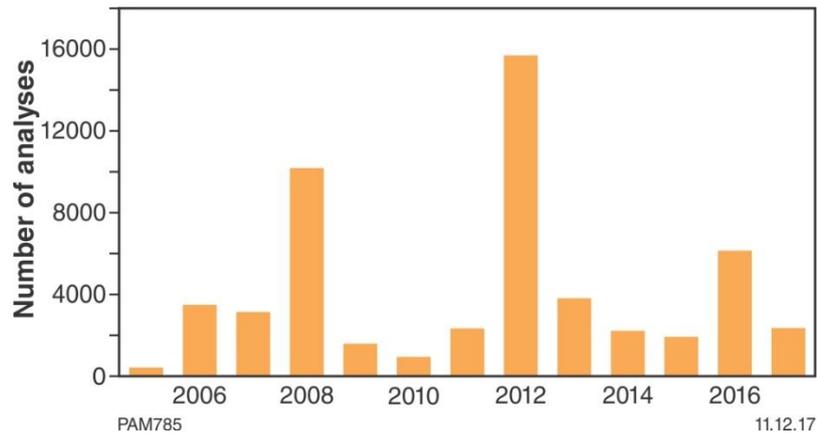
27. Land Use Geoscience section — annual referral statistics



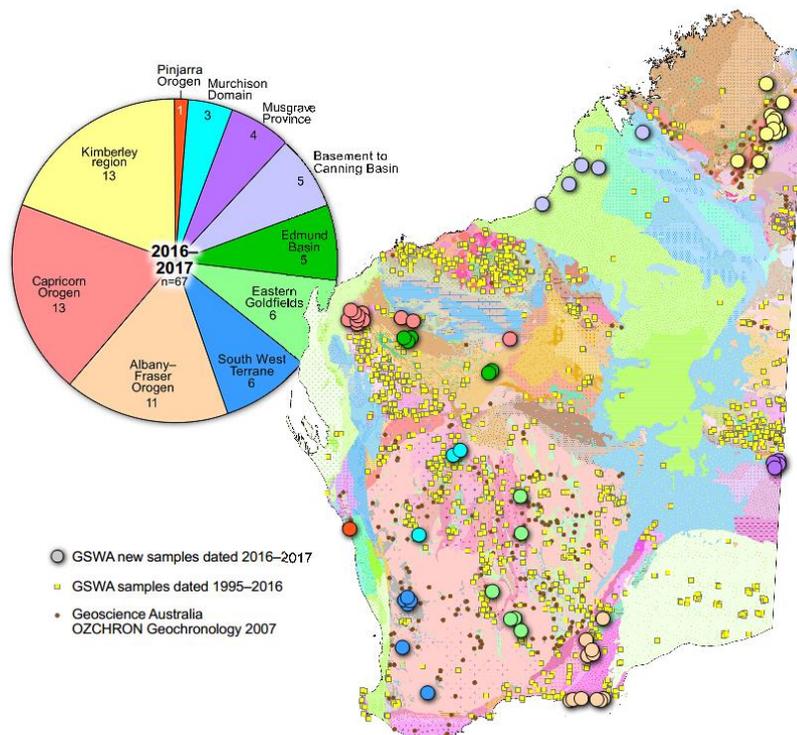
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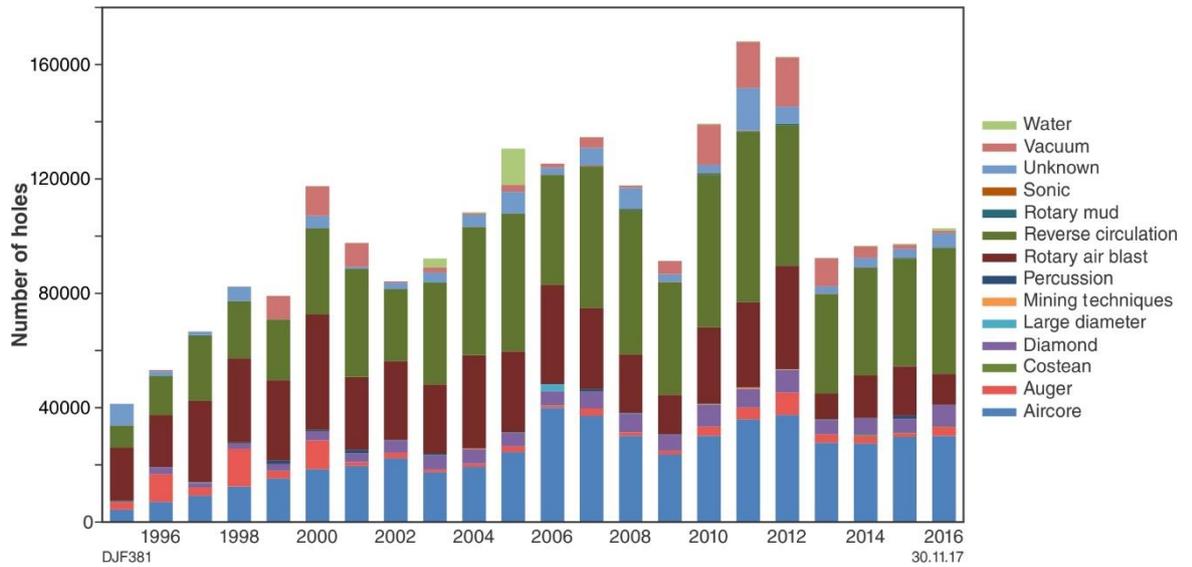
28. Histogram of samples loaded into the WACHEM database since its inception in 2005. The high number of samples in 2008, 2012, and 2016 correspond to importing of legacy data, the results of GSWA's 1994–2001 regolith geochemistry program, and analyses from the Albany–Fraser, Eastern Goldfields, and regolith geochemistry programs respectively



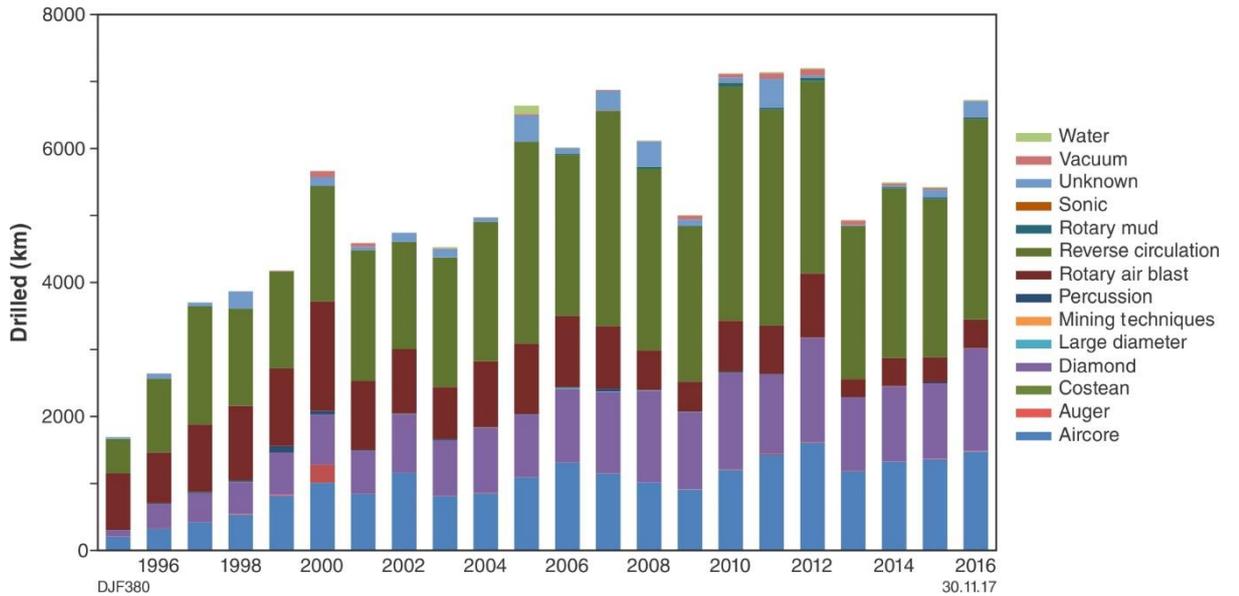
29. Geographical and tectonic distribution of GSWA samples analysed by SHRIMP ion microprobe



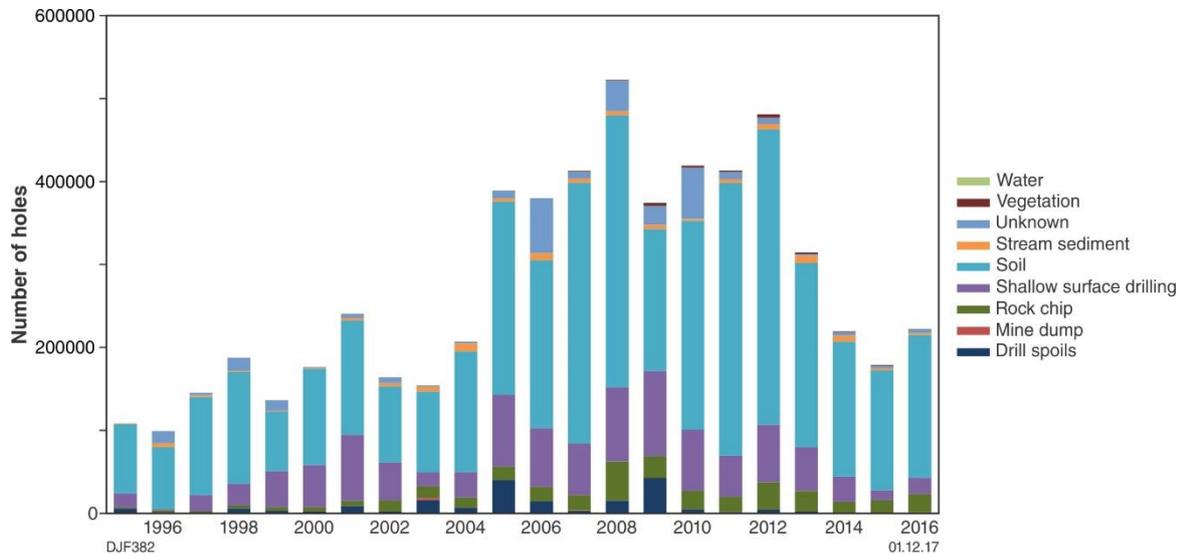
30. Drillhole database: number of drillholes recorded, by year of drilling and drilling type



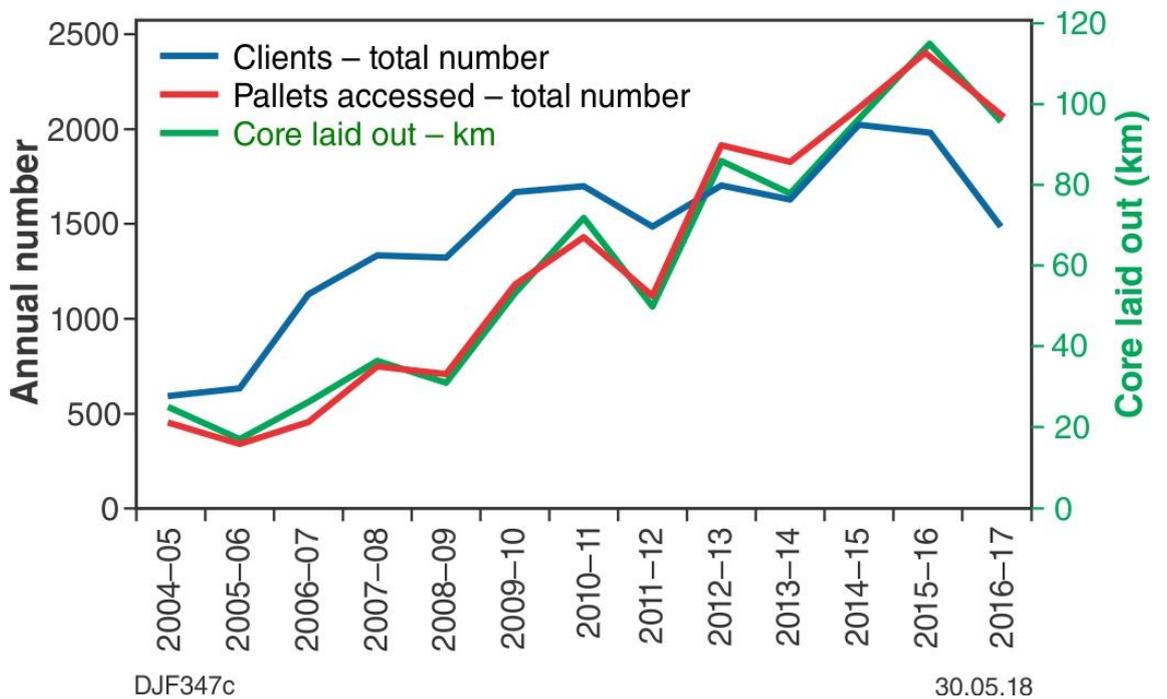
31. Drillhole database: amount of metres drilled, by year of drilling and drilling type



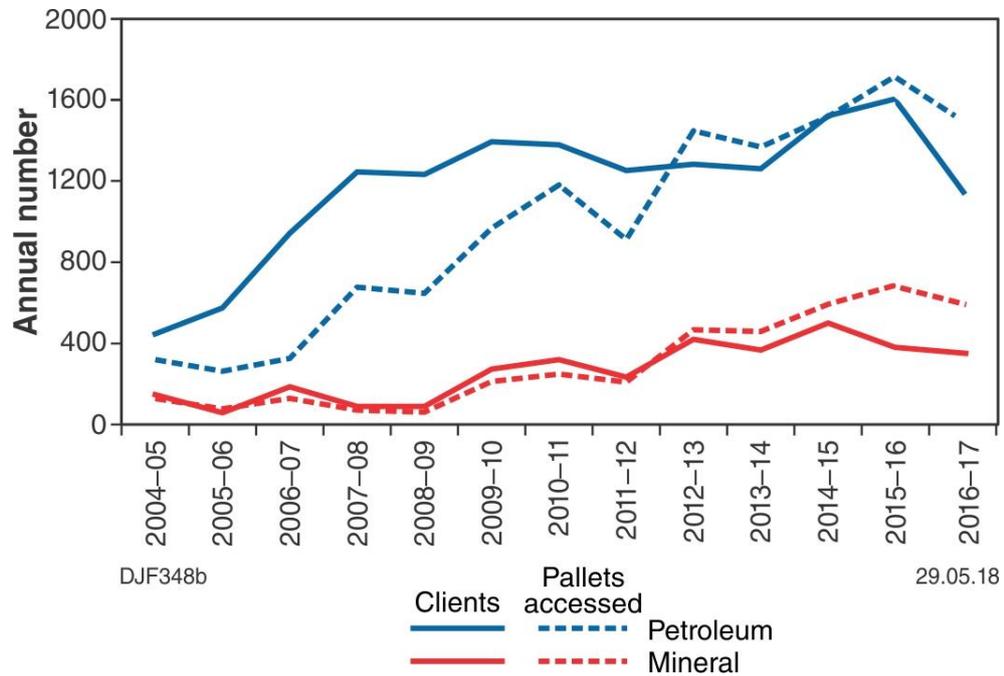
32. Drillhole database: number of surface geochemistry samples recorded, by year of drilling and sampling type



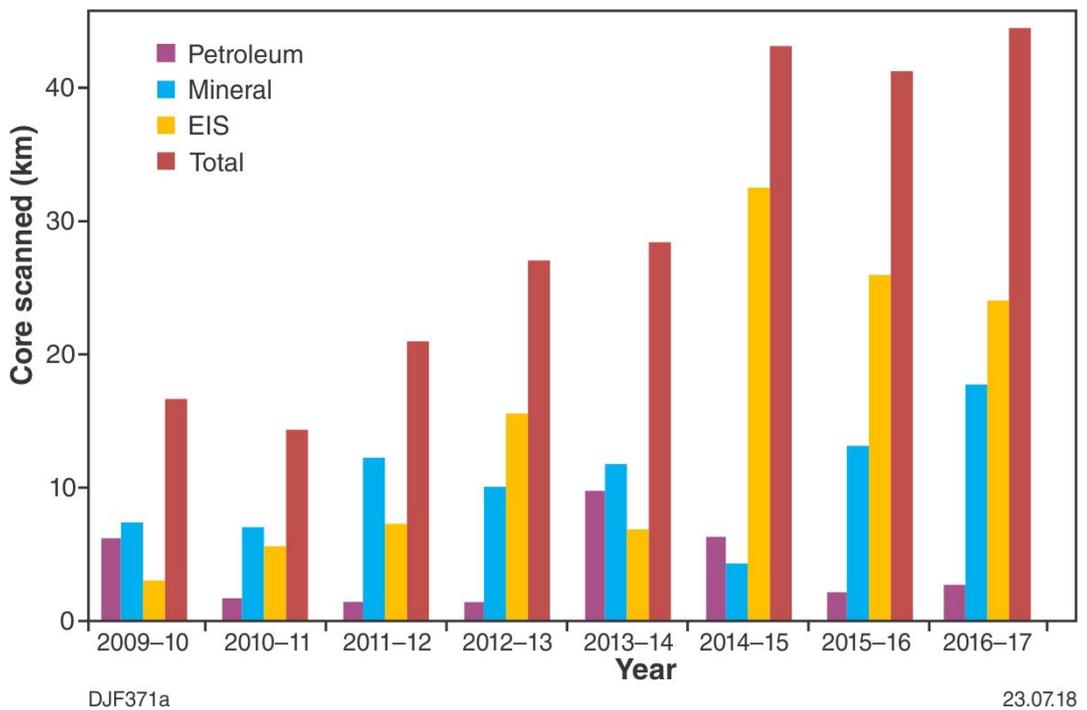
33. Perth Core Library usage statistics since 2004–05 for number of clients, pallets accessed, and core laid out



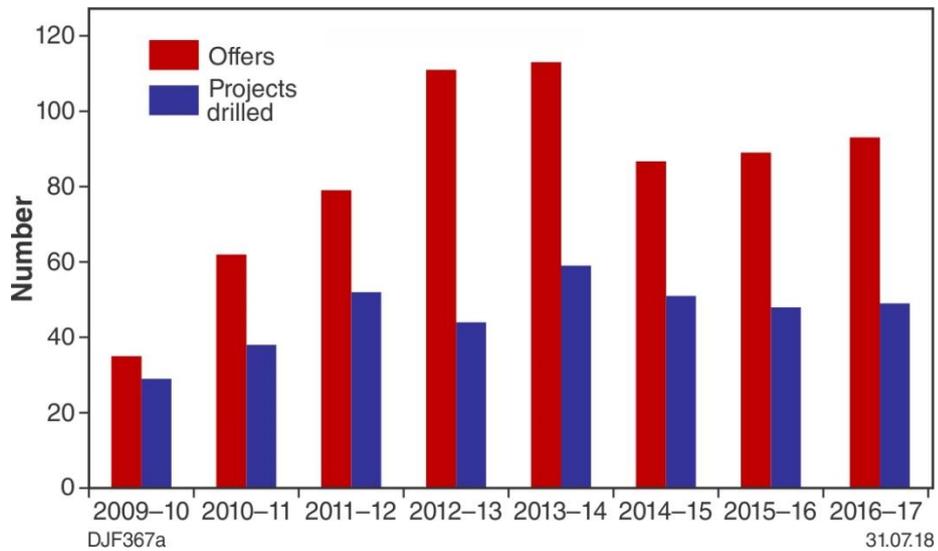
34. Perth Core Library usage statistics since 2004–05 for petroleum versus mineral clients



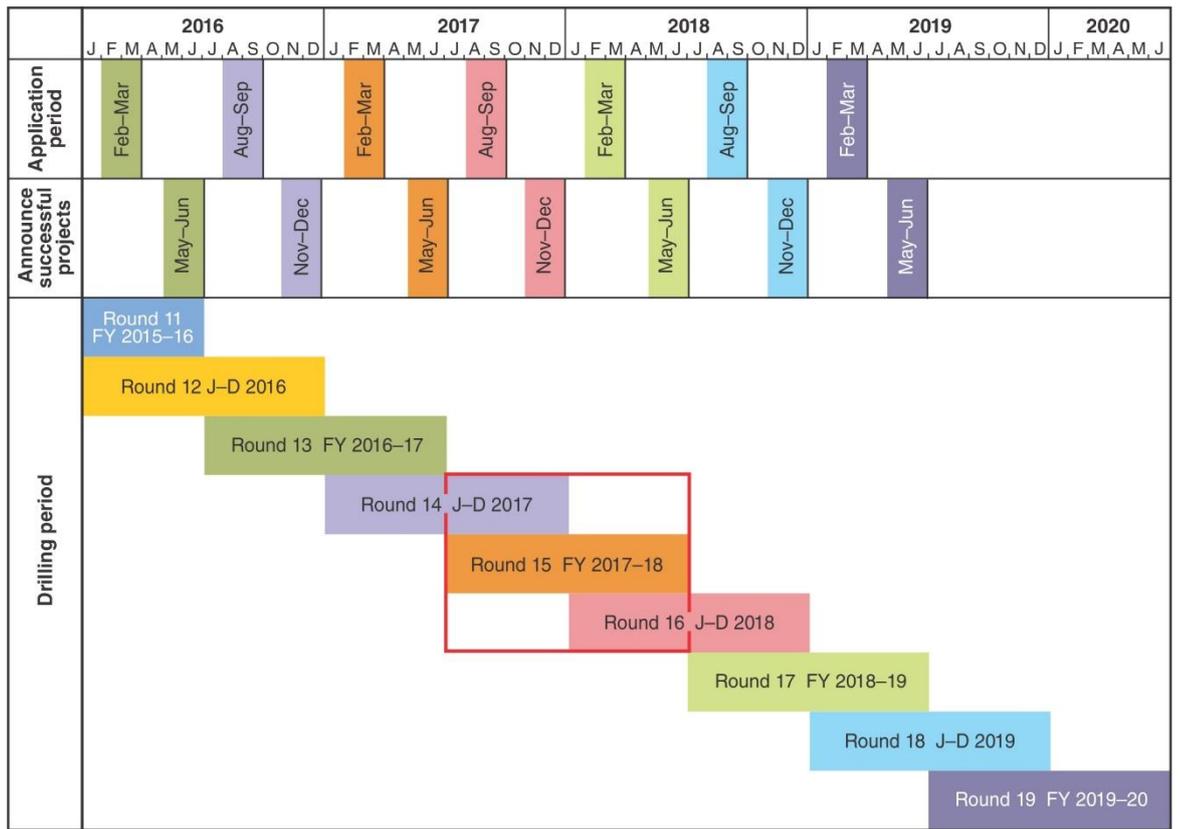
35. Spectral scanning of core through GSWA's HyLogger at Carlisle



36. EIS Co-funded Drilling program — projects offered funding versus projects actually drilled



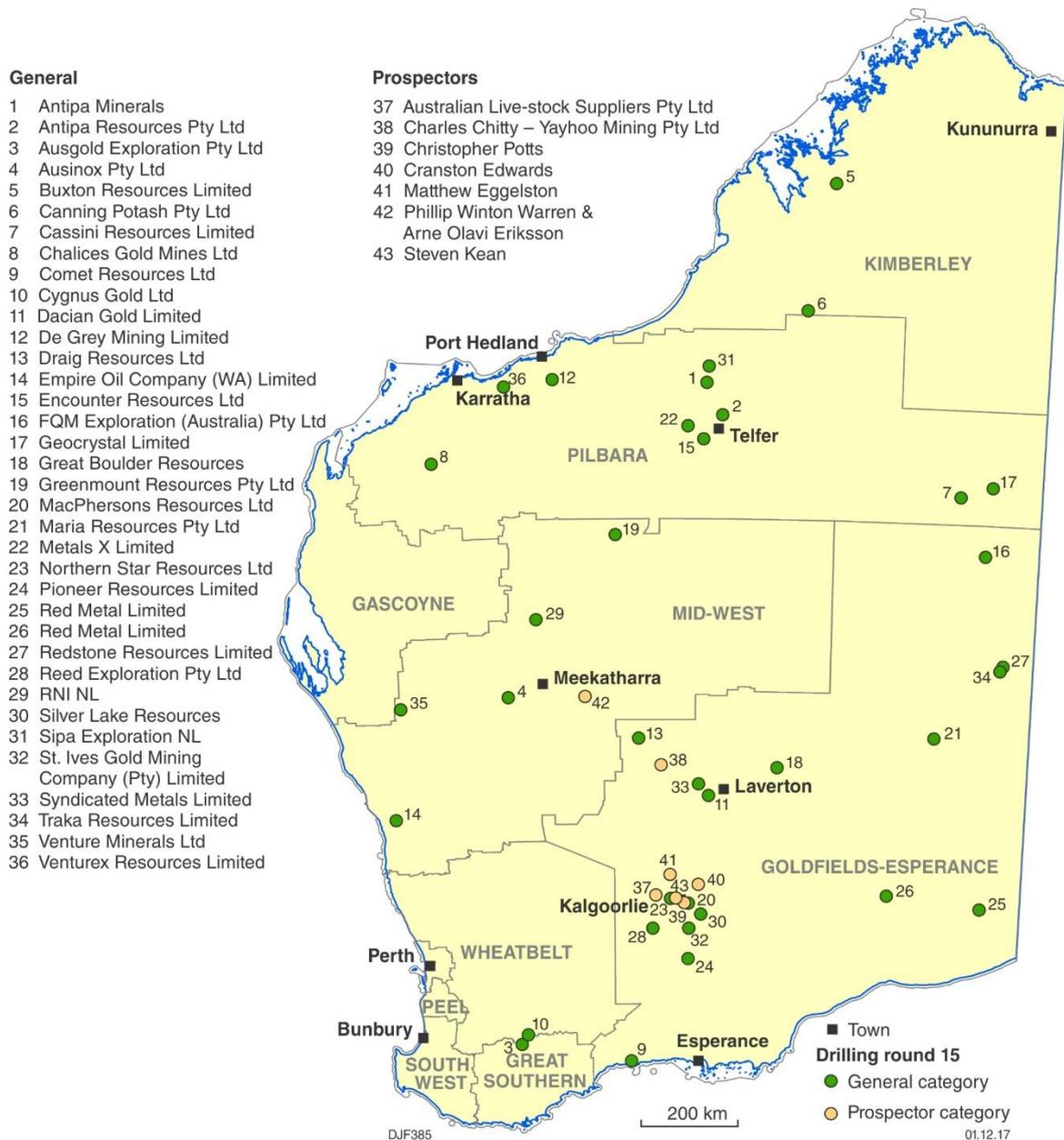
37. EIS Co-funded Drilling program — schedule of Rounds 6–16



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38. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 14



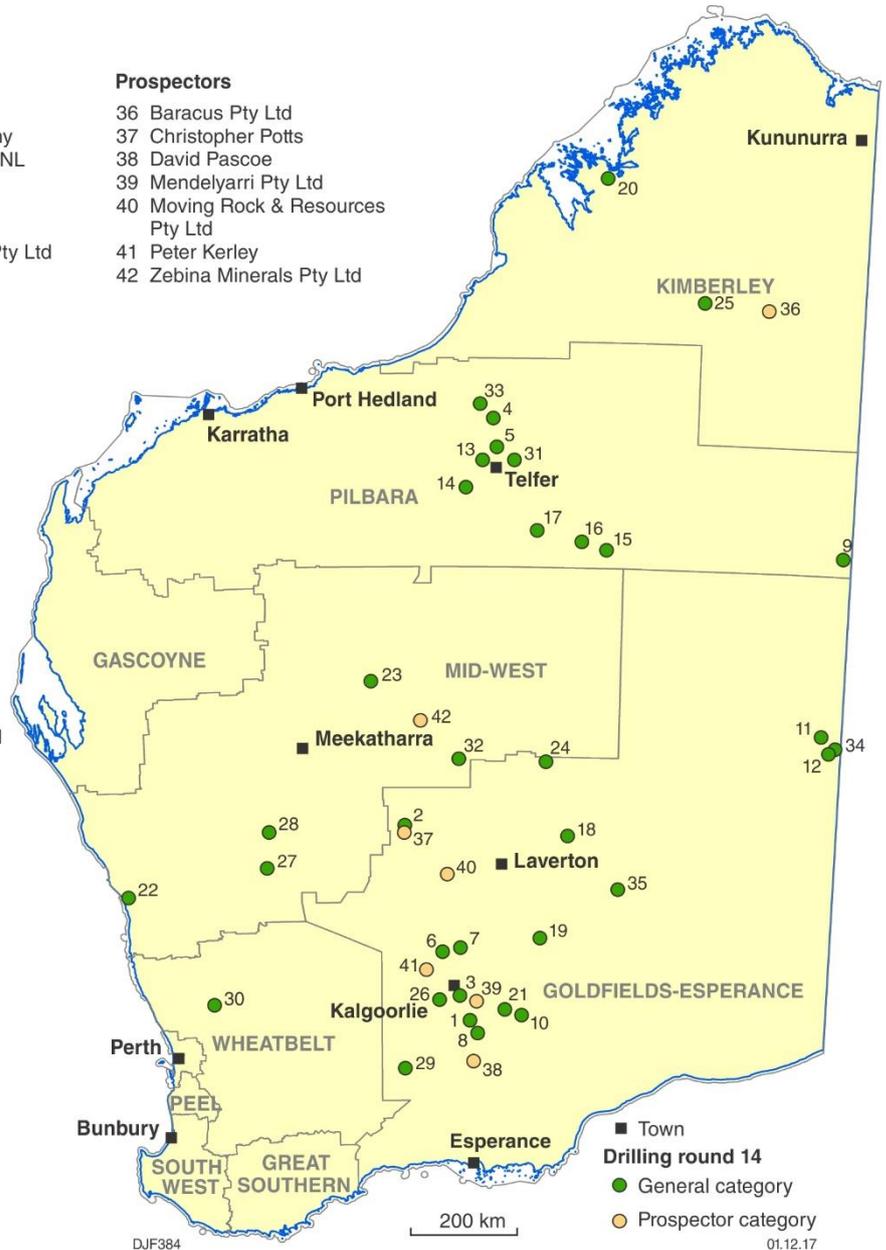
39. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 15

General

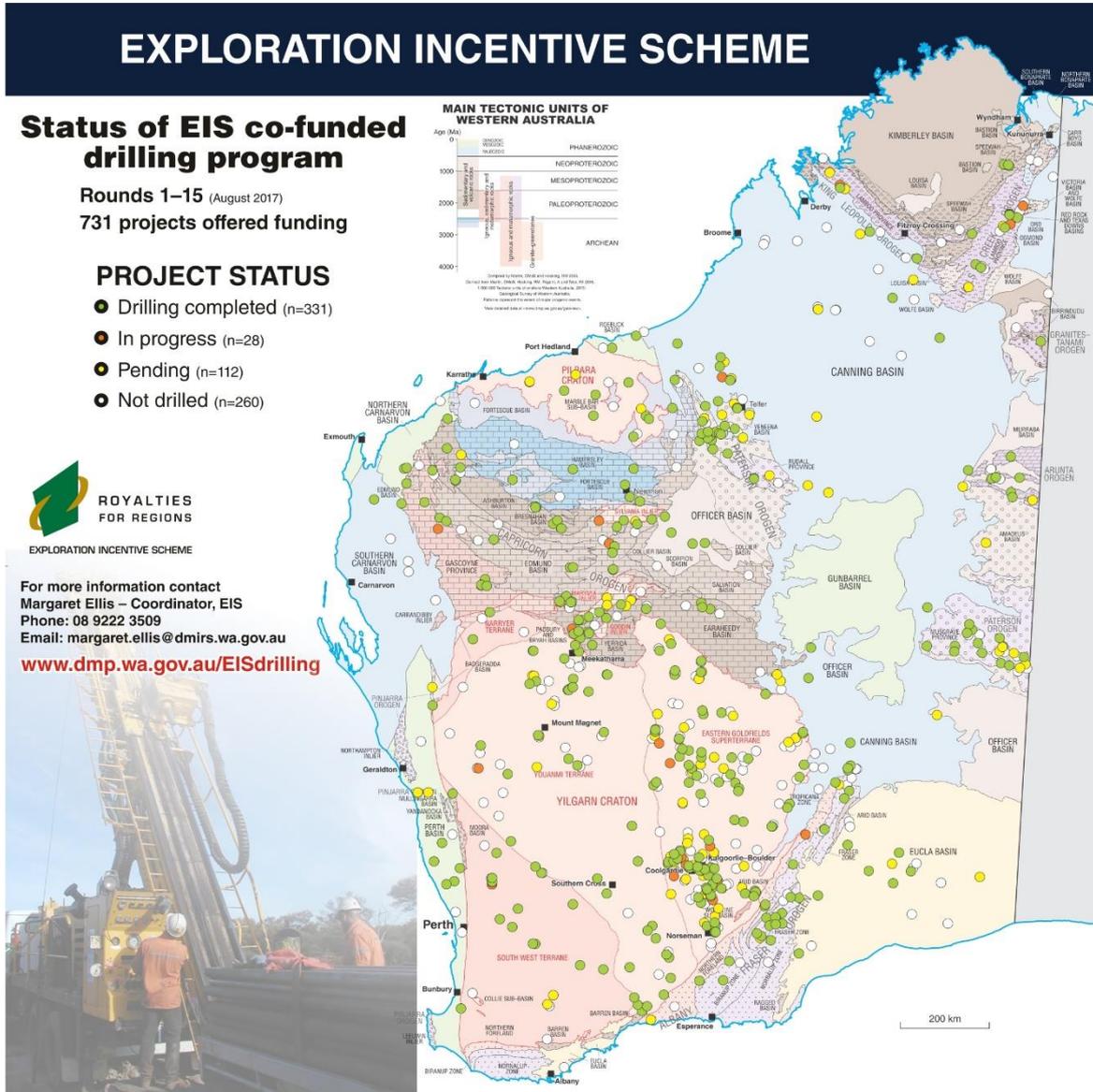
- 1 ACH Nickel Pty Ltd
- 2 Agnew Gold Mining Company
- 3 Anglo Australian Resources NL
- 4 Antipa Minerals
- 5 Antipa Minerals
- 6 Aphrodite Gold Ltd
- 7 Apollo Phoenix Resources Pty Ltd
- 8 Austral Pacific Pty Ltd
- 9 Australian Mines Ltd
- 10 Black Raven Mining
- 11 Chalice Gold Mines Ltd
- 12 Chalice Gold Mines Ltd
- 13 Encounter Resources Ltd
- 14 Encounter Resources Ltd
- 15 Fortescue Metals Group
- 16 Fortescue Metals Group
- 17 Fortescue Metals Group
- 18 Gold Road Resources
- 19 Impact Minerals Ltd
- 20 IronRinger (Tarraji) Pty Ltd
- 21 Kairos Minerals Ltd
- 22 Key Petroleum (Australia) Pty Ltd
- 23 Lodestar Minerals Ltd
- 24 MB Exploration Pty Ltd
- 25 Meridian (Lennard Shelf Project) Pty Ltd
- 26 Middle Island Resources Ltd
- 27 Minjar Gold
- 28 Mt Magnet Gold Pty Ltd
- 29 Poseidon Nickel Limited
- 30 Quadrio Resources Pty Ltd
- 31 Rio Tinto Exploration
- 32 Rox Resources Ltd
- 33 Sipa Exploration NL
- 34 Traka Resources
- 35 Ventnor Resources Pty Ltd

Prospectors

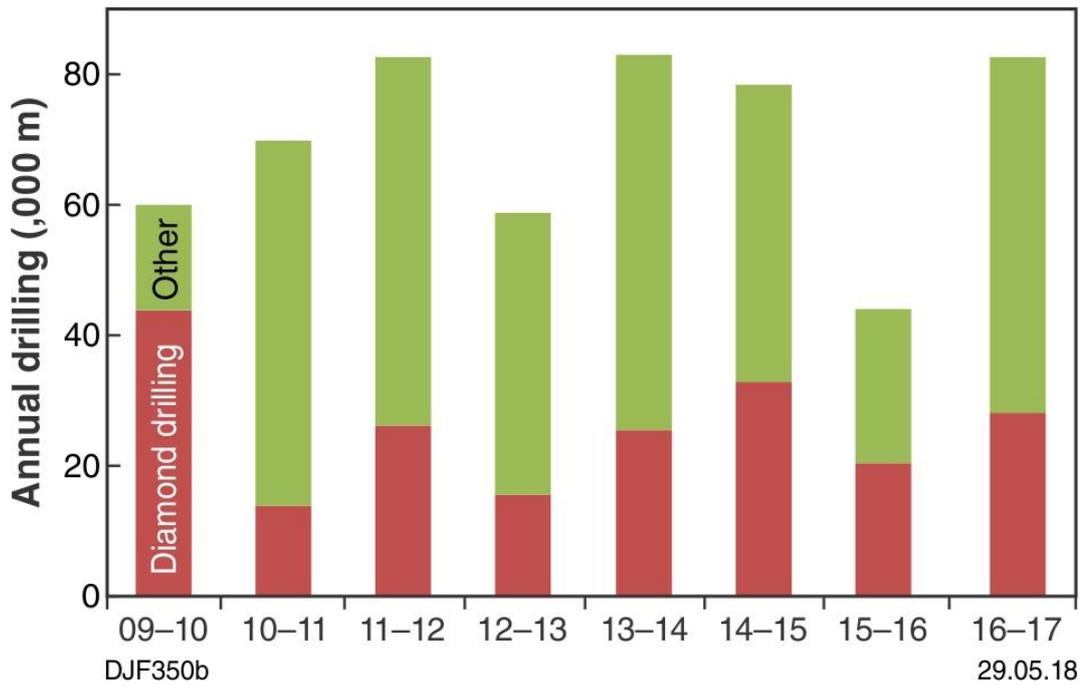
- 36 Baracus Pty Ltd
- 37 Christopher Potts
- 38 David Pascoe
- 39 Mendelyarri Pty Ltd
- 40 Moving Rock & Resources Pty Ltd
- 41 Peter Kerley
- 42 Zebina Minerals Pty Ltd



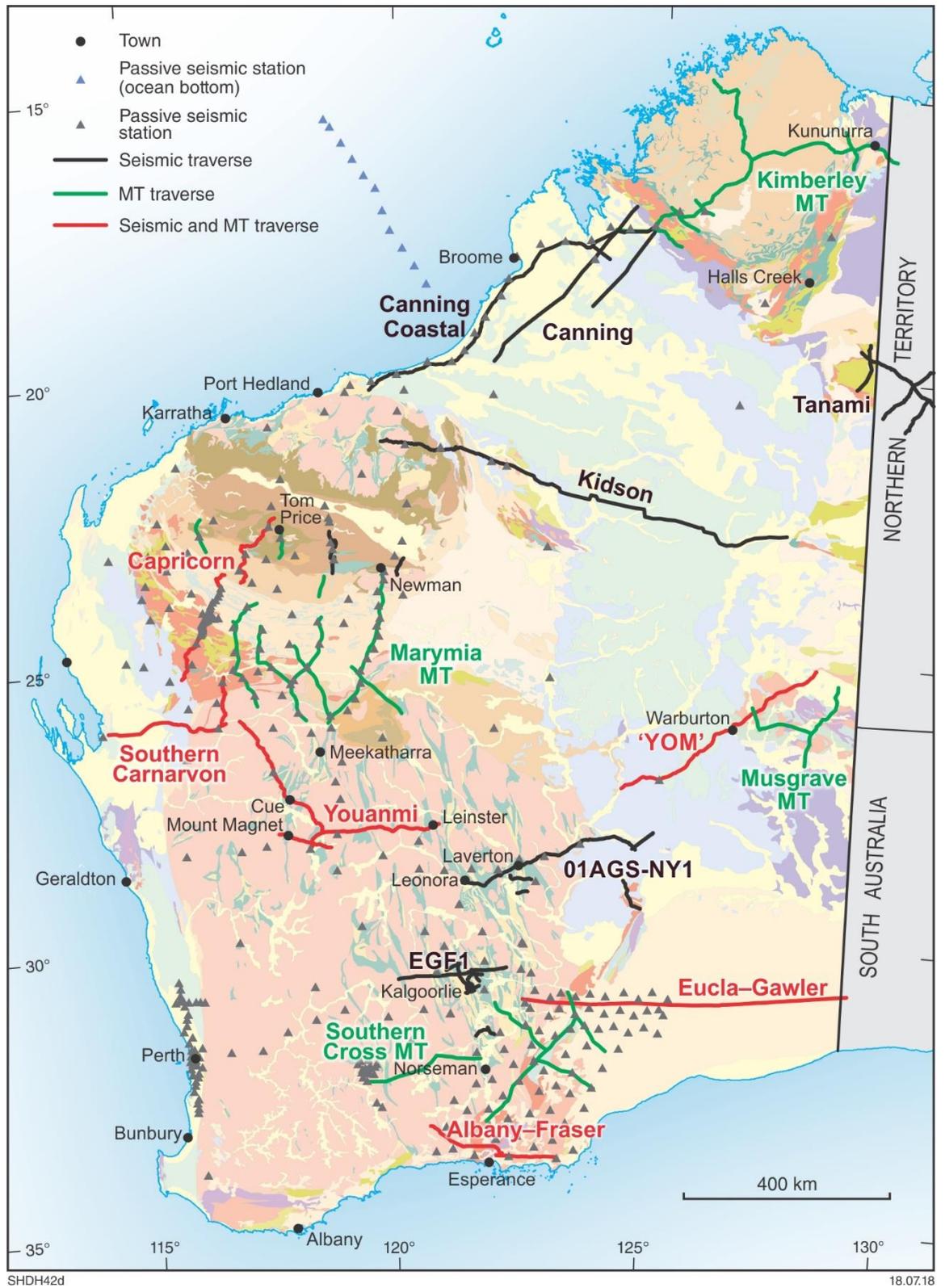
40. EIS Co-funded Drilling program — map showing projects offered funding in Rounds 1–15 inclusive



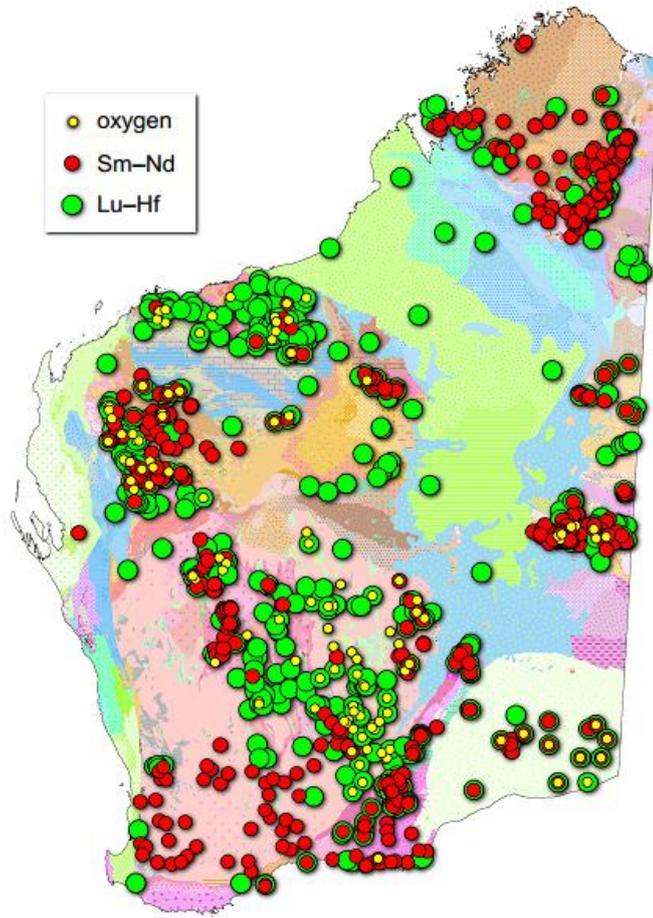
41. EIS diamond drilling versus all other drilling types, by year



42. EIS-funded deep crustal seismic and magnetotelluric, surveys



43. Locations of Lu–Hf, Sm–Nd, and oxygen isotope samples up to June 2017



Tables

1. Real local currency GDP in 2015 and 2016 for selected trading partners (IMF statistics)

<i>Country</i>	<i>2015 GDP (real, billion)</i>	<i>2016 GDP (real, billion)</i>	<i>GDP increase 2016/2015%</i>
Australia AUD	1,617.02	1,654.86	2.34%
China RMB	68,905.20	74,412.72	7.99%
Germany Euro	3,032.82	3,134.07	3.34%
India INR	136,820.35	151,837.09	10.97%
Japan JPY	530,545.20	537,369.90	1.29%
South Korea KRW	1,564,123.90	1,637,420.80	4.69%
United Kingdom GBP	1,872.71	1,939.64	3.57%
United States USD	18,036.65	18,569.10	2.95%

2. Quantity and value of minerals and petroleum production in WA 2016–17

COMMODITY	UNIT	Financial Year 2015-16		Financial Year 2016-17	
		QUANTITY	VALUE	QUANTITY	VALUE
ALUMINA AND BAUXITE	t	13,941,243	4,939,232,470	14,098,163	5,088,560,195
BASE METALS					
Copper Metal	t	190,298	1,180,826,384	170,601	1,237,682,406
Lead Metal	t	5,988	14,810,595	3,507	10,146,717
Zinc Metal	t	82,676	195,494,453	82,933	201,562,473
TOTAL BASE METALS			1,391,131,432		1,449,391,596
CHROMITE	t	0	0	0	0
CLAYS		21,969	1,104,708	20,865	1,390,448
COAL	t	6,890,951	336,466,825	6,806,389	338,435,045
CONSTRUCTION MATERIALS					
Aggregate	t	1,244,225	40,200,886	1,052,475	29,142,593
Gravel	t	200,934	2,264,091	261,219	1,652,110
Rock	t	304,395	4,685,177	390,243	5,234,964
Sand	t	3,537,282	38,325,803	2,560,475	24,306,381
TOTAL CONSTRUCTION MATERIALS			85,475,956		60,336,049
DIAMONDS	ct	13,869,547	354,047,664	12,607,032	268,383,094
DIMENSION STONE		4,113	2,205,326	4,795	1,823,218
GEM & SEMI-PRECIOUS STONES	kg	242,919	623,746	332,399	729,579
GOLD	kg	196,198	10,116,600,502	203,166	10,868,087,846
GYPSUM	t	551,910	13,724,991	531,399	12,980,853
MINERAL SANDS					
Garnet	t	251,162	n/a	565,618	n/a
Ilmenite	t	174,687	39,692,103	178,528	42,912,243
Leucoxene	t	18,137	16,452,584	5,892	5,364,559
Rutile	t	45,888	44,260,114	21,562	21,953,547
Zircon	t	191,551	151,297,003	184,700	101,083,491
Other	t	0	320,102,140	0	410,707,490
TOTAL MINERAL SANDS			571,803,944		582,021,330

IRON ORE	t	748,100,421	48,768,099,970	793,236,080	63,866,462,235
LIMESAND-LIMESTONE-DOLOMITE	t	4,509,980	44,279,689	4,094,677	25,896,887
MANGANESE ORE	t	425,303	146,188,090	236,565	n/a
NICKEL INDUSTRY					
Cobalt	t	5,479	174,846,826	4,732	238,867,102
Nickel	t	175,752	2,202,734,451	157,490	2,083,077,451
Palladium and Platinum By-Product	kg	687	16,656,441	783	21,808,381
TOTAL NICKEL INDUSTRY			2,394,237,718		2,343,752,934
PETROLEUM					
Condensate	kl	6,775,142	2,213,709,834	6,037,603	2,228,626,174
Crude Oil	kl	7,685,922	3,042,849,325	5,404,294	2,063,573,585
LNG	t	20,955,641	10,764,545,353	28,685,477	12,603,581,678
LPG - Butane and Propane	t	531,595	249,059,073	527,391	273,097,308
Natural Gas	'000m3	10,223,641	1,913,134,982	9,708,934	1,830,012,904
TOTAL PETROLEUM			18,183,298,567		18,998,891,650
SALT	t	10,974,721	336,253,755	10,874,279	292,285,826
SILICA-SILICA SAND	t	581,966	18,072,793	727,099	20,331,215
SILVER	kg	155,897	104,401,339	143,894	99,358,909
TIN-TANTALUM-LITHIUM		0	269,771,196	0	605,406,327
OTHER (Includes Vanadium, Manganese, Rare Earths, Spongolite and Talc)			199,236,526		242,499,614
TOTAL VALUE			88,276,257,207		105,167,024,848

Note: Quantities used in this table only apply to Minerals and Petroleum covered by the Mining Act 1978, the Petroleum and Geothermal Energy Resources Act 1967, the Petroleum (Submerged Lands) Act 1982, the Offshore Petroleum Act 2006 and relevant State Agreement Acts.

(r) Revised from previous edition

n/a Breakdown of chromite, garnet, manganese, talc, spodumene, vanadium, rare earths, tin, tantalite and lithium not available

3. WA's ranking in Fraser Institute mining company surveys for the period 2010–11 to 2016

	<i>Ranking relative to jurisdictions world-wide</i>							<i>Ranking relative to Australian jurisdictions</i>						
	2010–2011	2011–2012	2012–2013	2013	2014	2015	2016	2010–2011	2011–2012	2012–2013	2013	2014	2015	2016
<i>Number of jurisdictions surveyed</i>	79	93	96	112	122	109	104	7	7	7	7	7	7	7
Policy perception index	17	12	15	6	10	8	9	2	1	1	1	1	1	1
Best practices mineral potential index	7	11	6	2	8	1	1	1	1	1	1	1	1	1
Investment Attractiveness Index*	7	5	4	1	5	1	3	1	1	1	1	1	1	1
Quality of geological database	17	8	10	11	5	3	1	6	3	4	3	2	1	1

* Formerly "Composite policy and best practices mineral potential index"

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

Jurisdiction	Initiative	Funding
Queensland	Future Resources Program	\$30 million (4 years, ended in 2016–17)
NSW	New Frontiers Initiative (2012 – ongoing)	From licence rentals since 2012; \$41 million spent so far (to the end of 2016–17)
Victoria	TARGET: including \$12M co-funded exploration grants Victorian Gas Program	\$15 million over 4 years ending 2017–18 \$42.5 million over 3 years ending 2019–20
Tasmania	Northern Tasmanian Geosciences Initiative Mining Innovation Initiative	\$1.2 million over 4 years ending 2019–20 \$1.0 million over 4 years ending 2020–21
South Australia	<i>PACE</i> Discovery Drilling	\$5 million over 4 years ending 2020–21
Western Australia	Exploration Incentive Scheme Phase 3 South West Settlement Project	\$20 million over 2 years ending 2018–19 \$1.6 million over 5 years ending 2017–18
Northern Territory	CORE (Creating Opportunities for Resource Exploration)	\$23.8 million over 4 years ending 2017–18. Extension expected
Geoscience Australia	Exploring for the Future (aka “Northern Australia” geoscience program)	\$100.5 million over 4 years ending in 2019–20

5. Recommendations of the 2012 functional review of GSWA – implementation update 1 July 2017

<i>Recommendation</i>	<i>GSWA response</i>	<i>Implementation plan</i>
1. Develop a new funding model applicable beyond 2016 that recognises the dependence of the WA economy on the resources industry and the cost of modern geoscience programs	Accept	EIS3 funding for 2017–18 and 2018–19 approved in Budget forward estimates (from Royalties for Regions funding), but not beyond that. It remains a priority task to ensure long-term initiative funding.
2. Develop a staff development and recruitment strategy to address the age profile of GSWA with plans for succession	Accept	The graduate program (MSc) is finished. Budget and FTE limits imposed greatly restrict ability to employ new staff — as does the 60/40 harvesting rule when someone leaves the department.
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 Geoscience Australia's <i>Exploring for the Future</i> in northern Australia. The change of government following the State election in March 2017 has resulted in significantly different and new goals of a new government. DMP has merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety from 1 July 2017.
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. Note that within the new enlarged department (DMP has become DMIRS) there is the proposal to abolish the Petroleum Division in the structure from 22 January 2018.
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 (National Offshore Petroleum Data and Core Repository (NOPDCR)). GSWA's new WAPIMS system has previously displayed Commonwealth historical information. GSWA assisted the development of and helps maintain the new NOPIMS system.
6. Recruit a Chief Petroleum Geologist for the Executive Team	Accept	Chief petroleum geologist was recruited in early 2016 and remains with GSWA.
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/NOPIMS
8. More closely integrate the work of the Mineral Systems group with the regional mapping teams and research collaborators to produce integrated tectonic and metallogenic syntheses of terranes	Accept	Already implemented: review of Mineral Resources group in GSWA has resulted in a model involving assignment of a mineral geologist to most mapping teams
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. The 2017 update to the Canning Basin SEEBASE model does extend offshore for WA's jurisdiction.
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, but despite that about 80% of all reports are currently written and lodged online.
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 department's website, but specific applications are commercially sensitive to applicants and remain confidential. Applicants who were unsuccessful will be given, on request, reasons why they were

		unsuccessful. The award process is already externally audited.
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

6. GSWA products delivered 2008–09 to 2016–17

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
Books (Reports, Records, non-series books, etc.)	26	36	52	35	39	39	39	40	38
External publications	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	38.	54	52
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	8	10	5
Maps — other (includes Plates and geophysical maps)	17	11	8	14	17	20	19	18	9
Digital information packages	19	21	17	18	11	20	20	16	15
1000 line-km of airborne geophysical data (EIS) ^(a)	398	908	720	768	1157	588	0	110	38.4
Weighted Total Published Product	118	170	188	174	173	187	124	140	N.A. ^(b)
Days of effort to produce all GSWA product	N.A.	26 613 ^(b)							

(a) Plus release of 28 690 gravity points and 287 km of deep crustal seismic in 2015–16

Geophysical surveys in 2016–17 were airborne gravity

(b) Note that for 2016–17 the methodology for calculating the KPI-style 'Weighted Total Published Product' was discontinued and replaced by a measure of the total days of effort to produce all GSWA products — hence is fundamentally different and is not by itself a KPI measure. As such, it now also includes the effort to produce additional products not included this table.

7. GSWA high-level budget for geoscience information

	2013–14 \$M	2014–15 \$M	2015–16 \$M	2016–17 \$M	2017–18 \$M
Consolidated Revenue Fund					
Base funding (recurrent budget)	18.158	19.294	19.488	18.612	18.374
Kimberley Science and Conservation Strategy (KSCS)	1.039	—	—	—	—
Exploration Incentive Scheme*	24.194	11.075	10.000	10.000	10.000
Total budget	43.391	30.369	29.488	28.612	28.374

NOTE: * Budget allocation for GSWA for each financial year; excludes departmental corporate overheads; does not reflect final end-of-year actual expenditure. The base funding (recurrent budget) for 2017–18 includes a project-specific allocation from the Department of Premier and Cabinet of \$115 000 for the South West Native Title Settlement project. The 2017–18 budget allocation excludes the special allocation to the Carbon Strategy project, which covers the geosequestration project at Harvey in the State's South West, but which came under the control of the Geological Survey from 1 July 2017.

8. GSWA's 2017–18 recurrent budget for both projects and support activities

GEOLOGICAL SURVEY 2017–2018 PROJECT & SUPPORT BUDGETS

SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE - RECURRENT BUDGET ALLOCATIONS

2016–17 Budget \$,000	Project and Support Activities Operational Group/Cost Centres Description	2017–18 Allocations			Div
		Salary \$,000	Non-salary \$,000	Total \$,000	Plan FTE
	3101 - Executive and Administrative Support				
693	GS01 Executive Team	669	26	695	4.0
331	GS02 Executive Support	270	10	280	4.0
1024	Subtotal cost centre 3101	939	36	975	8.0
	3102 - Minerals and Petroleum Resources				
1656	GS10 Petroleum Geology	1306	209	1515	11.5
923	GS12 Land-use Geoscience	842	74	916	7.0
870	GS14 Commodity & Industry Analysis	501	312	813	5.0
679	GS20 Mineral Systems Studies	600	67	667	6.0
53	GS77 Mining Act Section 16(3) Referrals Information system development	0	0	0	0
105	GS79 MINEDEX/Royalties Information system development		37	37	0
4286	Subtotal cost centre 3102	3249	699	3948	29.5
	3103 - Regional Geoscience Mapping				
175	GS43 Geochemistry	151	34	185	1.0
151	GS45 Pilbara Craton	152	0	152	1.0
263	GS47 Gascoyne Province	132	25	157	2.0
140	GS49 Edmund and Collier Basins	0	0	0	1.0
430	GS52 East Yilgarn (Kalgoorlie Office)	211	217	428	2.0
554	GS53 Chief Geoscientist and Terrane Custodianship	730	82	812	5.0
737	GS54 Geochronology	493	234	727	4.6
345	GS55 Geophysics and Remote Sensing	272	81	353	2.0
102	GS56 North Australian Craton	103	0	103	1.0
0	GS57 West Musgrave	0	0	0	0.0
604	GS58 Youanmi Terrane	510	45	555	4.0
335	GS61 Albany–Fraser Orogen and Eucla basement	261	65	326	2.0
347	GS62 3D Geoscience	364	0	364	3.0
224	GS63 Tectonic evolution of the Fortescue and Hamersley Groups	132	21	153	0.9
4407	Subtotal cost centre 3103	3511	804	4315	29.5
	3104 - Logistics and Field Support				
1364	GS70 Field Support	316	1,221	1537	4.0
1364	Subtotal cost centre 3104	316	1221	1537	4.0
	3105 - Geoscientific Editing and Publishing				
1056	GS80 Publications	751	219	970	7.0
757	GS81 Series Mapping	685	67	752	8.0

256	GS82	Publication Drafting (CADD)	313	0	313	3.0
631	GS83	GIS Services	640	51	691	6.0
98	GS78	Geoscience Information and Resource Centre	0	150	150	0
1045	GS84	Business Systems Support	566	895	1461	5.0
405	GS85	Promotion and Exhibitions	238	49	287	3.0
4248	Subtotal cost centre 3105		3193	1431	4624	32.0
3106 - Geoscientific and Exploration Information						
751	GS91	Mineral Exploration Information Management	564	160	724	6.5
849	GS92	Petroleum Exploration Information Management	739	109	848	9.0
847	GS94	Core Library Perth	386	260	646	6.0
376	GS95	Virtual Core Library	119	237	356	1.0
419	GS96	Core Library Kalgoorlie	159	135	294	2.0
3242	Subtotal cost centre 3106		1967	901	2868	24.5
18571	GEOLOGICAL SURVEY BUDGET		13,175	5,092	18,267	127.5

13169.0 5089

allocated budget is but includes south west settlement
\$150K

SWS
115000.0
12000.0
127000.0

9. GSWA's 2017–18 recurrent budget, with support budgets distributed pro rata to geoscience activities

GEOLOGICAL SURVEY 2017–18 RECURRENT BUDGET DISTRIBUTION

With support budgets distributed on a pro rata basis (FTE) to geoscience activities

Cost centres	2016–17	2017–18 Fully attributed budget			Div
	TOTAL	Salary	Non-salary	TOTAL	Plan
	\$,000	\$,000	\$,000	\$,000	FTE
Projects and support activities					

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	345.2	271.8	99.5	371.3	2.1
GS45	Pilbara Craton	321.2	272.8	65.8	338.6	2.1
GS47	Gascoyne Province	603.4	373.6	156.5	530.2	4.3
GS49	Edmund and Collier Basins	310.2	120.8	65.8	186.6	2.1
GS52	East Yilgarn (Kalgoorlie Office)	770.4	452.6	348.5	801.2	4.3
GS55	Geophysics and Remote Sensing	685.4	513.6	212.5	726.2	4.3
GS56	North Australian Craton	272.2	223.8	65.8	289.6	2.1
GS57	West Musgrave	0.0	0.0	0.0	0.0	0.0
GS58	Youanmi Terrane	1284.8	993.3	308.1	1301.3	8.6
GS61	Albany–Fraser Orogen and Eucla basement	675.4	502.6	196.5	699.2	4.3
GS62	3D Geoscience	857.6	726.4	197.3	923.7	6.4
GS63	Tectonic evolution of the Fortescue and Hamersley Groups	377.2	240.7	80.2	320.9	1.9
Sub-Total		6503.0	4692.2	1796.4	6488.7	42.7

Petroleum System Studies and Exploration Information

GS10	Petroleum Geology	3613.2	2695.4	965.3	3660.7	24.7
GS92	Petroleum Exploration Information Management	2026.7	1312.7	581.7	1894.4	15.7
Sub-Total		5639.9	4008.1	1547.0	5555.1	40.4

Mineral Resource Services and Exploration Information

GS12	Land Use Geoscience*	1528.7	1271.5	234.1	1505.6	11.0
GS14	Commodity & Industry Analysis**	1369.8	807.8	463.4	1271.1	7.9
GS20	Mineral Systems Studies	1700.2	1324.9	461.5	1786.4	12.9
GS91	Mineral Exploration Information Management	1829.6	1070.6	589.2	1659.7	12.6
Sub-Total		6428.3	4474.7	1748.2	6222.9	44.3

TOTAL GSWA BUDGET

18,571.2 | 13,175.0 5,091.6 18,266.6 | 127.5

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 & Field Support	Distributed pro rata to all mapping and petroleum geology projects
GS80	Publication Editing and Information	Distributed pro rata to all mapping and resource projects
GS81	Series Mapping	Distributed pro rata to all mapping and resource projects
GS82	Publication Drafting and Design	Distributed pro rata to all mapping and resource projects
GS83	GIS Services	Distributed pro rata to all mapping and resource projects
GS84	Business Systems Support	Distributed pro rata to all projects
GS85	Promotion & Exhibitions	Distributed pro rata to all projects
GS94	Core Library Perth	Distributed pro rata to exploration information projects
GS95	Virtual Core Library	Distributed pro rata to exploration Information projects
GS96	Core Library Kalgoorlie	Distributed pro rata to exploration Information projects
GS77	Mining Act Section 16(3) Referrals*	Distributed pro rata to Land Use Geoscience (GS12)
GS78	Geoscience Info & Resource Centre - ISD	Distributed as per Business Systems Support (GS84)
GS79	MINEDEX / Royalties**	Distributed pro rata to Commodity & Industry Analysis (GS14)

10. Distribution of GSWA staff (excluding EIS-, CO2- and KSCS-funded staff) among specialist groups funded by the Consolidated Revenue fund in 2017–18

Specialist group	Actual FTEs 2013–14		Actual FTEs 2014–15		Actual FTEs 2015–16		Actual FTEs 2016–17		Planned FTEs 2017–18	
	FTEs	%	FTEs	%	FTEs	%	FTEs	%	FTEs	%
Geoscientists	72.1	54.9	73.1	56.6	73.1	57.7	70.6	58.7	67.0	55.7
Cartographers and GIS specialists	26.0	19.8	26.0	20.1	26.0	19.9	23.0	19.1	23.0	19.1
Other (technical and field support, data entry administrative support)	33.3	25.3	31.3	23.3	31.3	22.5	26.7	22.2	26.7	22.2
Total	131.4	100	130.4	100	124.9	100	120.3	100	116.7	100

11. Distribution of recurrent budget to high-level strategic objectives in 2017–18

Monitoring Inputs Needed To Achieve Strategic Objectives

GSWA DISTRIBUTION RATIOS				SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE																			TOTAL			
				A Geological Framework of the State and Its Resources and An Archive of Geoscientific and Resource Exploration Data																						
				3162				3165														3166				
				Petrolium Geology		Mineral Resources		Regional Geoscience Mapping														Exploration Information and Core Libraries				
Projects		GS10	GS12	GS14	GS20	GS43	GS45	GS47	GS49	GS52	GS55	GS56	GS57	GS58	GS61	GS62	GS63	GS91	GS92							
STRATEGIC OBJECTIVES	Enhancement and Promotion of State Prospectivity	Prospective pathways of data and use of information	13.72	Minerals	Established and Producing Areas	3.81	Precious metals	0.01	0.01	0.15	0.02	0.08	0.04		0.10	0.10	0.05	0.05	0.20	0.20	0.40	0.02	1.12			
							Base metals	0.01	0.01	0.10	0.02	0.09	0.03	0.10	0.05	0.05	0.05	0.05	0.17					0.10		
							Ferro-alloys	0.01	0.01	0.10	0.02	0.09	0.02		0.05	0.10			0.20					0.10	0.70	
							Non-Metals	0.01	0.01	0.05			0.01			0.05			0.02							
				Green Fields	8.42	Precious metals	0.01	0.01	0.10	0.25	0.20	0.30	0.25	0.30	0.30	0.40	0.30	0.10	0.30	0.20	0.10	0.25	0.08	3.42		
						Base metals	0.05	0.01	0.01	0.10	0.25	0.20	0.35	0.45	0.10	0.10	0.30	0.40	0.10	0.30	0.20				0.10	
						Ferro-alloys	0.01	0.01	0.10	0.25	0.20	0.10	0.10	0.10	0.15	0.10	0.10	0.10	0.10	0.10	0.10					
						Non-Metals	0.01	0.01	0.05		0.05	0.05			0.05			0.01								
				Petrolium and Coal	1.49	Producing Areas	0.28	0.10	0.01	0.01												0.01	0.15	0.28		
						Frontier Areas	1.21	0.70	0.01	0.01													0.04	0.45	1.21	
PROSPECTIVITY ENHANCEMENT				SUB TOTALS		0.85	0.10	0.10	0.75	0.81	0.91	0.90	0.90	0.70	0.90	0.90	0.90	0.90	0.90	0.70	0.70	13.72				
Assisting in Development of the State	Responsive management, custodianship and provision of policy advice and information	4.28	Information on resource potential	2.37	0.04	0.45	0.55	0.10	0.00	0.07	0.07	0.08	0.20	0.00	0.08	0.08	0.08	0.08	0.08	0.08	0.08	2.37				
			Policy advice on resource issues	1.12	0.08	0.45	0.35	0.10															0.07	0.07	1.12	
			Information for R&D and the general public	0.76	0.03			0.05	0.10	0.02	0.03	0.02	0.10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.15	0.15	0.79	
INFORMATION SERVICES				SUB TOTALS		0.15	0.90	0.90	0.25	0.19	0.09	0.10	0.10	0.30	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.30	0.30	4.28		
TOTALS						1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.00			

KEY

- The budget of each project has been attributed in proportion to its perceived contribution to various strategic objectives.
- The vertical total column to the right represents the aggregated weighted contribution of all Output 4 projects to various strategic objectives.

Project Titles

- GS10 Petrolium Geology
- GS12 Land Use Geoscience
- GS14 Commodity & Industry Analysis
- GS20 Mineralization Mapping
- GS43 Geochemistry
- GS45 Pilbara Craton Field Mapping
- GS47 Geoscience Complex Field Mapping
- GS49 Edmund & Collier Basins Field Mapping

- GS46 Edmund & Collier Basins Field Mapping
- GS52 East Yilgarn Field Mapping (Kalgoorlie Office)
- GS55 Geophysics & Remote Sensing
- GS56 North Australian Craton Field Mapping
- GS57 West Musgrave Field Mapping
- GS58 Macintyre Field Mapping
- GS61 Albany Fraser Orogen
- GS62 3D Geology
- GS63 Hamersley Field Mapping

- GS90 Inventory of Abandoned Mine Sites
- GS91 Mineral Exploration Information Management
- GS92 Petrolium Exploration Information Management

12. Planned achievements for release in 2017–18

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18 Planned
Books (Reports, Records, non-series books, etc.)	26	36	52	35	39	39	39	40	38	40
External publications	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	38.	54	52	55
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	8	10	5	4
Maps — other (includes Plates and geophysical maps)	17	11	8	14	17	20	19	18	9	18
Digital information packages	19	21	17	18	11	20	20	16	15	
1000 line-km of airborne geophysical data (EIS) ^(a)	398	908	720	768	1157	588	0	110	38.4	120
Weighted Total Published Product	118	170	188	174	173	187	124	140	N.A. ^(b)	N.A. ^(b)
Days of effort to produce all GSWA product	N.A.	26 613 ^(b)	N.A.							

(a) Plus release of 28 690 gravity points and 287 km of deep crustal seismic in 2015–16
Geophysical surveys in 2016–17 and 2017–18 are airborne gravity

(b) Note that for 2016–17 the methodology for calculating the KPI-style 'Weighed Total Published Product' was discontinued and replaced by a measure of the total days of effort to produce all GSWA products — hence is fundamentally different and is not by itself a KPI measure. As such, it now also includes the effort to produce additional products not included this table.

13. Fraser Institute's Policy Potential Index — relative ranking of Australian States only

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	WA
2	Qld	Tas	NT	NT	WA	SA	SA	SA	SA	SA	SA
3	Tas	NT	WA	WA	NSW	NSW	NT	NT	Tas	NT	NT
4	Vic	WA	NSW	NSW	NT	Tas	Vic	Qld	NT	Qld	Tas
5											Qld
6											Vic
7	WA										NSW

14. EIS budget allocation by project and by year

Programs 2014-2017		Programs 2017 onwards		FTEs	2014-15 (\$000)	2015-16 (\$000)	2016-17 (\$000)	2017-18 (\$000)	2018-19 (\$000)	Total (\$000)
Exploration Facilitation		3301			350	300	80	0	0	730
ES01 Exploration and Environmental Coordination					350	300	80	0	0	730
		3302								
Innovative Drilling Promotion		Innovative Drilling Promotion			5800	5800	5800	5150	5150	27700
ES20 Government-Industry co-funded exploration drilling		ES20 Government-Industry co-funded exploration drilling		1	5675	5675	5675	5000	5000	27025
ES21 Mineral and Exploration Promotion		ES21 Targeted international exploration promotion			125	125	125	150	150	675
		3303								
Geophysical and Geochemical surveys		Encouraging exploration through cover			300	600	1340	2250	2250	6740
		ES30 Airborne and ground geophysical surveys			0	0	0	1000	1000	2000
ES31 Deep seismic survey program		ES31 Deep crustal seismic and MT surveys			300	300	0	800	800	2200
ES32 Regional Gravity Surveys					0	300	880	0	0	1180
ES33 Yilgarn Margin Geochemistry		ES33 Regolith geochemical and resistate mineral surveys			0	0	460	150	150	760
		ES34 Regolith and 3D paleosurface mapping		2	0	0	0	250	250	500
		ES35 Big data: Exploration data analysis			0	0	0	50	50	100
		3304								
		3D Prospectivity Mapping			3070	2950	2430	2250	2250	12950
ES40 WA Geology Online		ES40 WA Geology Online		1	150	100	200	550	550	1550
ES42 3D Geoscience		ES42 3D lithosphere visualisation			300	300	300	150	150	1200
ES43 Mineral Systems Atlas		ES43 Mineral systems			890	850	200	100	100	2140
ES45 Geological Mapping and Interpretation		ES45 Mapping geodynamic setting		3	520	500	530	450	450	2450
ES46 Enhanced Geochronology and Isotopic Fingerprinting		ES46 Enhanced geochronology and isotopic mapping			310	300	300	300	300	1510
ES47 Petroleum, Coal and CO2 Geosequestration Program		ES47 Petroleum systems		1	900	900	900	700	700	4100
		3305								
		Promoting Strategic Research with Industry			480	350	350	350	350	1880
ES50 Strategic Industry Research Program		ES50 MRIWA support			480	350	350	350	350	1880
		Total		8	10000	10000	10000	10000	10000	50000

15. List of successful applicants for Round 14 of the Co-funded Drilling program

Co-funded Drilling Round 14, 2017



Map ID	Applicant Name	Drilling Project Title	Target Commodities
1	ACH Nickel Pty Ltd	Kenilworth Magnetic Anomaly	Au, Ni
2	Agnew Gold Mining Company	Agnew Strategic Stratigraphic	Au
3	Anglo Australian Resources NL	Feysville	Au
4	Antipa Minerals	Citadel Project	Cu, Au
5	Antipa Minerals	Minyari Dome IP	Au, Cu
6	Aphrodite Gold Ltd	Phi North Deep	Au
7	Apollo Phoenix Resources Pty Ltd	Carr Boyd	Ni, Cu, PGE
8	Austral Pacific Pty Ltd	Paris Gold Project	Au, Ag, Cu
9	Australian Mines Ltd	North Dovers Stratigraphic	Cu, Au
10	Black Raven Mining	Erayinia King North	Au, Cu, Zn
11	Chalice Gold Mines Ltd	West Musgraves La Serena, Harvarti & Manyas	Ni-Cu-PGE
12	Chalice Gold Mines Ltd	West Musgraves Pepperjack & Rokpol	Ni-Cu-PGE
13	Encounter Resources Ltd	Telfer West Project	Au, Cu
14	Encounter Resources Ltd	Fishhook	Cu, Co
15	Fortescue Metals Group	Separation East	Cu, Au
16	Fortescue Metals Group	Separation Graben	Cu, Au
17	Fortescue Metals Group	Rudall West	Cu, Au
18	Gold Road Resources	Hann Structural Corridor	Au
19	Impact Minerals Ltd	Mulga Tank Pan Handle	Ni, Cu, Au, PGE
20	IronRinger (Tarraji) Pty Ltd	Tarraji	Cu, Zn, Au
21	Kairos Minerals Ltd	Roe Hills Project	Ni, Cu
22	Key Petroleum (Aust) Pty Ltd	Wye Knot-1	Petroleum
23	Lodestar Minerals Ltd	Contessa Gold Prospect	Au
24	MB Exploration Pty Ltd	Lakes Edge Project	K
25	Meridian (Lennard Shelf) Pty Ltd	Mt Talbot North	Pb, Zn
26	Middle Island Resources Ltd	Two Mile Hill BIF Deeps	Au
27	Minjar Gold	Curara Well	Au
28	Mt Magnet Gold Pty Ltd	Morning Star Deeps	Au
29	Poseidon Nickel Ltd	Abi Rose Genesis	Ni
30	Quadrio Resources Pty Ltd	Calingiri	Cu
31	Rio Tinto Exploration	Budjidown	Cu, Au
32	Rox Resources Ltd	Camelwoop deeps	Ni
33	Sipa Exploration NL	Paterson North	Au, Co

34	Traka Resources	West Musgraves Munster & Cambozola	Ni-Cu-PGE
35	Ventnor Resources Pty Ltd	Silver Dragon Copper Nickel Project	Cu, Ni
36	Baracus Pty Ltd	Mt Dockerell	Au
37	Christopher Potts	Mc Auley	Au
38	David Pascoe	New Waverley	Au
39	Mendelyarri Pty Ltd	Proprietary Project	Au
40	Moving Rock & Resources Pty Ltd	Braemore Project	Au
41	Peter Kerley	Never Can Tell	Au
42	Zebina Minerals Pty Ltd	Mizina / Coralie Prospect	Au

16. List of successful applicants for Round 15 of the Co-funded Drilling program

Co-funded Drilling Round 15, 2017/18



Map ID	Applicant Name	Drilling Project Title	Target Commodities
1	Antipa Minerals	Greater Rimfire	Au-Cu-W
2	Antipa Resources Pty Ltd	Minyari	Au; Cu
3	Ausgold Exploration P/L	Katanning Gold Project Regional Drilling	Au
4	Ausinox Pty Ltd	Chromite Reef	Cr, Cu, Ni, PGE
5	Buxton Resources Ltd	Double Magic	Ni; Cu; Co
6	Canning Potash Pty Ltd	West McLarty	Potash
7	Cassini Resources Ltd	West Arunta Project	Zn Pb
8	Chalices Gold Mines Ltd	Ashburton Gold Project	Au
9	Comet Resources Ltd	Springdale Graphite	Graphite
10	Cygnus Gold Ltd	Stanley	Au
11	Dacian Gold Limited	Westralia Deep Stratigraphic Drilling	Au
12	De Grey Mining Limited	King Col Pegmatite	Li, Ta
13	Draig Resources Ltd	Bellevue Gold Project	Au
14	Empire Oil Company (WA) Limited	North Erregulla Deep-1	Oil
15	Encounter Resources Ltd	BM2	Zn
16	FQM Exploration (Australia) Pty Ltd	Rhea Copper Project	Cu
17	Geocrystal Limited	Webb Diamonds	Diamonds
18	Great Boulder Resources	Yamarna JV	Cu, Ni
19	Greenmount Resources Pty. Ltd.	Karlawinda Strat/Fault	Au
20	MacPhersons Resources Ltd	Boorara	Au
21	Maria Resources Pty Ltd	Lennis	Ni, Cu Pb Zn PGE Co
22	Metals X Limited	Finch Prospect	Cu, Pb, Zn
23	Northern Star Resources Ltd	Back Flag Group	Au
24	Pioneer Resources Limited	Pioneer Dome	Li, Cs
25	Red Metal Limited	Forrest Project	Cu; Au
26	Red Metal Limited	Sharon Dam	Cu Au
27	Redstone Resources Ltd	Tollu	Cu, Ni, Co
28	Reed Exploration Pty Ltd	QVR Nickel Project	Massive nickel sulphides
29	RNI NL	Wodger VMS Target	Au-Cu
30	Silver Lake Resources	Stratigraphic characteristics Daisy Milano	Au
31	Sipa Exploration NL	Paterson North Dome	Au, Cu, Pb, Zn
32	St. Ives Gold Mining Company (Pty) Limited	Invincible South	Au
33	Syndicated Metals Ltd	Old Copper	Au
34	Traka Resources Limited	Mt Morphett Project	Ni-Cr-Cu-PGE
35	Venture Minerals Ltd	Caesar Project	Cu; Ni; Co
36	Venturex Resources Ltd	Mons Cupri South VHMS	Zn-Cu-Pb-Ag-Au
37	Australian Live-stock Suppliers Pty Ltd	Derrys Own Extensions	Au
38	Charles Chitty –Yayhoo Mining Pty Ltd	Lehmans Well Project	Au & Base Metals
39	Christopher Potts	Lakewood	Gold
40	Cranston Edwards	Mayday Prospect	Au
41	Matthew Eggelston	Bardoc	Au
42	Phillip Winton Warren & Arne Olavi Eriksson	Gum Creek East	Au
43	Steven Kean	Binduli North	Au



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

RECORD 2017/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2017–18 AND BEYOND

PERTH 2017



Geological Survey of Western Australia

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Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

Record 2017/1

GEOLOGICAL SURVEY WORK PROGRAM FOR 2017–18 AND BEYOND

Perth 2017



**Geological Survey of
Western Australia**

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Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownamina Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph by I Zibra, DMIRS

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Geological Survey work program for 2017–18 and beyond

Executive summary

Last year (2016–17) was again a very successful year for the Geological Survey of Western Australia (GSWA) and the Department of Mines and Petroleum (DMP). In 2016, the Fraser Institute's Annual Survey of Mining Companies (Fraser Institute, 2017) ranked Western Australia as the third most attractive mining investment destination worldwide and the most prospective for mineral exploration. Very pleasing was our continued improvement in perceptions of our online geoscience databases (includes online tenement and other specialist information systems) to be ranked the best in 2016. Perceptions of our mineral policy environment remained in the top 10 worldwide. This is an absolutely outstanding achievement, and an acknowledgement of the vision of those who implemented EIS and of those who have supported it since.

However, GSWA's activities planned for 2017–18 are (as was the case in the previous two years) in a macro environment characterized by slow growth in China and with low commodity prices generally. Petroleum exploration (onshore and offshore) in Western Australia remains in its serious four-year decline since 2012–13 — a decline of 80% and is now at levels last experienced in about 2005; and with no signs of any improvement soon in 2017–18. However, the four-year downward trend in mineral exploration expenditure (2011–12 to 2015–16) has now switched to rising mineral exploration activity. Other positive signs are emerging — particularly with a new focus on lithium and other battery metals, renewed interest in Western Australia's gold endowment and opportunities, and with these leading to an increase in Initial Purchase Offerings (IPO) on the ASX. Western Australia's spodumene production doubled during 2016–17, and Western Australia's iron ore exports increased yet again in 2016–17 to a fresh record of 793 million tonnes.

However, the biggest challenge for GSWA during 2017–18 remains unchanged from last year, that is, to secure long-term funding for the EIS beyond 30 June 2019 — the current limit of EIS in the budget forward estimates. EIS is currently funded from Royalties for Regions (RfR). At the March 2017 State election, a Labor government was elected, so 2017–18 will also be a time of change as policies and priorities of the new government are implemented. One of the new initiatives has resulted in the old Department of Mines and Petroleum (DMP) merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety (DMIRS), with effect from 1 July 2017. Many more changes within the public service, DMIRS and the Geological Survey are expected over the next year. The new government has also introduced a permanent ban on fracking in the South West, initiated a moratorium on fracking in the State while an Inquiry is held into the scientific aspects of fracking, and is philosophically opposed to the mining of uranium and thorium.

Last year (2016–17) was again a very busy and productive year for GSWA. For 2017–18 and using its recurrent and EIS budget totalling \$28.6 million, ~120 planned full-time equivalent (FTE) staff in 2017–18,

eight FTE contract staff funded from EIS, about 65 short-term fee-for-service contractors, and ~40 collaborative research projects partly funded by GSWA, GSWA plans to publish the following flagship products:

• Reports, Records, Bulletins & non-series books	40
• Series maps (1:100 000, 1:250 000)	4
• Other maps (including State maps & Plates)	18
• Digital information packages	15

Other headline deliverables for 2017–18 are to:

- obtaining government approval for the continuation of EIS (EIS 4)
- obtaining government funding for expansion of the Joe Lord Core Library at Kalgoorlie
- release in full GSWA's digital 1:100 000 IBG for areas covered by Geological Information Series products via GeoVIEW.WA
- release GSWA's next suite of Geophysical Modelling Products
- Release of the Ngurrupa lands soil geochemistry Record and interpreted regolith-landform map
- Release of a Record and data USB on the geochemistry of Archean granitic rocks in the South West Terrane of the Yilgarn Craton
- Release of Explanatory Notes System - Eastern Lamboo Province, Halls Creek Orogen, Murchison Domain, and Hamersley Group
- release of the interpretative report and extensive database of diamond and diamond indicator mineral occurrences, geochemistry and prospectivity for Western Australia
- release of GSWA's concept and demo of the prototype of the Mineral Systems Atlas for komatiite-hosted nickel, orogenic gold, and iron in the Yilgarn Craton
- release of a seismic interpretation of the southwestern Canning Basin
- release of the updated SEEBASE model for the entire Canning Basin (by Frogtech Geoscience)
- release of the second of the innovative product in the series Digital Core Atlas — Theia 1, Canning Basin
- moving on to better IT systems for handling the core library assets, improved lodgement of mineral production data (lodged through the online royalties system but flowing through to MINEDEX), enhancing the WAMEX online report-writing system, and assisting Geoscience Australia with its NOPIMS 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.

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

Northern Australia (which finishes in June 2020), and the MinEx CRC project. GSWA is a sponsor of the MinEx CRC and a decision on its bid for Commonwealth funding will be known during 2017–18.

Note: all currencies are Australian dollars unless otherwise indicated.

Part 1

Strategic overview

International events

Economic growth picks up

The IMF and World Bank estimate that global growth in 2016 is around 3.2% and expect global growth to be 3.5% in 2017. It was clear in mid-2017 that the economic volatility that marked the last four years had declined significantly and growth had returned to Western Europe, the US and Canada, while continued high levels of growth continued in India and China. However it must be said that China's growth has declined from the over 10% it was prior to 2013 but seems to have settled in the 6.5 – 7% range.

In April 2017 in response to Europe's improving economic situation, the European Central Bank began reducing the level of quantitative easing used to stimulate the European economy. Figure 1 shows the critical statistics underlying these growth estimates.

Sustained but not spectacular growth in the US economy during the 2016–17 financial year is a prominent feature of Figure 1a, as well as the continued growth in India's economy and a marked upturn in Japan's growth rate that arresting a marked decline in growth in US dollar terms since 2012.

The impact of slides in currencies against the US dollar is evident the US dollar denoted GDP statistics in Figure 1 where the currencies of Australia, South Korea and importantly the UK have seen depreciations against the US dollar. With the UK beginning formal BREXIT discussions with the European Union in early 2017, there is concern over the UK's depreciated pound sterling post BREXIT encouraging a flood of cheap imports into continental Europe and undercutting Euro prices.

Table 1 demonstrates economic growth rates of the same countries as shown in Figure 1 expressed in local currencies. India again is a standout, followed closely by China. Relatively strong German and UK growth bodes well for higher demand for resources coming from Europe and more demand should be driven by the economic expansions underway in Japan and South Korea.

Importantly, the risk of imminent financial collapse of Greece and potentially several larger European economies has almost totally disappeared, which has contributed to the more positive outlook of most central bankers around the world.

Figure 1b shows that the 2016 economic recovery is, at this early stage in the cycle, associated with benign inflation levels (0 to 2%) in major economies, and India at 4.9% inflation is rapidly reducing its inflation levels from the around 10% level in 2013.

Commodity prices show early signs of recovery

During 2016/17, the “battery metals” boom continued in lithium, cobalt, graphite, and vanadium but except for the last few months of 2016–17, there also appeared to be sustained price rises in thermal coal, base metals, gold, aluminium, and Tapis crude (Figure 2).

During most of 2016–17, the Australian dollar hovered around \$US0.75 (Figure 2a) providing some stability for exporters and importers but probably a little higher than the Reserve Bank’s preferred range of less than \$US0.70. Similarly, the Australian dollar purchased around Euro 0.7 for most of the year, but against the Japanese Yen and China RMB, appreciated slightly, probably because the latter is now effectively pegged to the US dollar. The US dollar gold price declined by \$US200 from its high of \$US1341 in August 2016 to \$US1141 in December 2016 in response to speculation and then the reality of US interest rates being increased after a long period of very low rates. However, the gold price increased by June 2017 to an average of \$US1260 with some speculation that it could go higher. In Australian dollar terms, the gold price was above \$AUD1600 for most of the year providing an important stimulus to WA’s gold exploration and mining industry.

Until February 2017, base metals (Cu, Pb, Zn, Ni) all show a rising trend (Figure 2c) but all declined around \$US200 per tonne in the last few months of the financial year. However, zinc maintains the around \$US 2500 per tonne price it has achieved over the last two years in response to supply concerns and the copper price has shown a marked improvement to \$US5700 per tonne average in June 2017 from its low point of \$US4707 per tonne average in September 2016. Overall, these are positive price trends that began in early 2016 and should continue as the World’s economy improves and demand from China picks up. How the diversion of more existing nickel production to lithium battery manufacture might impact the nickel price is unknown at this stage, with some commentators suggesting that there will be a two tier nickel pricing regime established with higher prices for battery grade nickel sulphate. It is within this context that BHP

announced in August 2017 that it would build a 100,000 tonne battery-grade nickel sulphate plant in Kwinana and divert its WA production to this end-use.

Iron ore and aluminium prices (Figure 1d) continued to improve during 2016–17, despite their slight drop late in the financial year. Aluminium in particular has seen a slow price rise since early 2016 to an average of \$US1887 per tonne in June 2017 and iron ore has improved to around \$US60 per tonne average in May and June 2017 from its price trough around an average \$US40 per tonne in December 2015 and January 2016.

The price of rock phosphate continues to be soft at around \$US93 per tonne average in the latter part of the 2016–17 financial year (Figure 2d).

Hydrocarbon-based energy prices (Figure 2e) have been on an upward trend since January 2016. Metallurgical coal (not produced by WA) has increased markedly in the last year to over \$US200 per tonne driven by short term supply disruptions such as Cyclone Debbie in Queensland and the impact of Chinese Government policies favouring higher grade iron ore and coking coal to minimise CO₂ emissions during iron and steel making.

From its low price point of \$US53 per tonne average in January 2016, thermal coal was an average of \$US86 per tonne in June 2017 after reaching \$US111 per tonne in November 2016.

Tapis crude prices have also risen markedly since January 2016 when one stock barrel was priced at an average \$US32.30. The June 2017 average price was \$US48 per barrel after being at the mid \$US50s most of the 2016–17 financial year.

The optimism over hydrocarbon prices does not extend to uranium which continued its dismal price run to settle at an average price of \$US20.10 per pound in June 2017. The much heralded increase in demand from the about 50 new reactors under construction around the world and dwindling supplies from reprocessing material from decommissioned former Soviet bloc sources has not eventuated, with some analysts suggesting it will be 2020 at least before prices reach \$US50 per pound.

More investment still drives the battery bubble two years after it began. At the end of June 2017, Western Australia has four operating spodumene mines (Greenbushes, Mt Cattlin, Wodgina and Mt Marion), three more at an advanced stage of permitting or under construction (Bald Hill, Pilgangoora – Pilbara Minerals, Pilgangoora – Altura) and another major discovery — Mt Holland, had been made. In 2016, Western Australia

produced approximately 41% of the World's lithium production and Greenbushes was the World's largest lithium mine.

Downstream processing of minerals is unusual in Western Australia. However, Tianqi (51% owner of Greenbushes lithium) began construction of a plant at Kwinana to downstream process spodumene concentrates to lithium hydroxide and Albermarle (40% equity in Greenbushes lithium) was widely rumoured to be considering construction of a lithium carbonate plant in the south of the state.

ASX announcements by companies suggest that if demand for lithium continues at current levels, WA's lithium production could reach 5 million tonnes of 6% lithium concentrate by the early twenty twenties.

The global average price of lithium carbonate increased 138% from US\$5,731 per tonne in June 2015 to US\$13,625 per tonne in June 2017. How much longer this very high price will be maintained before rapidly rising supply begins to influence the market is a subject of some debate.

Similar price rises in other battery metals were noted, including cobalt trading at \$US60,000 per tonne in mid-2017 and there has been a notable increase in exploration activity associated with cobalt, graphite and vanadium in the State, all driven by demand for battery metals.

2016 mineral exploration budget continues to decrease

SNL (2016) reports that World exploration budgets for greenfields, late stage and mine stage exploration all decreased in 2016. The total budget for mineral exploration, excluding for iron ore, coal, aluminium and some industrial minerals, was only \$US6.886 billion (Figure 3) with Australia recording \$US897.4 million (13% of World —Figure 4), with \$US288.8 million (or 32.2%) of the Australian total in the greenfields category.

In 2016, the global grassroots budget was \$US1.92 billion, the lowest allocation since 2004. SNL points out that this represents a year-on-year decline of 25% — more than the 21% decline in the global budget for all stages.

Although exploration budgets for all three stages of project development continued to decline in 2016, late-stage exploration continued to command the largest share of global

exploration spending, except in Australia where grassroots was marginally higher than late stage expenditure

National trends

National economy slowly recovers

The Australian government budget for 2017–18 (Commonwealth of Australia, 2017) delivered in May 2017 revealed an economy beginning to accelerate after the post resource boom slow-down in the period 2013 to 2016, during which the rapid decline in resource capital investment detracted over 1.5% annually from Australia’s GDP growth. The economy and jobs growth is improving because of business investment in mainly Sydney and Melbourne and a slight improvement in household consumption.

A “return to fiscal surplus” in 2020–21, albeit small, was predicted in the 2017–18 budget

Predicted indicators for 2017–18 included the following:

Nominal GDP	4.0	Real GDP	2.75%
Inflation	2.0	Unemployment	5.75%

The Commonwealth Government budget was predicated on improving World economic growth and resulting growth in trade, including resources.

EDI scrapped then resurrected

Although the Commonwealth Government did not extend the Exploration Development Initiative (EDI) in the May 2017 budget, on 2 September 2017 it announced a replacement scheme called the Junior Mineral Exploration Tax Credit (JMETC) scheme. This allows a portion of tax losses in a year to be passed on, via a share issue in that year, to Australian resident shareholders who will then be issued with a refundable tax offset or addition franking credits.

The scheme will be limited to \$100 million and run from 1 July 2017 to 30 June 2021 and hopefully, during an upturn in the exploration investment cycle, will be more effective than the EDI that was introduced in 2014 during a massive downturn in exploration investment. Operational details of the scheme were not available when this plan was compiled.

Foreign investment growth insipid

Foreign investment into Australia's resources sector during 2015–16 was \$AUD 27.6 billion (Figure 5a), one billion more than in 2014–15 (Foreign Investment Review Board, 2017) and just 11.1% of the FIRB-approved \$AUD 247.9 billion of foreign investment in 2015–16.

Royal Dutch Shell's takeover of east coast Australia LNG producer BG Group was responsible for the Netherlands dominating resources-related foreign investment in 2015–16. Japan and the UAE were the next largest investors with China slipping to fourth largest investor with only \$US1.74 billion.

Figure 5b shows that most of the foreign investment activity in 2014 to 2016 was in oil and gas.

Equity flows for mineral exploration

The S&P/ASX 300 Energy and Metals and Mining indices continued their general positive trends apart from the last few months of the 2016 financial year (Figure 6). More equity flowed to metals and mining compared to energy (mainly petroleum and coal) on the Australian Securities Exchange (ASX) and this is reflected in initial public offerings (IPOs) by mineral exploration companies on the ASX.

There were no energy exploration or production IPOs on the ASX during the first half of the year and the number of listed ASX energy companies dropped from 233 at the end of June 2016 to 209 at the end of June 2017, a decline of 10.3%.

In contrast, there were 15 mineral exploration IPOs between January and June 2017 and IPO numbers for the 2017 calendar year are on target to be the best result since 2011 when there were 59 (Figure 7). However, there were still casualties among listed mineral companies due to backdoor listings by IT, pharmaceutical and tech companies, mergers and takeovers, and becoming unloved by shareholders. As a sign of the times, one previously listed pharmaceutical/biotech company relisted and morphed into a gold exploration company with projects in WA. Overall listing numbers for mineral companies dropped from 689 at the end of June 2016 to a low of 665 in October 2016 before rising to 674 at the end of June 2017 — a 2.2% decline compared to June 2016.

In the “Geological Survey Work Program for 2016–17 and beyond” (GSWA, 2016), it was suggested that gold and lithium investment reflected 7:30 to 8 o’clock on the Widdup investment cycle, with other commodities probably a little behind at 6 o’clock, but rising rapidly. Figure 8 shows that we have revised our estimate of the investment climate distinguishing again between the feverous activity in battery metals and gold in WA and the growing exploration interest in other commodities.

State trends

Western Australian economy still struggling

Figure 9 shows that Western Australia’s Gross State Product (GSP), fell by 2.7% in 2016-17, in real chain volume terms, with the State’s economy valued at \$233.15 billion (Government of Western Australia, 2017). The major driver of the fall in GSP was business investment, which fell by 28.6% in 2016-17, although partly offset by an increase in exports of resources, which grew by 7.3%. State final demand, the demand created by State-based business and private activity, dropped 7.2% and unemployment rose to an average of 6.2% for the financial year.

In its 2017–18 budget, the State Government predicted the State economy would grow by 3%, 20,000 new jobs would be created after unemployment peaked in 2016–17, and State Final Demand would grow for the first time in six years. A small budget surplus was budgeted in 2020–21.

New Government brings resources policy changes

The WA Labor Government elected in a landslide in March 2018 has begun implementing two resources policies included in its platform. These are a ban on new uranium mines not already approved by the previous government, and the combination of a ban on hydraulic fracture stimulation (fracking) of gas wells in the Perth metropolitan, Peel and South West regions of the State and a moratorium on fracking in the remainder of the State pending the outcome of a scientific inquiry into the technology.

In early September 2017, the Government announced that the scientific inquiry would be conducted using a panel established by the Minister for Environment under section 25 of

the *Environmental Protection Act 1986* and was expected to release its final report in August 2018.

As part of its first State budget, the Government announced an increase in the gold royalty rate from 2.5% to 3.75%, applying when the Australian dollar gold price exceeded \$1200. The measure, expected to raise \$392 million over the four year forward estimates, was a recommendation of the previous government's 2015 Royalty Rate Review (Government of Western Australia, 2015). At the time of going to press, the measure had not been voted on in parliament.

Soon after gaining office, the Government announced an amalgamation of the Department of Mines and Petroleum and the Department of Commerce, thereby creating a new entity named the Department of Mines, Industry Regulation and Safety which began operating on 1 July 2018. The new Department will regulate all non-primary industry in Western Australia, including industrial relations.

Value of WA's resource production increases

Figure 10, which graphs the three resource cycles until the end of the 2016 calendar year, shows the value of Western Australia's resource production (\$AUD93.4 billion) beginning to increase — the first year since 2013. However, total mineral and petroleum exploration expenditure and capital investment into production and export facilities were still in free-fall after the completion of major construction of gas production facilities, LNG plants and iron ore processing facilities.

For 2016–17, the total value of mineral and petroleum production rose to \$AUD105 billion, which is an impressive 19% increase from the value of \$AUD88 billion in 2015–16 (Table 2). Most of the production value increase can be attributed to the increase in iron ore production volume which was 793 billion tonnes worth \$AUD63.87 billion in 2016–17, or 2.17 million tonnes per day, or around 1 million tonnes per tide.

For the financial year ending June 2017, the only other production value increases were for cobalt, PGEs (palladium and platinum), LNG, LPG, silica sand – silicon, gold and lithium (as spodumene direct shipping ore and spodumene concentrate), with the latter rising in value from \$AUD269 million in 2015–16 to \$AUD605 million in 2016–17, and doubling in production quantity (Table 2).

While 2016–17 production value shows a welcome increase, production trends for most commodities have been disappointing (Figure 11). LNG and iron ore show strong increases in production, while diamond, zircon, nickel and crude oil show moderate longer term declines. Production of other commodities (copper, gold, alumina and coal) remains relatively flat.

Western Australia mineral sector again near top in Fraser Institute survey

Western Australia continued its leadership in significant elements of the annual Fraser Institute survey of perceptions of jurisdictional risks associated with mineral investment. In the 2016 survey (Fraser Institute 2017), our State was ranked the third most attractive mining investment destination worldwide and the most prospective for mineral exploration. Very pleasing was our continued improvement in perceptions of our online geoscience databases (includes online tenement and other specialist information systems) to be ranked the best in 2016. Perceptions of our mineral policy environment remained in the top 10 worldwide (Figure 12).

More detail on Western Australia’s rankings are provided in Table 3, and particularly on our improvement relative to other Australian jurisdictions. For the first time, WA was the leader of all jurisdictions in all categories on Table 3.

Disappointingly, trends in perceptions of some components (Figure 13) of Western Australia’s petroleum policy and regulatory environment (Fraser Institute 2016) were not as positive as those for minerals. The petroleum survey calculates a multifactor Policy Perception Index (PPI) for each jurisdiction 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.

In 2016, Western Australia’s PPI again showed a slight 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 35th for PPI (37th and 47th in previous two years) out of the 96 jurisdictions surveyed in 2016 and ranked 2nd in Australia after the Commonwealth offshore jurisdiction. Another piece of good news was the improvement in the “Regulatory duplication and uncertainty” category.

Despite launching a new online petroleum geoscience information platform widely hailed as a vast improvement on the previous system, WA lost ground in industry perceptions in the “Geological data” category.

Mineral exploration expenditure increases

During 2016–17, increasing levels of mineral exploration expenditure occurred in WA with the clear delineation of 2015 being the low point in the exploration cycle (Figure 14). Throughout 2016–17, WA has accounted for over 60% of Australia’s mineral exploration expenditure. WA has increased its share of exploration expenditure probably because of the relative importance of gold in the State’s exploration mix.

The importance of gold in the exploration mix is emphasised by Figure 15 showing the contributions major commodities and commodity groups make to total exploration spend. Gold exploration increased to \$509.5 million, or 30% in 2016–17 compared to 2015–16 and nickel–cobalt exploration increased to \$67.4 million or 40% over 2015–16 expenditure. However, the big mover was the “Others” category that increased to \$92.1 million or 50% more than in 2015–16. Constituents of the “Others” category are not known but anecdotally lithium exploration is probably responsible for the rise compared to previous years. This is consistent with the 40% rise in nickel–cobalt exploration expenditure given that these elements are, along with lithium, part of the battery metal group.

Figure 16 shows that what the Australian Bureau of Statistics calls exploration expenditure on new deposits — a proxy for greenfields exploration expenditure, has been increasing since March 2015 when quarterly new deposits expenditure was only \$43.3 million. Partly as an impact of the State Government’s Exploration Incentive Scheme, a new wave of exploration is underway in rank greenfields areas of the State including the Arunta Orogen, Tanami, Aileron Province, Paterson Orogen, Canning Basin, Yeneena Basin, Musgrave, Western Yilgarn, and Albany-Fraser.

Not only has the absolute expenditure on greenfields exploration been increasing, the proportion of greenfields exploration expenditure has also been increasing from 23.6% of total exploration expenditure in March 2015 to 30.5% in the June quarter 2017. Anecdotal evidence of mineral tenement take-up in the remote area northwest of Telfer suggests that the proportion of greenfields exploration expenditure will increase further.

Petroleum exploration expenditure slows further

Petroleum exploration expenditure in WA and adjacent Commonwealth waters fell to the lowest level since the mid-1990s (Figure 17) and WA's share of national exploration dipped to less than 47%. Low world oil and LNG prices are largely responsible for the exploration downturn although Figure 2e above demonstrates that crude oil prices are increasing. However, WA's low proportion of Australia's petroleum exploration spend is a concern suggesting there may be WA factors at play, including a decline in the number of wells being drilled to feed the expansion of LNG processing facilities in the state.

Government geoscience

Most States have geoscience initiative funding

Geological Survey organizations in Australia continue to mount powerful business cases to incentivise private sector exploration using government-funded pre-competitive geoscience surveys and improved systems for the delivery of larger and more complex information. Table 4 lists the current initiatives which for the most part are funded by government. Most of the funding goes towards programs that benefit the mineral industry, although with historically low levels of petroleum exploration in Australia, including WA, there is a case to be made for additional funding for basin-focussed pre-competitive geoscience initiatives.

UNCOVER implementation plan released

UNCOVER was established as a result of the Australian Academy of Science's 2010 Theo Murphy Think Tank which led to the preparation of a report under the aegis of the Academy that outlined the broad areas of research and other activities required to revitalise greenfields exploration in Australia.

At the request of the mineral industry and supported financially by industry and governments across Australia, 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 (AMIRA International 2017) arising from Stage 2 of the Roadmap was released in 2017 and included:

- Key scientific research and new technology development programs required for priority areas
- The status of the newly acquired and compiled data required as inputs to the research and technology development programs
- The status of existing research activity that is addressing or complementing the priority areas
- A funding plan and a recommended vehicle in which the research and technology development programmes could be undertaken through a National Research Program for Exploration Under Cover.

Geological Survey organizations across Australia have contributed funding to the Roadmap Stage 2 project and in many cases have established government-funded pre-competitive geoscience initiative programs outlined in the previous section that address key priorities arising out of the Roadmap.

While the Roadmap process has produced a well-argued and documented strategic plan for medium to long term geoscience research and pre-competitive geoscience programs, it is the need to find a balance between the industry and government funding sources required to implement the plan that is the most problematic and critical issue.

Australia has shown leadership in developing the Roadmap, which is World-leading in its scope and depth — now it needs to show leadership in developing a public–private funding model that can implement the plan over the next 20 years.

National Mineral Exploration Strategy revised

In March 2017, the Geoscience Working Group (GWG) of the COAG Energy Council resolved to update the *National Mineral Exploration Strategy*, to reflect changes in government, industry and community priorities since 2012. The revised *2017-2022 National Mineral Exploration Strategy* was approved by the COAG Energy Council at its 14 July 2017 meeting.

The GWG will deliver the strategy, in partnership with the resources industry, the research community and the services sector, by:

- **Encouraging investment** through a renewed commitment to the creation and delivery of government-funded pre-competitive geoscience from all jurisdictions, including new techniques, and a refreshed approach to the global promotion of Australia as the lead destination for investment in mineral exploration and mining.
- **Harnessing our capability**, including a cross-institutional research venture focused on delivering the applied geoscience needed for industry to better explore beneath the covered regions of Australia, as well as continued development and promotion of Australia's world-leading METS sector.
- **Protecting the environment** through provision of robust baseline pre-competitive geoscience data for evidence-based decision making and reducing the exploration footprint.
- **Supporting our people and communities** through wider engagement and clear communication of relevant geoscience information, and the economic and social benefits of a vibrant minerals industry to a broad audience.

The plan commits Australian geological survey organizations to align their programs where possible with key pre-competitive geoscience priorities identified in the UNCOVER Roadmap Implementation Plan.

MinEx CRC application gets to first base

In 2017, the MinEx CRC application was one of six applications in the 19th CRC selection round approved to progress to stage two of the assessment process and submit a full business case to support their applications.

The bid, totalling \$182 million, includes \$36 million cash and \$96 million in-kind commitments from geological surveys, industry and research organisations and seeks a \$50 million cash investment from the CRC Program.

MinEx CRC plans to break new ground by pioneering cheap, safe and environmentally friendly coiled tubing drilling to build a 3D picture of the subsurface. It will build on the technical success of the Deep Exploration Technologies (DET) CRC to address declining mineral discovery rates in Australia by novel coiled tubing drilling and related technologies to revolutionise mineral exploration. The three major themes to be explored are:

- Acquiring previously unattainable data on prospective rocks under deep, barren cover. To be carried out with the assistance of government geological surveys and in the context of the National Drilling Initiative.

- Developing cheaper, safer and more environmentally friendly methods to discover, analyse and drill-out deposits. Enhanced depth, steering and sensing capabilities will permit a dramatically reduced cost of resource definition.
- Optimising conventional drilling such as diamond drilling.

GSWA has made a commitment to the National Drilling Initiative, subject to a continuation of Exploration Incentive Scheme funding.

Part 2
Recurrent budget and work program
for 2017–18 and beyond

Context of the program

The biggest impact in the context of the Geological Survey's work program has been the election of the McGowan Labor government in March 2017, following many years of Liberal government. This has resulted in significantly different goals of the government, together with a big shake-up of the public service. The old Department of Mines and Petroleum (DMP) merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety (DMIRS), with effect from 1 July 2017.

Government policies for the resources sector

The policies for the Labor government for the resources sector involve creating the conditions that will enable the future growth of the Western Australian resources sector and deliver jobs. This is expected to be achieved by a focus on:

- supporting continual investment in exploration, which is the lifeblood of the industry;
- facilitating the development of new and innovative technologies to improve productivity and deliver efficiencies in the resources sector;
- encouraging more local jobs and apprenticeships from resources development;
- working with industry to reduce red tape, regulatory duplication, and agency processes; and
- engaging with communities to build confidence in its regulation and improve the understanding of the economic contribution of the resources sector.

The safety and health of workers is also a high priority of the State Government. This is reflected in the Towards 2020 regulatory strategy for resources safety, as well as the creation of the new Department of Mines, Industry Regulation and Safety.

A partial extract from the 2017 WA Labor Platform for matters dealing with the minerals, petroleum (including fracking), energy (including uranium and thorium), CO2 sequestration, and Asian Engagement is included as Appendix A. The Platform includes the policies of:

- WA Labor will immediately ban fracking in the Southwest, Perth, Peel and Swan Valley Regions;

- WA Labor supports a scientific approach to the regulation of fracking, and will conduct a public inquiry to examine environment, health, agriculture, heritage and community impacts prior to any fracking activity;
- WA Labor will place a moratorium on the use of fracking until such an inquiry can demonstrate that fracking will not compromise the environment, groundwater, public health or contribute adversely to climate change;
- Oppose the mining and export of uranium;
- Oppose nuclear enrichment, nuclear power and otherwise the production of dangerous radioactive waste;
- Oppose the storage of nuclear energy waste in Western Australia;
- The long term legacy issues associated with the closure and rehabilitation of mining and other industrial sites in Western Australia must be addressed as a matter of urgency to ensure that proponents, and not taxpayers, pay the costs of closure and rehabilitation;
- Introduce changes to the Mining Act directed at harmonising its process with those of the Native Title Act with a view to ensuring mining titles are processed in the shortest practical time;
- Investigate ways to increase ‘green fields’ exploration undertaken in the State.

In the State Budget handed down in September 2017, the Exploration Incentive Scheme remained as funded from Royalties for Regions and only funded until 30 June 2019.

Change in the public service

The McGowan Government delivered on its election promise of early 2017 and moved immediately on a 40% reduction in government departments from 41 to 25. The Government’s powerful reform agenda aims to create collaborative departments focused on whole-of-government objectives and delivering services in the most efficient way.

Other measures targeting government policies and objectives included very strict budgetary controls (its first budget was delayed and handed down in September 2017), a 20% reduction in the Senior Executive Service of the public service, and the introduction of a Targeted Voluntary Redundancy Separation Scheme (VTRSS). VTRSS is seeking to find 3000 redundant positions in the public sector state-wide. With each redundancy, the

position and the funding for that position is removed from the relevant government department.

Another step in the McGowan Government's commitment to public sector reform is a Service Priority Review, which was also underway at the beginning of 2017–18 and aimed at creating better public services at a lower cost.

Change in the departmental vision, mission, strategic intent and structure

As part of this rationalisation of government agencies, the Department of Mines and Petroleum and the Department of Commerce's regulatory and labour relations functions were amalgamated into the newly formed Department of Mines, Industry Regulation and Safety, effective from 1 July 2017. DMIRS, as the new department is known, now regulates the mining, building and construction industries and is elevating the focus on worker safety.

The department is working on *'Towards 2020 — regulatory strategy for a safe and healthy resources sector'*. Towards 2020 is the first of a series of high-level three-year rolling strategies to guide the department's efforts to raise awareness and seek compliance in the Western Australian resources sector, going beyond the day-to-day inspectorate activities. It will describe the goals, focus areas and measures of success for safety and health initiatives undertaken by the regulator and it will provide an overview of the regulator's commitments so industry can better understand why focus areas are targeted, the desired outcomes, measures and achievements.

Although DMIRS formed on 1 July 2017, the department embarked on a lengthy and extensive transition process, with numerous taskforces and working groups examining a wide suite of issues, some of which directly related to policies and directives of the new government. These included but were not limited to identifying and implementing all the functions needed for the new department to be operating as a legal entity; organisational review (industry versus function); policy function; customer-centric service delivery; opportunities for digital solutions; and equal employment opportunity and diversity. These, as well as the flow-on effects from them, are expected to be on-going throughout much of 2017–18 and probably into 2018–19 as well.

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 and Royalties for Regions (RfR), and made 12 recommendations (Table 5).

Most of these recommendations have been accepted and implemented (where possible) in previous years. However, developments during 2016–17 that relate to these long-term objectives have been updated in the 'Implementation plan' column of Table 5.

Achievements 2016–17

In 2016–17, GSWA maintained the high-level output of products funded from both Consolidated Revenue and the EIS (Table 6). A full list of GSWA products released for the year is included as Appendix B, with this including a total of 38 Bulletins, Reports, Records etc. and, in addition, there were a further 52 papers published externally on Western Australia's geoscience where at least one author was a GSWA staff member (Appendix C). A total of five 'Series maps' and nine 'Maps — other' were produced entirely by funding from Consolidated Revenue, whereas all geophysical data surveys were funded by the EIS. Other product categories were produced from a mix of Consolidated Revenue and EIS funding. During 2016–17, the amount of data released from airborne gravity surveys declined to 38 436 km (East Kimberley), but substantially more is planned to be delivered and released in 2017–18 as three further surveys are committed (Northeast Canning, Tanami, and Kidson).

The main headline numbers of products released during 2016–17 were similar to 2015–16, but the number of printed maps were less as there is now more emphasis on incorporating new information into the on-line Explanatory Notes System.

Note that the Weighted Total Published Product (WTPP), historically used as an attempt at an all-in measure of GSWA performance, was not used during 2016–17 following the formation of the new mega-department (DMIRS) and new KPI-style measures were changed across the department. The new measures are a mix of activity measures (some

of which are and will be incorporated into the descriptions of specific projects in this series of Records), determining weightings on the wider range of products produced and services offered by the Geological Survey, and improving the estimate of total resources available and work effort (number of staff and staff working hours, including the numerous consultants and contractors). For the last measure, it is estimated that there were 26 613 days of effort to produce all of the GSWA products in 2016–17, with this also including provision of technical advice (Table 6).

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). Since then, GSWA has remained productive and output oriented, but the drop in EIS funding to around \$10 million since 2014–15 has meant that the level of product output has stayed relatively constant in recent years.

Other significant target deliverables set for 2016–17 and their status at year end (status shown in italics) include:

- obtaining government approval for the continuation of the EIS. *Following the State election in March 2017, the business case and other related documentation were updated and submitted to DMP's new Minister and senior executives (DMIRS also had a new Director General from 1 July 2017), Treasury, and Department of Regional Development. EIS is currently funded through Royalties for Regions so multiple approvals are required across government*
- preparing a business case for expansion of the Joe Lord Core Library at Kalgoorlie. *Ongoing — the business case was prepared and submitted for approval; but the measure was not supported in the State Budget presented in September 2017 (where there was very tight fiscal restraint imposed across all of government*
- 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. *Released as a digital package on USB*
- 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. *Released*

- releasing GSWA's concept and demo of the prototype of the Mineral Systems Atlas. *Done and the prototype continues to be worked on*
- releasing GSWA's next suite of 3D products – Rocklea Dome and the Albany–Fraser Orogen. *Released*
- 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. *Released*
- interpreting the Eucla–Gawler deep seismic reflection survey. *Released*
- releasing Explanatory Notes System – West Musgrave Province. *Released*
- releasing Exploration targeting for BIF-hosted iron ore deposits (joint project with MRIWA). *Released*
- releasing Explorer's guide for gold in the Yilgarn Craton (Part 3). *Released*
- releasing Western Australia unearthed (part 3): the Paleozoic of Western Australia. *Released*
- revising Mineral Resources Bulletin on the Gemstones of Western Australia. *Released*
- 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. *Mostly done, though implementation of the MINEDEX–Royalties enhancement for lodging mineral production returns delayed till the first quarter of 2017–18. Use of the WAMEX on-line report writing application remains optional*
- creating TENGRAPH web, which will use the Geocortex software (that is, similar look and feel to GeoVIEW.WA). *Released*
- upgrading to GSWA's Data and software Centre on the DMP website. *Released*
- releasing an upgrade to the WA Geology mobile application, with new layers and new functionality. *Released*
- releasing an upgrade to the free GeoMap.WA software. *Released, but work continues on further upgrades*

The challenges remaining for GSWA include:

- persuading the new Labor Government for an extension of EIS funding beyond June 2019

- continuing to align GSWA’s work program to obtain maximum leverage from the industry-led roadmap of UNCOVER, GA’s *Exploring for the Future* project in Northern Australia, and the MinEx CRC drilling initiative
- 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, together with a minerals component to the online Explanatory Notes System
- lobbying for capital funds to expand the Joe Lord Core Library at Kalgoorlie
- managing the transitioning-out of GSWA’s high-productivity baby boomers in a time of strict government fiscal restraint
- managing the large number of short-term fee-for-service staff in GSWA who are funded through both the recurrent operational budget and EIS, and aligning this practice with the policies of the new Government.

GSWA’s budget 2017–18

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 — and that trend continued with the Labor budget handed down in September 2017 for the 2017–18 year and beyond. It did, however, show the \$10 million component within the departmental budget that is allocated to the EIS, including the popular and widely recognized co-funded drilling program.

The State Budget papers do not show a specific line item for the budget for the Geological Survey, but the papers do indicate that for DMIRS as a whole (including the Geological Survey) the budget allocation for 2017–18 is \$34.068 M for ‘the cost of providing resource sector information and advice to industry, community and government’. This compares with \$34.890 M for 2016–17, so the 2017–18 allocation represents a 2.3% decrease.

The 2017–18 budget decided within the department and allocated to GSWA (but excluding the EIS budget) is \$18.374 million, which is a drop of \$0.238 million (-1.3%) from 2016–17. Factors associated with the drop is the tight government fiscal constraint, low inflation rate but no adjustment for inflation, pay increases for public servants capped at \$1000 for 2017–18 per person (and a freeze in salary for the Senior Executive Service), and the on-going of both the voluntary redundancies (100% harvesting of salary and on-costs) and the ‘60/40 salary harvesting’ for staff who retire or resign (the latter is explained below).

The budget shown in previous editions of the Work Program (in earlier equivalents of the current Table 7) showed the total recurrent (or headline) funding for GSWA, inclusive of departmental corporate overheads. However, Table 7 now shows the budget amount allocated by the Director General of the department to GSWA as the discretionary funding for salaries plus direct operational funding. The difference is due to the fact that employee overheads (superannuation, workers compensation, etc.) and public utilities are paid centrally by the department. However, there is an increasing trend of more of some of the departmental costs (internet usage, Microsoft licences, mobile phones, etc.) being charged instead back to the GSWA operational budget, while corporate overheads seemingly remain the same. As a result, there is a continual squeeze on the operational (non-salary) budget of GSWA.

Overall, the squeeze on government spending — particularly on salaries — continues, with 40% of a person’s salary (60/40 rule) and related on-costs removed from the departmental budget when a staff member retires or resigns from the department. This generally equates (once related on-costs are factored in) to a ‘2-for-1’ rule, that is, two people need to retire or resign before one person can be recruited. This policy was initiated under the Liberal Government and applied during 2016–17, and will continue unchanged under the Labor Government for 2017–18.

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 consult with impacted exploration and production tenement holders. Although the cost of this is

normally within the GSWA base funding (recurrent budget), projects that are a government priority may attract special short-term funding from the Department of Premier and Cabinet. An example of that for 2017–18 is the South West Native Title Settlement, with \$0.115 million provided. Even with that extra project funding, the overall GSWA base funding declined by 1.3% for 2017–18.

Table 8 shows GSWA’s 2017–18 recurrent operational budget for both projects and their support activities. This table excludes the special funding from DPC of \$115 000 for the South West Native Title Settlement. The overall forecast distribution of funds for the projects and their support activities for 2017–18 is similar to the previous year. In the Mineral and Petroleum Resources area, the differences in expenditure are mostly related to the timing of IT projects from one year to the next. In Regional Geoscience Mapping, there is planned winding back of field mapping and expenditure in the Gascoyne Complex, Edmund and Collier Basins, and the Murchison — but with a planned increase in 3D Geology activities. In the work area of Geoscientific Editing and Publishing, the increased expenditure is related to IT projects (from across the Geological Survey) clustered under and managed through ‘Business Systems Support’.

Table 9 shows GSWA’s 2017–18 recurrent operational budget after support areas are distributed on a pro rata basis to geoscience information-producing projects.

In 2017–18, funding for the EIS is again \$10.0 million per year. The government has recognized the early successes of the EIS by extending funding, however, EIS funding in forward estimates of the current budget shows EIS apparently finishing in June 2019. GSWA is preparing a business case for extension of EIS beyond then — either by funding from the current method of Royalties for Regions or by a return to Consolidated Revenue.

Staffing related to base funding 2017–18

For 2017–18, salaries will continue to account for about 72% of GSWA’s Consolidated Revenue funding, which is unchanged from 2016–17.

Table 10 shows planned staffing of 116.7 FTE in 2017–18. This compares with actual staffing of 120.3 FTE in 2016–17, so staffing numbers remain strictly controlled and are gradually diminishing. Experience also reveals that actual staffing levels (at year end) turn

out to be less than planned or budgeted at the beginning of the year. 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 department's 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. GSWA has in past years and continues to use fee-for-service contractors in order to continue to provide services and advice, but where this is paid from the operational budget rather than the salary budget.

The staffing data of Table 10 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. At this time, EIS funding is assured to 30 June 2019, but not beyond that. Table 10 also excludes the fee-for-service staff that are funded by either the recurrent operational or EIS budgets.

Figure 18 illustrates the 20-year trends in GSWA's recurrent expenditure and employment. Actual 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 specific projects, but where employment under EIS was strictly capped at an additional eight FTE staff (who are not shown in Figure 18).

Recurrent-funded staffing recovered to a level of 133 in 2010–11 as EIS activities gathered momentum, but have stayed strictly controlled since then and have overall gradually declined to an actual level of 121 at the end of 2016–17, and with a further fall down to only 117 FTE planned for 2017–18. The sharp drop in staffing levels in the last few years has resulted from the strict budgetary restraints, and the drop is beginning to have an impact on the level of products and quality of services provided.

The government squeeze on salaries and recruitment since January 2015 means that, once again it is not possible to recruit staff into the sponsored Master's program or a graduate program this year. So although the 'baby boomers' are retiring in greater numbers, recruitment is at a much slower rate.

The strict Government controls on expenditure and staffing will continue in the short term, at least for 2017–18. Employment through short-term fee-for-service arrangements for specific project work has remained the most flexible way to achieve operational objectives while balancing budget restraints, but government policies on such arrangements are under review with the new Labor Government (see Appendix A).

The proportion of geoscientists has — since 2007–08 — slowly increased 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 56–58% of all full-time and part-time employees (Fig. 19; Table 10). Geoscientists and IT support staff (but not support staff) dominate the fee-for-service staff (not included within the data of Table 10 and Figure 19).

Appendix D shows the organizational structure for GSWA at 30 June 2017.

Strategic allocation of Consolidated Revenue funding 2017–18

Table 11 contains the result of allocating GSWA's Consolidated Revenue 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 11 reveals that 69% of GSWA's 2017–18 budget will be applied to the outcome of encouraging the exploration and discovery of mineral and energy resources and 31% will be directed towards informed land-use planning. The amounts are essentially unchanged from the previous year.

With the objective of encouraging exploration and discovery, the split between targeting minerals versus petroleum and coal is 46 basis points versus 23 basis points — totalling 69% of the GSWA budgetary resources for 2017–18. Again, these are little changed relative to 2016–17.

Pre-competitive geoscience applied to greenfields/frontier areas targeting minerals, petroleum and coal (combined) consumes 47% of the budget compared to the 22% directed towards brownfields/production areas, a ratio of about 70:30. This ratio has been maintained for many years.

For the outcome of ‘Informed land-use planning’ (31% of total GSWA recurrent budget for 2017–18), the split of expenditure is subdivided into the following, which are again very similar amounts to previous years:

- Information on resource potential: 15 basis points
- Policy advice on resource issues: 11 basis points
- Information for R&D and the general public: 5 basis points

Recurrent budget work program 2017–18

The 2017–18 field mapping and map compilation program will extend the 1:100 000 Geological Series maps (Fig. 20) for the Murchison Domain of the Yilgarn Craton, and the 1:250 000 Geological Series maps for the Kimberley, and the west Arunta and the Amadeus Basin. The Geological Information Series (GIS) products (Fig. 21) covering the Kimberley, Murchison, East Yilgarn, Tanami–Arunta, Albany–Fraser and west Capricorn will be updated with revised interpreted IBG layers at 1:100 000 and 1:500 000 scales. Field mapping and desktop studies will continue for the compilation of GIS products for the southeast Capricorn Orogen basins, the Fortescue and Hamersley basins, and the Southwest Yilgarn. The 1:500 000 IBG map of the State will be updated, and a 1:100 000 IBG, for areas covered by Geological Information Series products, will be released via GeoVIEW.WA. There will be a further release of WAROX, GSWA’s field observation database, as a digital package. 3D products will include further 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. Explanatory Notes System entries will be completed for the Eastern Zone of the Lamboo Province in the Kimberley, the Hamersley Group, and the Murchison Domain of the Youanmi Terrane of the Yilgarn Craton.

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 limiting factor to better integration is the paucity of staff in the Mineral Systems group (now only five staff) in comparison to the large number of geoscience mapping staff and dozens of EIS-funded research projects. Development of the Mineral Systems Atlas will also continue. The group will finish constructing several significant geological proxy layers for komatiite-hosted nickel systems, and will undertake systematic analyses of gold and iron mineral systems to define mappable geological proxies for critical metallogenic processes. Design work will also begin on the interactive, digital Mineral Systems Atlas that will deliver the ‘proxy’ datasets. Development work will begin on a Mineral Deposit Explanatory Notes System. The Mineral Systems Studies section, in conjunction with MRIWA and industry, will investigate the possibility of developing a technique for direct dating of iron oxide mineralisation.

Ongoing entry of mineral deposit information will continue into GSWA’s mines and mineral deposits information database (MINEDEX), which is used throughout the department for a number of policy and approvals purposes. An area of policy focus during 2015–16 and 2016–17 was 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. The emphasis during 2017–18 will switch to improved online reporting of mineral production data into the royalties system and then automatically through to MINEDEX, which will for first time allow for ready calculation of total known geological endowment (current resource estimates and total recorded production) for all commodities — at least down to project level and in many cases down to the level of single deposits.

The Basins and Energy Geoscience section will continue its major investigations of the Canning, Perth and western portion of the Centralian Superbasin using a mix of recurrent and EIS funding. This work involves the high-priority projects of finalising interpretation of the Phanerozoic portion of the Canning Coastal seismic survey (700 line-km) and assisting Geoscience Australia plan and undertake the deep crustal seismic survey of the Kidson Sub-basin (900 km). The Basins and Energy Geoscience section is gradually switching work from the South Perth Basin to the north Perth Basin, where AWE Ltd’s discovery and development of gas in the Waitsia/Senecio fields has renewed much interest in the northern Perth Basin. The group is expected to have greater involvement

with the geoscience aspects of the Harvey geosequestration project now that the Carbon Strategy project and its staff are part of the new Geoscience and Resource Strategy Division. Exploration in the petroleum sector remains at cyclical low levels, with minimal industry-funded drilling and little interest by the petroleum sector in EIS co-funded drilling. The Basins and Energy Geoscience section will continue to compile a digital core atlas for key petroleum wells in the Canning Basin (following publication of the atlas for Olympic 1).

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 2017–18 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.

The Mineral Exploration Information section will continue to update the Guidelines for submission of mineral exploration reports under section 115A of the *Mining Act 1978*, while encouraging greater use of the voluntary on-line report writing application (WAMEX). The Petroleum Exploration Information section will continue to enhance the WAPIMS application, with this done in tandem with Geoscience Australia’s development of the National Offshore Petroleum Information Management System (NOPIMS). The Petroleum Exploration Information section, in conjunction with staff from the Perth Core Library at Carlisle, continue to operate the Perth Core Library as the western hub of the Commonwealth’s National Offshore Petroleum Data and Core Repository (NOPDCR).

Cooperative projects

GSWA is currently involved in 39 cooperative projects with geoscience research organizations including universities (Cambridge University, Curtin University, Macquarie University, Johannes Gutenberg University of Mainz, University of Tasmania, Sydney University, University of Western Australia), Frogtech Geoscience Pty Ltd, MRIWA, CSIRO (including AuScope), AMIRA, Cooperative Research Centres (CRC), Centres of Excellence, Geoscience Australia, National Geographic Society, and Thermo Fisher Scientific. Research projects being undertaken in collaboration with exploration and mining companies include those with Kalnorth Gold Mines Ltd, Northern Star Resources Ltd, and Northern Minerals Ltd. A full list of the current projects is included in Appendix E. The number of collaborative projects increased greatly with the start of EIS in 2009, concomitant with a restriction of the number of extra staff allowed within GSWA. 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.

A suite of the current projects are with Geoscience Australia and operate under the National Collaboration Framework — these include project agreements covering:

- reprocessing of vintage seismic lines from the Canning and Southern Carnarvon Basins
- acquisition of the new deep crustal seismic survey across the Kidson Sub-basin
- Eucla–Gawler deep crustal seismic reflection, gravity and MT survey, processing and interpretation
- Regional reconnaissance airborne gravity surveys (WARGRAV2)
- the National Offshore Petroleum Data and Core Repository (NOPDCR)
- The National Offshore Petroleum Information System (NOPIMS)

Further details of these current projects are contained in descriptions of individual recurrent and EIS project plans.

Recurrent budget — planned achievements 2017–18

Table 12 shows GSWA's planned achievements predominantly using 2017–18 recurrent budgetary resources, but with significant contribution also from EIS funding. Importantly,

production of 1:100 000 and 1:250 000 Geological Series maps will see a drop this year to an anticipated four 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 GIS products, GeoVIEW.WA, and 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 (Table 12).

Other significant planned outputs of the 2017–18 recurrent budget include:

- obtaining government approval for the continuation of EIS (EIS 4)
- obtaining government funding for expansion of the Joe Lord Core Library at Kalgoorlie
- release in full GSWA's digital 1:100 000 IBG for areas covered by Geological Information Series products via GeoVIEW.WA
- release of a seismic interpretation of the southwestern Canning Basin
- release of a Report on the Liveringa Group, Canning Basin: correlating outcrop to subsurface
- release of the second of the innovative product in the series Digital Core Atlas — Theia 1, Canning Basin
- release of a Report compiling and interpreting palynology of the Harvey region, southern Perth Basin
- release of GSWA's concept and demo of the prototype of the Mineral Systems Atlas for komatiite-hosted nickel, orogenic gold, and iron in the Yilgarn Craton
- release GSWA's next suite of Geophysical Modelling Products
- Release of the Ngururrpa lands soil geochemistry Record and interpreted regolith-landform map
- Release of a Record and data USB on the geochemistry of Archean granitic rocks in the South West Terrane of the Yilgarn Craton
- Release of Explanatory Notes System — Eastern Lamboo Province, Halls Creek Orogen, Murchison Domain, and Hamersley Group
- moving on to better IT systems for handling the core library assets, improved lodgement of mineral production data (lodged through the online royalties system but

flowing through to MINEDEX), enhancing the WAMEX online report-writing system, and assisting Geoscience Australia with its NOPIMS 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 2017–18 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 to 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. 22). 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 (EIS3). The State election in March 2017 saw a change of government with the new government undertaking a review of all programs that were to receive funding from RfR, including the EIS. This led to a temporary suspension of some EIS activities post June 2017, including the announcement of successful applications in the Co-funded Exploration Drilling program. As a result of the review, the EIS was given \$10M per year in funding for 2017–18 and for 2018–19, with the funding source switched back to RfR, and bringing total EIS funding from 2009 to \$150 million.

EIS also aims to signal that the Western Australian Government continues to welcome 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 (in 2009) 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 2016 survey, released in February 2017, Western Australia was ranked first globally in both the Best Practices Mineral Potential Index measures and Geoscience Databases, and third in the world for the Investment Attractiveness Index (Fig. 12, Table 3). This is an absolutely outstanding achievement, and an acknowledgement of the vision of those who implemented EIS and of those who have supported it since.

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 13), with Western Australia ranked above all the other Australian states and territories in the major indices in 2016.

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 ran from July 2014 to June 2017 together with the proposed budgets for EIS3 to the end of June 2018, 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 the last survey being undertaken in the Yalgoo area in 2015–16 (Fig. 23). Most of the airborne magnetic–radiometric survey program was completed in late 2012. The program also extended the reconnaissance airborne electromagnetic (EM) surveys, with the Capricorn EM survey undertaken in 2013–14 (Fig. 24). 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.

The EIS has also supported a major expansion of the area covered by ground gravity surveys with stations spaced at 2.5 km apart (Fig. 25). In addition, airborne gravity data is being acquired in areas where ground gravity is difficult, with a survey of the East Kimberly completed in December 2016. Two further airborne gravity surveys covering the Kidson and Tanami were commenced in June and July 2017, respectively, and more surveys are planned. Figure 25 is a composite map showing the EIS-funded ground and airborne gravity surveys.

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.

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 the department’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 (for details see GS95 HyLogger and National Virtual Core Library).

Achievements 2016–17

Achievements during 2016–17, the eighth full year of operation of the EIS, are as follows:

- Drilling projects supported by the Co-funded Drilling program resulted in 27 919 m of diamond drilling and 54 380 m of non-cored drilling from 49 projects during 2016–17
- Forty two successful applicants were announced for Round 14 offers (for drilling

during 2017) under the Government–Industry Co-funded Drilling program

- The announcement of successful applicants from the R15 (2017–18 drilling) application process was delayed due to the uncertainty of EIS funding while RfR programs were being reviewed. After completion of the review process, 43 successful applicants were announced in September 2017
- Publication of the results of research on the petroleum source potential of, and an assessment of thermal maturity using bitumen, graptolite and bioclast reflectance, of the Ordovician Nambheet Formation, Canning Basin based on evidence from petroleum well Olympic 1
- Publication of “Crustal differentiation in the Proterozoic Capricorn Orogen” which was a result of collaboration with researchers from Curtin University, John de Laeter Centre, CCFS and GEMOC
- Release of the geological interpretation of the Canning Basin along Canning Coastal seismic lines 14GA-CC1 and 14GA-CC2, as well as release of the publication of ‘Canning Coastal seismic survey — an overview of the Canning Basin’
- VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks, which is the last of the reports from the CSIRO embedded researcher project
- Several publications on mapping using hyperspectral data on iron ore alteration patterns in banded iron-formation of the Yilgarn Craton
- Release of the record on the regolith chemistry of the Dambimangari area, west Kimberley and the accompanying data set
- Publication of the report on the collaborative MRIWA Project M426: exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia
- Acquisition of 38 400 line km of airborne gravity data in the East Kimberley
- The first two 3D models covering the Sandstone greenstone belt and the Windimurra Igneous Complex were released.

Full details of the achievements are included in the individual program plans — see Part 5.

Cooperative projects and consultancies

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 E contains a listing of all current collaborative projects and consultancies 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.

* 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, Ameer Ghori, Peter Haines, Lorraine de Leuw, Alan Millar, Sarah Martin, Arthur Mory, Leon Normore, Suzanne Simons, Charmaine Thomas, Vije (Alex) Zhan

The primary goal of this section is to develop consistent, basin-wide 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 DMIRS and other organizations including CSIRO, the Western Australian Energy Research Alliance (WA: ERA), University of Western Australia, Curtin University, Northern Territory Geological Survey (NTGS), Geological Survey of New South Wales and Geoscience Australia (GA).

Currently, the section's focus is the Canning, Carnarvon and Perth Basins. These basins have proven petroleum systems but are underexplored, particularly in the case of the vast Canning Basin. The section is also contributing to geological mapping or new reviews of the Western Australian portion of the Centralian Superbasin including the Amadeus, Officer and Murraba Basins, and interpreting results to better understand the petroleum potential of these older basins. An investigation commenced into the little-known Moora Basin, located adjacent to the northeastern margin of the Perth Basin.

Main issues and uncertainties

Canning Basin

The main issues and uncertainties in the Canning Basin include:

- unreliable and irregularly distributed geochemical data, creating uncertainties regarding the definition and distribution of petroleum systems
- inconsistent application of stratigraphic nomenclature across the basin, especially in the Palaeozoic section, resulting in variations in formation tops between wells
- lack of biostratigraphic data in many wells and intrinsic difficulties of biostratigraphically dating some stratigraphic intervals thereby rendering uncertain correlations
- 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 well and seismic data are sparse.

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
- Poor-quality vintage seismic data and sparse/irregular regional coverage.

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 many 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 Palaeozoic component)
- very limited biostratigraphic control, stromatolites previously reported are poorly preserved, a previously reported problematic “fossil” is reinterpreted as inorganic
- 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; aircore cuttings from recent mineral company drilling need assessment

- 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 2016–17

Canning Basin

Some of the main outcomes from studies in the Canning Basin 2016–17 were:

- reassessment of the palynology from the Grant Group and Reeves Formation indicates a significant break between these units, and the likely 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 away from those sub-basins is now included in the Grant Group
- ongoing interpretation of key horizons in the southern Canning Basin provides a series of maps to better understand its resources and structural framework
- mapping of the structural elements of the western Canning Basin confirming the presence of thick sedimentary sections within the Wallal and Waukarlycarly

Embayments and the downgrade of the Samphire Graben. Report published in 2017–18 financial year.

- Publication of GSWA Record of 2017/3 on provenance, depositional setting and regional correlation of the Ordovician Carranya Formation, Canning Basin.

Perth Basin

Some of the main outcomes from studies in the Perth Basin 2016–17 were:

- assessment of the source rock potential and thermal maturity of the Perth Basin, which incorporated 1D and 2D basin models and a set of mapped source rock quality trends. Report published in 2017–18 financial year.
- Completion of a revision of palynological data from other water bores in the Harvey area, as an aid to better constraining the biostratigraphy of this area. Report published in 2017–18 financial year.
- Completion of a regional seismic interpretation and mapping project, which has led to an 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. Report and map grids to be published in 2017–18 financial year.

Amadeus Basin

Some of the main outcomes from studies in the Amadeus Basin 2016–17 were:

- improved correlations as a result of ongoing work on stromatolite biostratigraphy; publication on the biostratigraphy of the prospective Aralka Formation nearing completion. Record published in 2017–18 financial year.
- refined cross-border correlations as a result of collaboration with NTGS
- completion of the WEBB 1:250 000 mapping revises the outcrop distribution and age of northern Amadeus Basin in WA, and (based on geophysics) significantly increases the extent of covered outliers of the Amadeus Basin within the Arunta Orogen
- improved understanding of the western Amadeus Basin with second edition MACDONALD map sheet in progress

Murraba Basin

Some of the main outcomes from studies in the Murraba Basin 2016–17 were:

- publications of GSWA Record of 2017/4 on geological reconnaissance of the Southern Murraba Basin
- addition of Murraba Basin chapter to Petroleum and Geothermal Explorer’s Guide in progress following upgraded prospectivity due to similarities to the Amadeus Basin.

Moora Basin

Some of the main outcomes from studies in the Moora Basin 2016–17 were:

- bitumen was analysed from Goonderoo 1, 1A cores and cuttings; GC-MS data provided some information about original ole composition, but samples were quite degraded
- field examination relocated “fossil” sites near Moora that were reported in the 1950s; these are reinterpreted as psuedofossils (probably silicified aragonite needle clusters)
- Examination of stromatolites in the field and in drill core to improve age constraints; heavy silicification thus far downgrades the biostratigraphic value of this material and better material is desirable

Regional studies

The main outcome from regional studies 2016–17 is:

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

Products released 2016–17

Record of 2017/4 on Geological Reconnaissance of the Southern Murraba Basin

Paleontology Report 2017/1 An Early Devonian fish fauna from an unnamed sandstone in petroleum exploration well Wendy 1, northern Perth Basin

Record of 2017/3 on Provenance, depositional setting and regional correlations of the Ordovician Carranya Formation, Canning Basin

A Booklet in the Western Australia unearthed series “A Paleozoic perspective of Western Australia”

Petroleum prospectivity of State Acreage Release Areas L17-1, L17-2, L17-3, L17-4 and L17-5, Canning Basin, Western Australia

Planned work program and products 2017–18

Regional geological, geophysical and petroleum geochemical studies for the Amadeus, Canning, Carnarvon, Moora, Perth and Officer Basins will continue during 2017–18 and beyond. During 2017–18, new areas of study will include:

- an expansion on the previous palynological review of the Harvey Ridge to include all of the southern Perth Basin. This will lead to a future reassessment of the stratigraphy compared to the northern Perth Basin
- provide input and assistance to GA prior to acquisition of a new regional seismic line in 2018 and drilling of a stratigraphic well in 2019 in the Kidson Sub-basin of the Canning Basin
- assist with QC of reprocessing of vintage 2D seismic lines in the Southern Carnarvon Basin and Coolcalalaya Sub-basin, and the Canning Basin
- seismic interpretation and mapping of the Southern Carnarvon Basin and continued interpretation of the Canning Basin – both projects incorporating the newly reprocessed data
- building 3D depth models of significant geological surfaces in the southern Perth Basin and southwestern Canning Basin
- compilation of a Digital Core Atlas for Theia 1, Sally May 2, and Nicolay 1.

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
- Publication of a field study of the Permian Liveringa Group and division of subsurface sections

- publication of the Report on seismic interpretation and mapping of the western Canning Basin
- Continued seismic interpretation of the Palaeozoic in the southern Canning Basin
- Interpretation of new airborne gravity surveys that were acquired over the Canning Basin in June and July 2017
- Write Record on Cobb Embayment, southeast Canning Basin

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

- publication of a palynological data review for the Harvey region and commence a similar review that encompass all of the remainder of the southern Perth Basin
- publication of a report on the seismic and structural interpretation of the southern Perth Basin
- Publication of a report on the petroleum geochemistry and petroleum systems modelling of the Perth Basin
- Revision of stratigraphy in Wendy 1 and surrounding wells.

Carnarvon Basin — continuation 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
- new age constraints on the Tumblagooda Sandstone.

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
- commence new analysis of well samples.

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

- possible further analysis to determine the origin of bitumen from the fractures within cores from Goonderoo 1 and 1A
- publication of 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
- ongoing studies of biostratigraphy including publication on the Aralka Formation
- cross-border collaboration with NTGS (including joint fieldwork) to facilitate better understanding of the evolution and resource potential of the Amadeus Basin
- examine recently acquired aircore samples from mineral company drilling to assess potential for organic geochemistry and palynology.

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 GSWA's Unearthed series)
- release of external publications related to many of the above topics.

Products planned for release 2017–18

The Wallal Rift System: geology and petroleum potential (Record)
 The Liveringa Group, Canning Basin: correlating outcrop to subsurface (Report)
 Seismic interpretation of the southwestern Canning Basin, Western Australia (Report)
 Revised geology of the Cobb Embayment, Canning Basin (Record)
 Seismic and structural interpretation of the southern Perth Basin (Report)
 Petroleum geochemistry and petroleum systems modelling of the Perth Basin, Western Australia (Report)
 Complete expanded extent and improved correlation of the Aralka Formation, Amadeus Basin (joint NTGS/GSWA Record)
 Petroleum prospectivity of State Acreage Release Areas, Western Australia
 Paleontology Reports (ad hoc, as required)
 Play types of the Canning Basin (Poster)

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 assessed, and recommendations or advice 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 DMIRS.

The number of proposals received as normal workflow from other government agencies decreased slightly in 2016–17, although there were a substantial number associated with the South West Native Title Settlement project.

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 (Fig. 26) in close collaboration with other government agencies, industry and other divisions within DMIRS. 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.

Considerable work was undertaken with other government agencies to incorporate new information received from the public comments.

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.

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 2016–17

The section produced the following outcomes:

- Additional funding continued to be provided for the South West Native Title Settlement project (Fig. 26). The new computer-based system for improving the efficiency of the assessment process and the extension of the ‘screening’ assessment process to a ‘full’ assessment system was completed. 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. Ten ‘full’ assessments and 650 ‘screening’ assessments for potential land tenure changes were completed specifically for this project. These assessments are additional to the 808 referrals listed below in the ‘products released’ table.

- Building upon work with the South West Native Title Settlement project, a new computer database, data input and assessment system (the Land Use Assessment or ‘LUA’ system) was completed for all Land Use Geoscience referrals. This new system was developed to facilitate full electronic referrals from the Department of Planning, Lands and Heritage when they become available.
- Consultation commenced with local government in the Goldfields region to discuss strategic land use planning around Goldfields town sites. In particular, the section worked closely with the City of Kalgoorlie–Boulder to identify a new industrial site. A prospectivity study identified a suitable area about 10 km south of the Kalgoorlie city centre close to other relevant features, that is, transport and utility infrastructure.
- The section has been assisting Main Roads WA with the identification of areas with potential for gravel resources for use in long-term road maintenance and construction throughout the State.

Products released 2016–17

Provision of information, advice and assessments in response to requests from other government agencies — 808 referrals dealt with

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

Planned work program and products 2017–18

The section will continue to provide information, advice, and assessment in response to routine requests from other government agencies. The estimated number of referrals are expected to continue at similar levels to those experienced in 2016–17, that is, about 800 referrals for the year (Fig. 27). In addition, the section also works on a range of special high-priority projects. Where the priority is set by other government agencies or by shires.

Additional funding will continue for the South West Native Title Settlement project to fund one additional fee-for-service geologist to facilitate the section’s role in this project. It is anticipated that there will be substantial land assessment ‘screening’ and approvals associated with the South West Native Title Settlement.

Contingent upon the completion of a new computer system within the Department of Planning, Lands and Heritage, full electronic integration will take place with the new DMIRS LUA system initially for around 40% of all referrals. Once completed, the

integration will result in significant efficiency gains for these referrals by removing the need for most data entry and spatial data creation.

The section will continue to contribute to the Strategic Assessment of the Perth–Peel region. The Department of Premier and Cabinet, which is leading this project, advises that a revised draft for public consultation is planned for the first half of 2018 subject to government decision-making in late 2017.

A revision of the titanium–zircon mineralization mapping will be completed after consultation with industry. This updated mapping will be published on the department’s online GeoVIEW.WA system and available for downloading from the Data and Software Centre. This will replace the former printed 1:50 000 scale map sheets. This will facilitate updating as new information becomes available.

Assistance with the identification of areas with potential for gravel resources for use in long-term road maintenance and construction for Main Roads WA will be completed this year. Learnings from this work will be included in a publication on the gravel resources of South Western Australia with the aim to assist others, particularly local governments in the search for these important road building materials.

Products planned for release 2017–18

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2018 (map)

Atlas of gravel resources: South Western Australia. Record and digital dataset

GS14 Commodity and Industry Analysis

Manager: Nicole Wyche (acting)

*Team members: Roger Cooper, Caroline Strong, Amanda Jones, Jutta Pagel,
Lyn Day*

The Commodity and Industry Analysis (CIA) group tracks mineral exploration activity to allow DMIRS to provide data and specialist technical advice on most mineral commodities. Data are collected on mineral exploration activity, mineralised sites, mineral resources, mineral production and mining activity. Users of CIA group outputs include other DMIRS groups, other government agencies, research organisations, minerals industry, and the community stakeholders.

A key component of this service is the maintenance and enhancement of Western Australia's mines and mineral deposits information database (MINEDEX). It is the one system within the department that has a broad view of industry activity (current and historic) and, unlike other database systems in DMIRS, it is not designed around a regulatory and structured workflow. However, MINEDEX has strong links to other departmental systems for maximum efficiency and minimised duplication of data and effort — including EARS (environmental), SRS (resources safety), RMS (royalties) and Records (records management). MINEDEX maintains information on all mineral commodities and specialises in keeping track of industry activity — not only at a broad project level, but also down to the operating status and location of every site. MINEDEX also specialises in 'geological endowment' — keeping track of all mineral resource estimates, mineral production, and mineralisation styles.

MINEDEX data (which is dominantly textual) can be accessed directly via the departmental website, and viewed spatially via the TENGRAPH and GeoVIEW.WA online systems, and on most maps produced by GSWA. In addition, the CIA group produces a range of commodity-related publications, often with an investment promotion theme, as well as providing data for other Geological Survey publications.

The CIA group also has a regulatory role and is responsible for the assessment of Mineralization and Resource Reports submitted in support of Mining Lease applications.

The group is also responsible for providing Mining Act advice on expenditure exemptions/extensions of term, Retention Licences/retention status, combined reporting, and reports for Special Prospecting Licences (SPLs) for the Warden's Court. Sterilisation Reports, which form part of some Mining Proposals, are also assessed to ensure that important resources or reserves are not being sterilised by proposed in-pit disposal of tailings or waste rock.

Outcome of work program 2016–17

The dominant routine work of the CIA group is maintenance of MINEDEX content, with this done so that the desired products and services are produced and provided efficiently. The following tables summarise the work completed in 2016–17. Some of this work began to be measured (from April 2017) as part of the Key Performance Indicators of the department.

- A total of 1089 tenure-related activities were carried out (mostly related to the Mining Act, but also includes advice to JTSI on State Agreement matters)
- The group monitors a variety of data sources to keep MINEDEX current, with about 3400 items used in 2016–17
- As commodity specialists, the CIA group receives a large number of queries for assistance (despite the database being online), with 1025 queries dealt with — of which the majority (86%) were assisting staff within DMIRS.

<i>Tenure-related assessment tasks 2016–17</i>	<i>Number</i>	<i>KPI measure</i>
Mineralisation reports and resource reports (Mining Lease applications)	67	Yes
Sterilisation reports (as part of Mining Proposals)	2	Yes
Expenditure exemptions and extensions of term	494	Yes
Retention Licences and retention status applications	45	Yes
SPL reports for the Wardens Court	51	Yes
Extractive Industries Licences	41	No
Mining Proposals	344	No
Combined reporting	41	No
Advice to JTISI on State Agreements	4	No
Total	1089	

<i>Data sources consulted for updating of MINEDEX 2016–17</i>	<i>Number</i>
ASX reports	2253
WAMEX reports	410
Annual environmental reports (AER)	148
SRS alerts (from Resources Safety Division’s SRS database)	107
MINEDEX–RMS (Royalties) messaging	174
Form 5s	255
Section 40E permits	86
Total	3433

<i>Queries 2016–17</i>	<i>Number</i>	<i>Source</i>
Resources Safety, DMIRS	370	DMIRS
Environment, DMIRS	376	DMIRS
Royalties, DMIRS	56	DMIRS
Resources Tenure, DMIRS	12	DMIRS
Ministerials	15	DMIRS
Departmental ‘other’	55	DMIRS
Companies and consultants	84	External
Academia and research entities	14	External
Other external entities	17	External
Individuals	26	External
Total	1025	

Products planned for 2016–17	Status
Major Resource Projects, Western Australia — 2017 (map)	Released
Mines – Operating and Under Development, Western Australia — 2017 (map)	Released
Iron Ore Deposits of the Pilbara Craton, 2017	Released
Significant Exploration Activity in Western Australia ('Hotspots' map update) – four updates during the year	General hotspot posters released July 2016, January 2017, June 2017. Special version (Li, Ta, graphite, REE, Zn, Co, U, zircon, and Ti–V) prepared for low emissions conference (October 2016)
Gemstones Bulletin (second edition)	Released
Investment Opportunity Flyers released for cobalt, copper, gold, graphite, lithium, nickel, potassioim, REE, vanadium, and zinc	Released
Manganese mineralization in the Pilbara Craton and Capricorn Orogen (digital product)	Released
Western Australian Atlas of Mineral Deposits and Petroleum Fields 2017 (A4 booklet)	Released
Western Australian Mineral Deposits and Petroleum Fields, 2017 (map)	Released

In addition to the products released, the CIA group provided hand-crafted sets of MINEDEX data on mines, deposits and prospects for inclusion on several published map sheets and assistance was also provided to external authors of manuscripts.

MINEDEX Developments

Several upgrades have been made to this database and application (which was launched in 2008) during 2016–17 to improve efficiency of data entry and data accessibility/extractability. The current version of MINEDEX is version 0.15.13.

The major data improvement project for the year was the MINEDEX–RMS integration project, which involved redesign of the Production Report forms used by the Royalties Management System (RMS) so that accurate mineral production data for all minerals could be collected for MINEDEX — with the long-term goal of users being able to undertake 'mineral endowment' calculations for all commodities by combining estimates

of mineral resources with mineral production; this will be a major enhancement in prospectivity assessments.

Prior to this project, only gold production data could be transferred routinely to MINEDEX. After this project is completed, all producers of minerals where royalty is calculated on an *ad valorem* basis will report production to the department by both site and tenement of origin, and with this done using allowable/controlled commodity units of measure. *Specific Rate* production data (gathered via Royalty Returns, not Production Returns) will be assigned to mine sites within MINEDEX by using database internal messaging. These changes will allow future production data for all commodities to be messaged from the royalties system (RMS) into MINEDEX. This project required a large amount of data clean-up in both MINEDEX and RMS. The project is due for completion in late 2017.

The CIA group also plans to change to a Geocortex-based data entry platform for the spatial component of MINEDEX; testing of this new system is continuing. MINEDEX spatial data are currently maintained by use of ArcEditor; the new solution is technically equivalent for MINEDEX purposes but considerably cheaper.

Planned work program and products 2017–18

Recurrent MINEDEX maintenance and regulatory activities will continue throughout 2017–18. The expected workload will be similar to that listed in the tables above for 2016–17 statistics on activities. Tracking of completed KPI and non-KPI tasks will continue according to internal procedures.

Once the new RMS Production Reports are live (expected late 2017) additional workload in the form of MINEDEX update requests will be expected (in the short term) as tenement holders contact the CIA section to ensure correct sites and tenements are available for lodging mineral production reports.

We are currently exploring the possibility of addressing compatibility issues between MINEDEX and modern web browsers more recent than Internet Explorer v.5, with a business analysis planned for 2017–18. This may initiate a redevelopment of the MINEDEX user interface during 2018–19.

The following table lists the planned products for 2017–18:

Products planned for release 2017–18

Major resource projects, Western Australia (map)

Mines – operating and under development, Western Australia (map)

Significant exploration activity in Western Australia ('hotspots' map poster)

Investment opportunity flyer updates and A1 maps for the following commodities: antimony, coal, chromium, cobalt, copper, diamond, garnet, gold, iron ore, lead, lithium, manganese, nickel, phosphate, potash, rare earth elements, titanium–zircon, tungsten, uranium, vanadium and zinc

Planned work program and products 2018–19 and beyond

As well as the usual products produced annually, other products are compiled only every two years, so are planned to be produced in 2018–19 but work will start on them in 2017–18. These include the iron ore deposits of the Pilbara (map and digital product), iron ore deposits of the Yilgarn (map), Western Australian atlas of mineral deposits (A4 booklet and wall map).

New products for 2018–19, once that the MINEDEX–RMS system is developed and installed, should include state-wide maps and datasets of mineral endowment, estimated mineral resources and cumulative historic production.

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

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

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 and successful. 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's 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 has been complemented by projects funded by the Exploration Incentive Scheme (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.

The section maintains a strong scientific capacity. It retains three of the geologists recruited via the GSWA Geology Masters (GeM) program (which provides Geology Honours graduates early professional development via completion of a Master's degree). Previous group member Lisa Roche resigned from GSWA in early 2017 to pursue professional development opportunities in the mineral exploration industry, but Dr Lee Hassan transferred back into the group in late 2016 to complete and publish some significant work on VMS systems, prior to her scheduled retirement in the latter part of 2017. Dr Lena Hancock continues to contribute her mineralogical expertise, and to manage and further develop the HyLogger facility (Project GS95). Dr Paul Duuring, recruited in early 2016, has considerably expanded the capacity and scope of the group for individual and team-based mineral systems studies, and is also a significant contributor to the continuing professional development of less-experienced team members. Dr Franco

Pirajno (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 2016–17

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 metallogenic interpretations, and also provide useful tools for targeting mineral deposits at all scales, thereby reducing the technical risk of discovery for resource companies.

VMS systems

The EIS-funded collaborative study of the VMS fertility of Yilgarn volcano-sedimentary successions was completed in late 2015. The results of the analysis of then-existing public domain data were published in GSWA Report 165 and in the journal *Precambrian Research* during 2016–17. Studies of the litho-geochemistry and geochronology of a number of under-represented terranes using newly collected data have also been compiled and are to be published in another GSWA Report in the coming year; some of the new work on the Nimbus, Teutonic Bore and King VMS deposits has also been published in *Precambrian Research* and presented at a variety of international conferences (see Appendix C and the work program for Project ES43).

Lee Hassan completed her study of variably deformed and metamorphosed Kingsley VMS deposits near Wheatley, in the South West Terrane of the Yilgarn Craton, and the GSWA Record describing this work will be published in early 2017–18. She also published in *Ore Geology Reviews* a short paper on tellurides occurring at the Yuinmery and Austin VMS deposits (see Appendix C). Studies of the geochemical and spectral footprints of metamorphosed and deformed VMS mineralization in the Quinns district of the Yilgarn Craton were published in the journal *Economic Geology*, and some of this work will also be published early in 2017–18 as a GSWA Report.

Representative diamond drillcore was acquired from one of the more significant deposits in the Manindi VMS 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 (described in GSWA Report 141).

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 group 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 a GSWA Report is being prepared describing the full details of the study. The age of the 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 commenced an examination of the metallogeny of the Paterson Orogen, using material available in the GSWA sample archive, obtained by collaborations with companies active in the region. Samples of buried basement rocks in the northern part of the Orogen have been collected for geochronological and petrochemical analyses, from core obtained by the EIS Co-funded Exploration Drilling program.

Lena Hancock and other GSWA and resource company colleagues completed the 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 came out of confidentiality in late 2015, and was published as GSWA Report in early 2016–17.

GSWA 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. Some results from this and similar, previously completed, studies were presented in August at the 35th International Geological Convention in Cape Town, South Africa.

Josh Guiliamse continued his systematic study of gold deposits in the Ashburton Basin, focussing primarily on the Mt Clement deposit, reviewing historical exploration data, field reconnaissance mapping and sampling of the local geology, logging and sampling of drillcore archived by GSWA, and petrographic and geochemical analysis of samples. Preliminary results were presented at the FUTORES-II conference in June 2017. This and subsequent work contributes 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.

The technical report authored by Trevor Beardsmore on the geology and metallogeny of the Agnew–Lawlers was published in early 2017 as GSWA Report 167, with the permission of the corporate owner of that report.

Nickel systems

Lauren Burley continued preparing her Master of Economic Geology dissertation on the Fisher East komatiite-hosted nickel mineralization for publication as a GSWA Report and as an article in *Ore Geology Reviews*. She is now undertaking a program of systematic, regional-scale sampling of lithostratigraphy and selected komatiite-hosted nickel sulfide systems adjacent to the boundaries between Kurnalpi, Burtville and Yamarna Terranes, as part of a larger collaborative project between GSWA, CSIRO and UWA, to understand the tectono-stratigraphic and metallogenic evolution of the far eastern Yilgarn Craton. She also began a study of the geochemical fertility of mafic volcano-plutonic rocks of the Warakurna Large Igneous Province for Ni–Cu–PGE mineralization, using targeted mapping and sampling of mafic intrusive rocks in the Edmund and Collier Basins, and petrological and litho-geochemical analyses.

Iron systems

The EIS-funded government–academia–industry collaborative study of BIF-hosted iron ore metallogeny in the Yilgarn Craton (part of Project ES43) was completed prior to project leader Paul Duuring joining GSWA in early 2016. Some of the results of mapping iron ore and associated alteration using spectral data from the HyLogging were published in 2016–17 as a series of GSWA Records. An overall synthesis is to be published as a GSWA Report and as a series of external publications. The study of Yilgarn iron ore systems is being extended with a program to obtain ages for hydrothermal iron mineralization, beginning with selected iron deposits in the Weld Range, Koolyanobbing and Windarling regions. Initial work during early 2017 focussed on SHRIMP U–Pb dating of cogenetic phosphates, using the facility at the John de Laeter Centre, Curtin University. A study on the physical–chemical characteristics and source of mineralizing fluids responsible for the Weld Range iron deposits has been submitted to the journal of Economic Geology.

The final report for the study of BIF-hosted iron ore metallogeny in the Pilbara Craton, completed by UWA–CET as part of MRIWA Project M426 (partly EIS co-funded), was released from confidentiality as GSWA co-badged Report 163.

Mineral Systems Atlas

In a significant new initiative, the section has commenced work to create an interactive, GIS-based Mineral Systems Atlas, which will deliver ‘mappable geological proxies’ for critical metallogenic processes, that are derived from systematic ‘mineral systems analyses’ of known or probable mineral systems in Western Australia. The mappable geological proxies are to be created from existing and enhanced or newly created public domain datasets, for use in GIS-based mineral prospectivity studies by mineral explorers. The Atlas will be engineered so that constituent ‘proxy layers’ are automatically updated whenever the underpinning databases are modified.

As part of a ‘proof of concept’ study, the Mineral Systems Studies group has defined mappable proxies for komatiite-hosted nickel systems, and commenced work to generate several high-priority geological proxies for this mineralization type. This early work has highlighted issues with access to, and content of, information in GSWA’s data holdings, prompting the group to initiate a review of all GSWA databases, with the goal of identifying and effecting improvements. Such improvements will include expanding the

information content of the MINEDEX database to include comprehensive published mineral deposit age data, which the Mineral Systems Studies section continued compiling throughout 2016–17.

GSWA also began developing 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 attended two training workshops provided by UWA–CET staff.

Other activities

Several members of the section are co-authoring papers on the Fisher East nickel deposits, Yilgarn and Pilbara iron deposits, and the metallogeny of the Paterson Orogen, that will be included in the ‘Australian Ore Deposits’ monograph to be published by the Australasian Institute of Mining and Metallurgy.

The section also continued to manage or monitor a number of other minerals-oriented research initiatives funded by GSWA’s Exploration Incentive Scheme (refer to the work programs for Projects ES43 and ES50). This included supervision of a study by UWA MSc student Henry Roll on the nature of gold mineralization at the Coyote gold deposit. This project included the logging and sampling of drillcore archived by GSWA and the interpretation of associated spectral data. The resulting thesis will be published as a GSWA Record.

<i>Products scheduled for release in 2016–17</i>	<i>Current status</i>
Report 163 MRIWA Report Project M426: exploration targeting for BIF-hosted Fe deposits in the Pilbara Craton, Western Australia	Published
Report 167 The geology, tectonic evolution and gold mineralization of the Lawlers region: A synopsis of knowledge to 2001 (authorized release of Company Technical Report)	Published
Record 2016/13 13 th International Ni–Cu–PGE Symposium, Fremantle, Australia, Abstracts, p.16, The Fisher East nickel sulfide prospects	Published
Record 2016/14 Mineralogy of gold from the Paulsens and Mount Olympus deposits, northern Capricorn	Published
Record 2016/16 Mapping iron ore and alteration patterns BIF using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia	Published
Record 2016/17 Mapping iron ore and alteration patterns in BIF using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia	Published
Record 2016/18 Mapping iron ore and alteration patterns in BIF using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia	Published

Record 2016/19 Mapping iron ore and alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia	Published
Record 2017/2 GSWA Open Day 2017 Extended Abstracts, p. 1–3, Tools for discovering BIF-hosted iron ore deposits in the Pilbara Craton	Published
Record 2017/6 TARGET 2017, Perth, Australia, Abstracts, p.18–19, Creating exploration tools from data and knowledge: an example using a mineral systems analysis of nickel-sulfide prospectivity for the Eastern Goldfields Superterrane	Published
Geological setting and nature of nickel mineralization at Fisher East, NE Yilgarn Craton (provisional title; based on MEconGeol dissertation) (Report)	In preparation
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
Alteration and age of the Browns Range heavy rare earth elements deposits (Report)	In preparation
External publications — see Appendix C	Published

Planned work program and products 2017–18

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 and nature of mineralizing fluids for 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.

Work in 2017–18 on VMS systems will involve further field and laboratory studies of the geological settings and metallogeny of deposits at the Manindi camp.

Ongoing studies of REE systems will include field geological mapping and sampling, and laboratory studies of fluid inclusions and alteration at the John Galt deposit, to place constraints on the physical and chemical condition of mineralization. The group will also embrace any opportunities that arise for industry-collaborative metallogenic studies of other REE deposit types in Western Australia.

Also continuing during 2017–18 is the collaborative pilot study of gold prospectivity for the Kurnalpi region using gold nugget morphology, geochemistry and regolith setting. Work during the early part of the year will focus on establishing the depositional context(s) of the gold nuggets with respect to regolith evolution. At least one GSWA Report will be published describing the results of the pilot study, and the Mineral Systems group will also co-author a publication describing the newly developed methodology for quantitative trace-element analysis of gold grains. Studies of gold provenance and prospectivity using “alluvial” nuggets will be expanded to other districts and terranes, pending negotiation of projects and sourcing of suitable sample material.

The study of the Mt Clement gold deposit will be completed and the results published, following which there will be reconnaissance mapping, sampling and laboratory studies of less well documented deposits in the region, to further the larger study of the metallogeny of the Ashburton Basin. The metallogenic analysis of the Paterson Orogen will continue, and include targeted, field-based logging and sampling of drillcore from significant domains, arranged where necessary via newly developed government–industry collaborative projects.

Field mapping and sampling, and petrological and lithogeochemical studies will be completed for the mafic Warakurna large igneous province, its Cu–Ni–PGE prospectivity assessed, and the results published. The study of regional nickel prospectivity of the eastern Yilgarn Craton will also continue, within the context of the larger GSWA–CSIRO–UWA collaborative project to understand the tectonostratigraphic evolution of that region.

The group will investigate the prospects for developing a technique for direct dating of iron-oxide minerals, that includes a collaborative, GSWA–MRIWA–industry-funded project to develop matrix-matched standards for geochronological analyses of hydrothermal iron oxides.

Development of the Mineral Systems Atlas will also continue. The group will finish constructing several significant geological proxy layers for komatiite-hosted nickel systems, and will undertake systematic analyses of gold and iron mineral systems to define mappable geological proxies for critical metallogenic processes, assisted where

possible by subject matter experts in other organisations. Design work will also begin on the interactive, digital Mineral Systems Atlas that will deliver the ‘proxy’ datasets.

Development work will begin on a Mineral Deposit Explanatory Notes System.

The Mineral Systems Studies section will continue to manage or monitor — and where relevant be involved with — other collaborative minerals-oriented research initiatives being funded by GSWA.

GSWA Products planned for release 2017–18

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

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

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

The significance of the Mount Clement gold deposit for metallogeny in the Ashburton Basin (Report)

Provenance fingerprinting of gold from the Kurnalpi Goldfield (Report)

Controls on hydrothermal alterations and gold mineralisation at Coyote deposit, Western Australia. Roll, H 2017, MSc thesis, University of Western Australia, 44 p. (Record)

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

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

Origin of rare earth element mineralization at the John Galt prospect, East Kimberley (Report)

SHRIMP U–Pb dating of xenotime from the Wolverine and John Galt REE desopits (Geochronology Records)

Planned work program, products 2018–19 and beyond

The Mineral Systems Studies group will continue examining significant Western Australian mineral systems. This work will be done in close collaboration with GSWA’s regional mapping section, and as appropriate with other government and 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 GSWA. The group will continue to lead the development of mappable Mineral System ‘proxies’, and a digital Mineral Systems Atlas to deliver these products,

as well as advance the concept of a 'Minerals' layer to the statewide Explanatory Notes System. Future products may include targeted prospectivity studies.

GS43 Geochemistry and Regolith

Manager: Paul Morris

Team members: Nadir de Souza Kovacs, Sara Jakica

The geochemistry of rocks and regolith, and the mapping of the distribution of different regolith types are data integral to an increasing number of geoscience studies throughout GSWA, as well as forming the basis of regional regolith geochemistry programs. This growth in the use of geochemistry reflects in part the refinement of analytical processes related to litho-geochemistry (enabling more precise and accurate analysis of a wide range of elements at low concentrations), the reduced per-sample analytical costs, and the shortened turnaround time. More sophisticated regolith mapping has resulted from the increasing availability and quality of satellite imagery (e.g. ASTER), and geophysical data attuned to near-surface cover (e.g. AEM). Algorithms for simplification of map layers reduce the level of subjectivity in onscreen digital mapping, and provide quantitative data on the distribution of different regolith types.

Several factors make geochemical data attractive to a wide range of users. These include: acquiring sufficient quality control data throughout the preparation and analysis procedure to determine if data are fit-for-purpose; analysing for a wide range of elements, thus catering for a wide customer base; and storing and making available data in a set format using easy-to-use software tools. GSWA has addressed these issues by acquiring data from laboratories selected by tender using rigorous criteria. Having a number of such suppliers means that analytical programs can be tailored to the sample media and the program outcomes. Data quality are checked by inclusion of 10% quality control samples by the provider, with a further 10% inserted 'blind' by GSWA. Each sample is analysed for between 55 and 64 elements. Data are stored in GSWA's corporate WACHEM database, which includes records of laboratory-related analytical techniques, sample duplicates, analyses of reference materials and analytical blanks. These data are linked daily to the sample's metadata in the WAROX database, and made available on GeoVIEW.WA. At the end of June 2017, The WACHEM database held over 54 000 analyses, of which over 6 800 (12.6%) were data for reference material or analytical blanks, and 3.9% were analyses of sample duplicates. The lower than expected number of duplicates reflects the incorporation of legacy data (generated by the Chemistry Centre of

WA), which lacked these QC data. Legacy data loading in 2008 accounted for over 10 000 samples, whereas peaks in 2012 and 2016 reflect loading of data from GSWA's regional regolith geochemistry programs, and litho-geochemistry programs carried out in the Albany–Fraser Orogen and Eastern Goldfields respectively (Fig. 28).

Regolith mapping is carried out by both members of the Geochemistry and Regolith group, and by GSWA mapping geologists. These users are catered for by a scale-independent regolith-landform classification scheme applicable regardless of geological terrain. This is complemented by a documented approach to regolith mapping which explains the use of geophysical and remotely sensed data, orthophotos, existing geological mapping, and point observations from GSWA's WAROX database in the compilation of maps.

Outcomes of work program 2016–17

In order to make geochemistry data more accessible, GSWA embarked on a program to centralise geochemical data regardless of origin, and ultimately acquire a software application that would permit flexible searching capabilities of these combined data. In late June 2017, the capabilities of the WACHEM database were expanded to store non-GSWA data, in particular data from CSIRO and tertiary institutions.

With GSWA's regolith geochemistry programs focussing on greenfields terrains, there has been a need to investigate what sort of sample media can provide some 'vision' through cover bedrock, and potential bedrock-hosted mineralization. In desert terrains dominated by eolian deposits, the fine (silt and clay) fraction of regolith has proven useful as a multi-element sample medium, especially when combined with a partial extraction approach during analysis. Recently, GSWA investigated the potential of biogeochemistry, specifically the chemistry of spinifex to detect abnormal fluid fluxes over regional faults, and whether this chemistry is indicative of fluids migrating from bedrock mineralization. The combined fine fraction and spinifex chemistry data from the Ngururpa area of northeastern Western Australia shows promise.

The 2D regolith-landform mapping is now being augmented by extension into 3D and 4D space. Since 2011, GSWA demonstrated the application of single-station passive seismic to provide estimates of shallow cover, with published case studies from the eastern

Yilgarn Craton and Eucla basin. The use of this technology is being further extended by purchase of four more recording devices, capable of providing an array coverage. Current work with CSIRO aims to integrate the passive seismic approach with regional AEM data captured over the Capricorn Orogen.

In conjunction with the John de Laeter Centre at Curtin University, GSWA embarked on a program of (U–Th)/He dating of ferruginous duricrust in mid–late 2016. This is a pilot program to determine, initially on a statewide scale, if the age of this material varies significantly. With increasing analytical sophistication, it is hoped that these data will become a routine part of GSWA’s regolith program.

Planned work program and products 2017–18

- Ongoing evaluation of new analytical techniques, including both laboratory-based and portable techniques
- Continued population of the WACHEM database
- GSWA record on the (U–Th)/He dating of duricrust
- First edition of 1:500 000 scale State regolith map
- Record on methodology for compilation of State regolith map

GS45 Pilbara Craton

Manager: Arthur Hickman

Team: GSWA staff as required

The Pilbara Craton provides Australia's best preserved geological record of Eoarchean to Mesoproterozoic crustal evolution. It also includes several of the world's oldest examples of various styles of mineralization, revealing how these varied with tectonic setting.

Paleoproterozoic metasedimentary rocks in the east Pilbara provide exceptionally good fossil evidence of early life on Earth and, with the recognition of distal impact ejecta layers, reveal that Earth experienced two major asteroid impact events at 3470 and 3460 Ma.

Although the craton underlies approximately 400 000 km² of northwestern Australia its total exposure is less than 70 000 km², and almost 90% of this is located in the northern Pilbara. Between 1995 and 2005 this northern part of the craton, 60 000 km² in area, was the subject of a collaborative mapping project between GSWA and Geoscience Australia. The project was established to clarify the tectonic evolution of the granite–greenstone terranes in the northern Pilbara, and how this evolution influenced mineralization. The 1995–2005 phase of the project enabled the release of 30 new 1:100 000-scale geological maps and seven revised 1:250 000-scale maps. From 2005 onwards data from the project continued to be released through additional maps, reports, and digital products.

The Pilbara mapping project resulted in a major revision of the stratigraphy, structure, and crustal evolution of the northern Pilbara Craton, with important implications for its mineral potential. Extensive geochronology established that the east Pilbara exposes the oldest granite–greenstone terrane of the craton, named the East Pilbara Terrane. Repeated volcanic cycles and contemporaneous intrusion of granites over 310 Ma (3530–3220 Ma) constructed this terrane in the form of an extensive volcanic plateau overlying older crust. Isotopic data reveal that the older crust included widespread felsic igneous rocks, mainly 3680–3550 Ma, that were derived from partial melting of substantially older mafic crust. The tectonic evolution of the East Pilbara Terrane was dominated by vertical tectonic processes instead of horizontal crustal growth and recycling that are typical of Phanerozoic-style plate-tectonic processes. Episodic vertical crustal growth and reworking in the East Pilbara Terrane explains its present dome-and-keel crustal

architecture, which has no Phanerozoic analogues. This provides an explanation for the rarity of large mineral deposits in the east Pilbara Terrane because fluid sources were more restricted than in plate-tectonic settings such as magmatic arcs above subduction zones.

The crustal evolution of the Pilbara Craton experienced a fundamental change at c. 3200 Ma, when the 300 Ma continental volcanism and vertical deformation of the East Pilbara Terrane was abruptly replaced by rifting, continental breakup, and the commencement of plate-tectonic processes. Only post-3200 Ma successions of the craton contain mineralization formed by plate-tectonic processes, and it is these processes that produced the largest mineral deposits.

Mineralization in the Pilbara Craton is extremely diverse and spans 650 Ma, from the 3480–3460 Ma VMS deposits of the Dresser and Duffer Formations (Warrawoona Group) to 2850–2830 Ma rare-metal pegmatites of the Split Rock Supersuite. The most economically important mineral commodity has been iron ore, with total historical production in excess of 300 Mt. Iron ore deposits are enriched Mesoarchean banded iron formations in the Gorge Creek and Soanesville Groups. Gold and copper mineralization is present throughout the East Pilbara Terrane but all the deposits are relatively small. Larger gold deposits are located along shear zones within late Mesoarchean sedimentary basins (Mosquito Creek and Mallina), but individual deposits are nevertheless small by Australian standards. Tin and tantalum have long been mined from pegmatites and secondary alluvial deposits but the current exploration focus is mainly on lithium. Current Pilbara resources of 3.9 Mt Li₂O comprise approximately 40% of the state's total resources.

Project work is currently focused on completion of a detailed geological Report on the east Pilbara Craton and on fully populating the ENS database for the northern Pilbara.

Outcomes of work program 2016–17

A geological Report describing a study of new zircon Lu–Hf and whole-rock Sm–Nd isotope data from the Mount Edgar Dome (East Pilbara Terrane) was written and will be released in 2017–18. The study, undertaken jointly with Curtin University, concluded that the Paleoproterozoic magmatic events in the East Pilbara Terrane, from 3460 to 3220 Ma,

mainly involved reworking of existing crust as opposed to addition of new juvenile material. Such crustal recycling is consistent with the volcanic plateau tectonic model and inconsistent with Phanerozoic-style subduction. A geological Report reviewing the Eo–Mesoarchean crustal evolution of the east Pilbara Craton was partly written, and will be completed in 2017–18. This Report includes a compilation of all available geochronological data on the east Pilbara and uses these data to supplement previously published information on crustal evolution. Contributions were made to five external papers, two being published in 2016–17 and three being submitted to publishers. Additions were made to the ENS database during work on the GSWA Reports.

Products released 2016–17

External publication: Lithostratigraphy and structure of the early Archean Doolena Gap greenstone belt (Precambrian Research)

External publication: Processes of crust formation in the early Earth imaged through Hf isotopes (Precambrian Research)

Planned work program and products 2017–18

The geological Report on the Eo–Mesoarchean geology of the east Pilbara Craton will be completed and released. Following completion of this Report, work will commence on writing up existing geological, geophysical, and geochemical information acquired from, and in association with, GSWA 2012 drilling of the Hickman Impact Crater. This will eventually be released in a GSWA Report. Further contributions will be made, as required, to the special volume ‘Archean, building the core of a continent’ (Western Australia unearthed series). Additional entries will be made to the ENS database, and journal papers will result from collaboration with a number of external workers.

Products planned for release 2017–18

East Pilbara Craton: a billion year record of Eoarchean, Paleoarchean, and Mesoarchean crustal evolution (Report 143)

Hf insights from the Mount Edgar Dome (Report)

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

External publication: Taking the pulse of the early Earth (Nature Geoscience)

External publication: SIMS microanalysis of the Strelley Pool Formation (Precambrian Research)

External publication: Pilbara Craton: Geology and metallogeny (Aus IMM monograph)

Planned work program and products beyond 2018

Work beyond 2017–18 will include completion of the Pilbara component of the ENS database and release of the digitally generated Explanatory Notes. A geological Report on the Hickman Impact Crater will compile and interpret all existing information from GSWA drilling (2012), a GSWA low-level airborne geophysical survey, and geochemistry of meteorite fragments and melt glass.

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 are 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, including the role of crustal differentiation processes and the thermal drivers of intracratonic orogeny, which lasted for well over one billion years. Other advances include the precise dating of numerous ore deposits in the Province (as well as the Capricorn Orogen) and the link between mineralization, hydrothermal fluid flow to major crustal structures and regional-scale orogenic events.

Outcomes of work program 2016–17

Personnel issues have affected the work program during 2016–17, with the manager having spent more than eighteen months acting in the Chief Geoscientist position (GS53). However, time has been spent compiling the geology of 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). Several external publications were released throughout the year, which highlight the role of crustal differentiation, the timing of mineralization across the Province, and the drivers of intracratonic orogeny.

Collaboration with Professor Birger Rasmussen at Curtin University has continued under an ARC Linkage grant. A significant proportion of time was spent supervising two PhD students as well as providing advice and working closely with various researchers in the UNCOVER Australia: Capricorn Distal Footprints project, which have resulted in the submission of several co-authored external journal publications.

Products released 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*

Crustal differentiation in the Proterozoic Capricorn Orogen (Report 168)

Two external publications that highlight the link between mineralization and regional-scale orogenesis

Two external publications that highlight crustal differentiation processes and the drivers of intracratonic orogeny

Planned work program and products 2017–18

Most of 2017–18 will be focused on supervising the two PhD students associated with the collaborative ARC Linkage project with Professor Birger Rasmussen. Both student projects are scheduled for completion at 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, as well as the thermal drivers of intracratonic orogeny across the Province. The results will be released as several Open Access external journal publications.

Products planned for release 2017–18

Final update of the Western Capricorn Geological Information Series 2018 (including UAROO and WONYULGUNNA* 1:100 000 Geological Series maps; digital product), including updated digital Explanatory Notes for the Gascoyne Province, Edmund and Collier, Wyloo, Shingle Creek and Turee Creek Groups

Three of four ‘Open Access’ external journal publications resulting from PhD student work

Release of a Capricorn Orogen project web page on the DMIRS site that summarizes the geology of the Gascoyne Province and Edmund and Collier Basins (GS49)

* EIS product

Planned work program, products 2018–19 and beyond

No work is planned for the 2018–19 financial year. However, both student theses will be released as GSWA Reports.

Products planned for release 2018–19

Two student PhD theses released as GSWA Reports

GS49 Edmund and Collier Basins and Eastern Capricorn Basins

Manager: Simon Johnson

From July 2017 and with the completion of 1:100 000-scale mapping of the Edmund and Collier Basins, the GS49 project will 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 VMS-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 2016–17

The 2016–17 work program has focused on compiling Edmund and Collier Group rocks on the UAROO and WONYULGUNNA 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 Irregularly 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 Record early in the 2017–18 financial year.

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 931–799 Ma fault movements (the Kuparr Tectonic Event).

The compilation of legacy data (aerial photographs, field notebooks and samples) for the Eastern Capricorn Basins project continued to gain pace during the latter part of the financial year.

Products released 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, ERRABIDDY, MARQUIS, CALYIE, TANGADEE, MOUNT EGERTON, MULGUL, MILGUN, TEANO, ELLIOTT CREEK, ULLAWARRA, CAPRICORN, EDMUND, MANGAROO, MAROONAH, MOUNT VERNON, JAMINDI, THREE RIVERS, CARDAWAN, UAROO, TOWERA, LYNDON, LOFTY RANGE, and ILGARARI 1:100 000 Geological Series maps

* EIS product

Planned work program and products 2017–18

Work during 2017–18 will continue on the compilation of legacy data (aerial photographs, field notebooks and samples) for the Eastern Capricorn Basins project and work will begin on the construction of seamless 1:250 000-scale digital geology layers with the progressive release of 1:250 000-scale mapping tiles (e.g. (NABBERU, STANLEY, PEAK HILL) as digital layers on the Eastern Capricorn Geological Information Series digital product. Work will continue on the K–Ar geochronology of fault gouges, in collaboration with Professor Zwingmann of Kyoto University, and Dr Tonguc Uysal and Andrew Todd of CSIRO. This work will focus on the Eastern Capricorn Basins, and potential correlation with abundant mineralization will be investigated.

Products for release 2017–18

Final update of the Western Capricorn Geological Information Series 2018 (including UAROO and WONYULGUNNA* 1:100 000 Geological Series maps; digital product), including updated digital Explanatory Notes for the Edmund and Collier Basins, Gascoyne Province, Wyloo, Shingle Creek and Turee Creek Groups

Recognition of a new Mesoproterozoic mafic intrusive event in the Capricorn Orogen* (Record)

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

‘Open Access’ external journal publication on the K–Ar dating of fault rocks in the Edmund and Collier Basins

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

* EIS product

Planned work program, products 2018–19 and beyond

Work during 2018–19 will focus on the continued compilation of legacy data (aerial photographs, field notebooks and samples) of the Eastern Capricorn Basins, and the progressive release of 1:250 000-scale mapping tiles as digital layers on the Eastern Capricorn Geological Information Series digital product. Work will also focus on the writing and update of explanatory notes for the Eastern Capricorn Basins. Reports or ‘Open Access’ external journal articles will be released on the continuing K–Ar dating of faults throughout the Capricorn Orogen.

Products planned for release 2018–19

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

Eastern Capricorn Geological Information Series 2019 including at least one 1:250 000 mapping tile (NABBERU)* and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earahedy Basins)*

One or more ‘Open Access’ external journal publication on the K–Ar dating of faults in the Eastern Capricorn Basins

* EIS product

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Hugh Smithies

Team members: Matt de Paoli, Jyotindra Sapkota, Melissa Drummond, Stephen Wyche

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 2016–17

New mapping and integration of data and stratigraphic information have been applied to the East Yilgarn GIS north of Kalgoorlie–Boulder in the Menzies and Davyhurst regions. The new 1:100 000-scale interpretation of this area has been released. Explanatory Notes (ENS database) have been completed and published for the Menzies and Leonora areas.

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 Open Day in November included a series of talks, workshops and core displays that attracted more than 100 members of the local geological community.

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 2016–17

East Yilgarn Geological Information Series 2017 update

Eastern Goldfields komatiites and nickel deposits excursion guide (GSWA Record 2016/12)

Abstracts volume for the 13th International Ni–Cu–PGE Symposium (GSWA Record 2016/13)

Abstracts volume for the TARGET 2017 conference (GSWA Record 2017/6)

Planned work program and products 2017–18

The ongoing revision of the East Yilgarn GIS to incorporate the new structural and stratigraphic framework will continue. In 2017–18, new geological interpretation will focus on the region between Kalgoorlie and Norseman, and the greenstones west of Menzies between Davyhurst and Mount Ida. Explanatory Notes coverage will include parts of the Kalgoorlie–Kambalda 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.

GSWA will also collaborate with Professor Ray Cass of CODES (University of Tasmania) to study the geological setting of the Golden Mile Dolerite at Kalgoorlie.

Products planned for release 2017–18

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

Towards a geochemical barcode for the Eastern Goldfields (GSWA Record)

External publications relating to work program where appropriate

Yilgarn portal for DMIRS website (East Yilgarn)

Planned work program, products 2018–19 and beyond

Beyond 2017–18, 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. Comprehensive GIS databases including metamorphic and non-GSWA geochronological data covering the Yilgarn Craton are also in preparation.

Products planned for release 2018–19

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

Yilgarn metamorphism GIS layer

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, Huntly Cutten, Olga Blay

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. Explanatory Notes System (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 2016–17

The continued update and release of State geoscience data layers were a high priority during 2016–17. Work concentrated on updating the 1:500 000 tectonic units layer and work has begun on the construction of a seamless 1:500 000 State regolith layer. The section continued populating the data entry module of ENS with the publication of 101 new lithostratigraphic units and updates to 53 units, bringing the total number of

published lithostratigraphic units to 793. The GSWA field and rock observation database (WAROX) was released for the first time as a statewide dataset, with annual updates scheduled for the end of each field season. It contains ~ 240 000 field observations, ~ 65 000 structural measurements, ~ 50 000 field photographs and sketches, as well as regolith and landform information, sample location data and petrographic descriptions.

The third part in the concise Geology of Western Australia (WA Unearthed) series ‘A Palaeozoic perspective of Western Australia’ was published, while work on the Archean part is now underway. Several geotourism products were released including virtual tours of the State’s meteorite impact structures and the mafic–ultramafic intrusions of the Youanmi Terrane of the Yilgarn Craton, as well as the release of the ‘Stepping Stones’ walking tour via the smartphone app ‘Everythere’.

The section is responsible for GSWA content of department webpages: it routinely supervises content updates and the creation of new pages, coordinated the half-yearly revision of all GSWA pages, and assisted the transition from the DMP to the new DMIRS website.

Products released 2016–17

Compilation of WAROX (field observation and rock database) data, 2017 (statewide data release)

Update to the 1:500 000 tectonic units layer

Extended ENS content over existing and new geological provinces

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

Geotourism virtual tour of State meteorite impact structures

Virtual tour of the mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton

Release of ‘Stepping Stones’ geotourism tour on the smartphone app ‘Everythere’

Planned work program and products 2017–18

Work during 2017–18 will focus on the update of our online data delivery systems and on progress towards the addition of key data layers to GeoVIEW.WA such as project-specific seamless 1:100 000-scale geology polygons, linear structure and geology, and regolith–landform layers. Updates are also planned to the 1:500 000 orogenic events layer

to ensure consistency with the newly updated 1:500 000 tectonic units layer. 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 2017–18 will be to finish the 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 continue on the development of a State metamorphic map (at various scales) due for delivery in mid 2018–19.

Population of ENS and WAROX, monitoring of the style and quality of GSWA geoscience, and overseeing GSWA database capture and validation will continue. Work on the completion and testing of a regolith module for the Explanatory Notes System will continue with release expected in 2018.

Work will continue on the fourth (Mesozoic) and fifth (Archean) parts of the concise Geology of Western Australia (WA Unearthed). Work will continue on the compilation and publication of Explanatory Notes for State impact structures and associated lithostratigraphic units. Several geotourism products are planned including a popular-geology book on Kalbarri and a fact sheet on Kennedy Range.

Products planned for release 2017–18

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

Compilation of WAROX data, 2018 update

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

Update of 1:500 000 orogenic events layer

Release of a regolith–landform module for ENS

Extended ENS content (including regolith) over existing and new geological provinces

Explanatory Notes for State impact structures and associated lithostratigraphic units

Popular-geology book on Kalbarri

Popular-geology fact sheet on Kennedy Range

Planned work program, products 2018–19 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.

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) are 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 tectonothermal 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 an understanding of the prospectivity of the State.

The sensitive high-resolution ion microprobes (SHRIMPs) in the John de Laeter Centre at Curtin University are used extensively by GSWA for U–Pb dating. GSWA also dates detrital zircons using laser-ablation inductively coupled mass spectrometers (LA-ICPMS) in the John de Laeter Centre, which allow very 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 Geochronology and Isotope Geology 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 also 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 2016–17

About 100 rock samples were processed for U–Pb geochronology by GSWA’s laboratory, and 67 were analysed up to 26 May 2017 by GSWA geochronologists using the SHRIMP facilities at Curtin University. Figure 29 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 Province, the Yilgarn Craton (Youanmi and South West Terranes, and Eastern Goldfields region), the Albany–Fraser, Capricorn, and Pinjarra Orogens, the Kimberley region, the Edmund Basin, and in basement rocks beneath the Canning Basin. Results are published as Geochronology Records, 89 of which were published during 2016–17. Some of the achievements for 2016–17 are outlined below.

In the Capricorn Orogen, new SHRIMP U–Pb geochronology was conducted on granites, mafic igneous rocks, and supracrustal rocks in granite–greenstone basement rocks of the Wyloo, Rocklea, and Sylvania Inliers. The results in all three inliers indicate major felsic magmatic events at c. 3.2 and 2.9 Ga, and inheritance of 3.5–3.3 Ga zircons. Detrital zircon ages for quartzite in the Sylvania Inlier indicate significant components at c. 3611, 3574, and 3516 Ma. Analysis of Lu–Hf and oxygen isotopes (as part of project ES46) in zircons from the basement inliers will elucidate the origins of these rocks and explore links with other regions, such as the East Pilbara Terrane. Additional geochronology will be conducted in conjunction with Fortescue Group and Hamersley Basin project GS63.

Geochronology of detrital zircons from the Lamboo Province has prompted a re-examination of geodynamic models for the region. Existing models invoke collision of the Kimberley Craton with the proto-North Australian Craton at 1832–1808 Ma, possibly involving an intervening oceanic arc. However, remarkably similar zircon age spectra across the Lamboo Province at 1870–1855 Ma are difficult to reconcile with exotic terranes separated by ocean basins. Instead, the new data suggest the North Australian Craton was largely assembled prior to c. 1870 Ma.

The Geochronology and Isotope Geology Section continues to provide sample materials and/or analytical and laboratory support to several PhD and MSc projects at Curtin University and the University of Western Australia that are conducted in areas of interest to GSWA. These projects include: 1). geological evolution of the northern Capricorn

Orogen, 2). geological evolution of the northern Gascoyne Province, 3). facies characterization and provenance of the Yarragadee aquifer, and 4). precise timing of Cu–Mo–Ag–Au mineralization in the South West Terrane.

Products released 2016–17

Compilation of geochronology information, 2017 (includes 89 new Geochronology Records on USB)

Report 164 Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia

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

Extended abstract Mafic dyke swarms and large igneous provinces in Western Australia get a digital makeover: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract In situ phosphate dating of orogenic gold mineralization at Paulsens mine, southern Pilbara: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract Revised tectono-stratigraphy of the Kimberley Basin, northern Western Australia: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Extended abstract Post-Giles Event evolution of the Musgrave Province constrained by (multi-method) thermochronology: *in* Record 2017/2 GSWA 2017 extended abstracts: promoting the prospectivity of Western Australia

Twelve external journal articles and 11 conference abstracts (see Appendix C)

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

Planned work program and products 2017–18

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.

A new one-year project will employ Ar/Ar geochronology of pyroxene to date mafic igneous rocks that could not be dated using U–Pb zircon or baddeleyite geochronology. This study is made feasible by new analytical instrumentation (Argus VI mass spectrometer) in the WA Argon Isotope Facility of the John de Laeter Centre at Curtin University, which permits precise analysis of minerals that contain only trace amounts of potassium. The project will demonstrate the technique by analysing several mafic samples that have been dated previously by U–Pb methods, and then apply the technique to date samples that could not be analysed by other methods.

Products planned for release 2017–18

Compilation of geochronology information, 2018

External journal articles and contributions to GSWA publications

Planned work program and products 2018–19 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 2018–19

Compilation of geochronology information, 2019

External journal articles and contributions to GSWA publications

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 2016–17

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.

The MAGIX data repository of company airborne survey data continued to grow. During 2016–17, 65 new company airborne survey datasets containing about 302 000 line-km of data were received for inclusion in the repository. At 30 June 2017, the MAGIX repository contained some 9.5 million line-km of company data from 2283 surveys. Open-file datasets are available for download via the department's GeoVIEW.WA online system.

Planned work program, products 2017–18 and beyond

The planned work program for 2017–18 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 member: Christopher Phillips

The North Australian Craton comprises most of the northern part of the Australian continent and incorporates a complex assemblage of terranes, basins and igneous provinces that range in age from Neoproterozoic to Phanerozoic. The craton is host to numerous 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–Cu (Sally Malay), Fe (Koolan Island) and V (Speewah). In Western Australia, the craton comprises Paleoproterozoic rocks exposed in the Kimberley, west Tanami, and west Arunta regions, which are overlain by sedimentary rocks of the Neoproterozoic Centralian Superbasin and the Phanerozoic Canning, Ord and southern Bonaparte Basins.

In the Kimberley region – which forms a focus area for the project – metasedimentary and meta-igneous rocks of the 1912–1788 Ma Lamboo Province are exposed along the upthrust margins of the overlying Kimberley Basin. The Lamboo Province has been subdivided into the King Leopold Orogen, which forms a northwesterly trending belt to the south of the Kimberley Basin and the Halls Creek Orogen, which forms a northeasterly trending belt to the east. The Lamboo Province records a complex history of sedimentation, magmatism and deformation that has been interpreted to reflect collision of the Kimberley Craton with the proto-North Australian Craton. The 1835–1740 Ma Kimberley Basin comprises an extensive shallow marine to fluvial sedimentary basin that extends across the Lamboo Province and possibly has correlatives in isolated sedimentary outliers around the margins of the basin. Extensive mafic intrusive and volcanic rocks within the basin comprise the c. 1795 Ma Hart–Carson Large Igneous Province. These rocks are overlain by sedimentary successions of Meso–Neoproterozoic age that include the Carr Boyd, Birrindudu and Louisa Basins.

Second edition 1:250 000 Geological Series mapping programs in 1986–1989 and 1990–1995 were focused on the King Leopold and Halls Creek Orogens, and were accompanied by SHRIMP U–Pb zircon geochronology and extensive whole-rock geochemistry, in

collaboration with AGSO (now Geoscience Australia). The current work program is expanding the coverage of second edition 1:250 000 Geological Series mapping, with the aim of delivering seamless coverage across the Kimberley region. Production of 1:100 000 Geological Series maps previously focused on the Halls Creek Orogen during the 1990–1995 mapping program, and has recently been extended into the King Leopold Orogen during the current work program. Targeted studies examining aspects of the geology of the Kimberley region have accompanied the geological mapping. These include dating of sedimentary units, igneous suites and tectonothermal events, geochemical and isotope studies of magmatism, and the studies of the sedimentology and volcanology of basin successions.

Current work includes progressive extension of the 1:250 000 Geological Series mapping, a project examining the age, character and correlations of Paleo–Neoproterozoic sedimentary basin outliers, and a study evaluating geodynamic models of the Paleoproterozoic development of the Lamboo Province.

Outcomes of work program 2016–17

The work program for 2016–17 involved the publication of a report on the geology of the eastern zone of the Lamboo Province, with the report drawing together work from GSWA, Geoscience Australia, Curtin University and the University of Western Australia. This report documents the sedimentology, geochronology, isotope characteristics and geochemistry of metasedimentary and igneous rocks in the eastern part of the Halls Creek Orogen. The study defines a robust time–event framework for the eastern zone, forming a key reference point against which other similarly aged successions in the North Australian Craton can be compared.

A 2017 Kimberley Geological Information Series digital data package was also released, which includes new images of airborne gravity data flown over the east Kimberley in 2016, regolith mapping and geochemical data for the Dambimangari area of the west Kimberley, and updates to GSWA databases.

A study of the pressure–temperature–time (P–T–t) evolution of the King Leopold Orogen was commenced in 2016–17, in order to better constrain the development of this understudied orogenic belt. This involved the collation of existing samples from the

GSWA sample collection, preparation and description of polished thin sections and initial calculations of metamorphic conditions based on microprobe data. This study is continuing, and will include dating of in situ monazite to provide time constraints on metamorphism, as well as analysis of $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology data recently obtained from the orogen.

Fieldwork was carried out in the eastern Kimberley in 2016, which included helicopter-supported sampling as part of a broader study of previously undated sedimentary outliers. A suite of samples were collected that will allow for more robust correlations between these units and other basins in the region. Sampling was also carried out to better constrain the spatial and temporal evolution of granitic rocks of the 1832–1808 Ma Sally Downs Supersuite, which are currently interpreted to have formed in an arc setting during continental collision.

Work during 2016–17 also involved the collection of geochronology and Lu–Hf isotope data for metasedimentary units within the western and central zones of the Lamboo Province to test current geodynamic models that consider these terranes to be exotic to the North Australian Craton. A study of the geochemistry and isotope compositions of granitic rocks of the Sally Downs Supersuite also commenced, which involves analysis of samples collected during the 2015 and 2016 field seasons, as well as re-analysis of samples collected during previous mapping to ensure assembly of a consistent geochemical dataset for the Halls Creek Orogen having a full suite of trace element data. Sm–Nd isotope data are also being collected as part of this study to assess the nature of the source rocks for this magmatism.

Initial U–Pb geochronology data were received as part of a program of LA-ICPMS dating of detrital zircons from several samples of previously undated basin outliers. This forms the first stage of data collection, which will conduct dating of each of the main sedimentary outliers in the region.

Products released 2016–17

Report 164: Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia
Kimberley Geological Information Series data package 2017

Planned work program and products 2017–18

A significant component of the work program for 2017–18 will focus on the production of the LANSLOWNE Second Edition 1:250 000 Geological Series map, incorporating the results of GSWA mapping over the past several years.

A report on the Kimberley Basin (redefined to include both the Speewah and Kimberley Groups) is also being prepared for publication in 2017–18. This will document the results of recent GSWA mapping and geochronology and the implications for the development and geodynamic setting of the basin. As part of this work, the ENS database will be updated with detailed descriptions of the stratigraphic units comprising the basin.

A report on the P–T–t evolution of the King Leopold Orogen is scheduled for release in 2017–18, which will present the results of thermobarometry and in situ monazite geochronology of amphibolite facies metamorphic rocks from the orogen.

LA-ICPMS dating and Lu–Hf isotope analysis will be carried out on detrital zircons from sedimentary basin outliers in order to build the geochronology dataset for regional correlations. SHRIMP zircon dating will be carried out on representative samples of the component granitic suites of the Sally Downs Supersuite to better define the spatial and temporal variations in magmatism.

Further fieldwork will be conducted in the Kimberley region with a view towards production of additional Second Edition 1:250 000 Geological Series maps.

A 2018 version of the Kimberley Geological Information Series data package is planned, which will incorporate the LANSLOWNE 1:250 000 Geological Series map and updates to the geochronology, geochemistry, ENS and WAROX databases.

Products planned for release 2017–18

LANSLOWNE Second Edition 1:250 000 Geological Series map

Report on the geology of the Kimberley Basin

Population of ENS database for units of the Kimberley Basin

Report on the P–T–t evolution of the King Leopold Orogen

Kimberley 2018 Geological Information Series data package

Planned work program, products 2018–19 and beyond

The work program for 2018–19 and beyond will include the production of Second Edition 1:250 000 Geological Series maps to ensure coverage across the Kimberley region, with CAMBRIDGE GULF a priority. A report documenting the results of LA-ICPMS dating of basin outliers will also be produced.

Future work on sedimentary basins, to the southeast of the Kimberley region is being considered as an extension of the sedimentary basin outliers study. This would aim to determine the ages of previously undated successions and to understand regional correlations with basins in the Kimberley Region and broader North Australian Craton.

Products planned for release 2018–19 and beyond

CAMBRIDGE GULF Second Edition 1:250 000 Geological Series map

Report on the ages of sedimentary basin outliers in the Kimberley region

Fieldwork and geochronology of sedimentary basins in the northern Tanami region

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 host 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. 1300–1330 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.

<i>Products released 2016–17</i>	<i>Current status</i>
ENS update (DIORITE and GOLDEN POINT)	Released
West Musgrave GIS (includes AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON)	Released

Thermo-mechanical evolution of orogeny in the Musgrave Province (Report)	Released
Petrogenesis of the mafic–ultramafic intrusions of the Mesoproterozoic Giles Event, Musgrave Province, central Australia (Report)	Released
The volcanology, petrogenesis, and economic potential of the Mesoproterozoic shallow-water, intra-caldera, lava-like rheomorphic Kathleen Ignimbrite, west Musgrave Province, central Australia (Report)	Released
The deep seismic reflection profile 11GA-Y01 in the west Musgrave Province: an updated view (Record)	Submitted

Planned work program and products 2017–18 and beyond

The fieldwork and map compilation components for the project have been completed and compilation of the remaining Reports will continue. Explanatory notes for AGNES, DEERING, REBECCA, MOUNT BUTTFIELD, and RAWLINSON will be released in the West Musgrave GIS update.

Products planned for release 2017–18 and beyond

West Musgrave GIS with ENS update (for AGNES, DEERING, REBECCA, MOUNT BUTTFIELD and RAWLINSON)

Neoproterozoic evolution of the west Musgrave Province; integrating deep seismic data with thermochronology (Record)

500 Ma of amagmatic tectonic reactivation of a continental interior: a case study from the west Musgrave Province, central Australia (Record)

GS58 Youanmi Terrane

Manager: Hugh Smithies

Team members: Tim Ivanic, Ivan Zibra, Sandra Romano, Stephen Wyche

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.

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 with associated structural studies in the Narryer Terrane with Dr Tony Kemp from UWA and Prof. Cees Passchier from the Gutenberg University in Mainz
- structural studies in the Murchison Domain with various collaborators (Monash University, Gutenberg University)
- an ARC Linkage project with Sydney University to study the geochemistry and tectonic setting of the Murchison region
- a mineral chemistry project on the Windimurra and Narndee Igneous Complexes with the Guangzhou Institute of Geochemistry
- a metamorphic study of contrasting greenstone successions in the Yalgoo–Singleton greenstone belt with the University of Waterloo (Canada)
- a whole-rock isotopes study of granites in the Youanmi Terrane with Monash University.

Outcomes of work program 2016–17

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. Other studies are being undertaken to determine the relationship between granite intrusion and deformation history.

Field mapping has been completed in the Meekatharra region, resulting in some modifications to the published Murchison stratigraphy and upgrading of previously published GIS products.

A program of sampling granites and associated rocks in the South West Terrane to collect geochemical and isotopic data commenced.

GSWA published excursion guides and abstracts for the 13th International Ni–Cu–PGE Symposium.

Products released 2016–17

THUNDELARRA 1:100 000 Geological Series map

WOODLEY 1:100 000 Geological Series map

MEEKATHARRA 1:100 000 Geological Series map

Murchison GIS 2017 update

Explanatory Notes covering some granitic components in the Murchison GIS

Petrology and geochemistry of the Eoarchaeon Manfred Complex: origin and components (GSWA Record 2016/22)

Layered intrusions of the Youanmi Terrane, Yilgarn Craton: non-series map

External publication: The Windimurra Igneous Complex: an Archean Bushveld?: Geological Society, London

External publication: The Waroonga Shear Zone: Tectonophysics

Planned work program and products 2017–18

Field mapping and compilation will be completed on the NINGHAN 1:100 000 map sheet in the Yalgoo–Singleton greenstone belt and the map will be published. The GABANINTHA

1:100 000 map will be compiled and published. New mapping will commence on the DALGARANGA 1:100 000 sheet.

Sampling and collection of new analytical data, including geochemistry, geochronology and isotopic data, in the South West Terrane will continue.

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

Products planned for release 2017–18

NINGHAN 1:100 000 Geological Series map

GABANINTHA 1:100 000 Geological Series map

Murchison GIS 2018 update

Granite geochemistry in the southwest Yilgarn (GSWA Record)

Murchison stratigraphy and Explanatory Notes update

GSWA Records and Reports derived from collaborative projects

External publications relating to work program where appropriate

Yilgarn portal for DIMIRS website (West Yilgarn)

Planned work program, products 2018–19 and beyond

Field mapping in the Murchison Domain of the Youanmi Terrane will continue in 2018–19. Data will be compiled for release in future versions of the Murchison GIS. A Report covering 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. Data collection will continue in the South West Terrane and results will be used to augment existing regional datasets and to interpret the tectonic history of the terrane. Comprehensive GIS databases including metamorphic and non-GSWA geochronological data covering the Yilgarn Craton are also in preparation.

Products planned for release 2018–19

Murchison GIS update

Explanatory Notes update

DALGARANGA 1:100 000 map sheet

Windimurra and Narndee Igneous Complexes Report

Yilgarn metamorphism map and GIS

GSWA Records and Reports deriving from collaborative studies

GS61 Albany–Fraser Orogen and Eucla Basement Project

Manager: Catherine Spaggiari

Team members: Hugh Smithies, Raphael Quentin de Gromard, Mark Munro

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 has enabled a better understanding of the development of the southern WAC margin over time, on the prospectivity of the region, and has informed 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 operational. 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, and are challenging to explore largely because of the extensive cover.

While a handful of diamond drillholes exist in the Madura Province, no basement mineral exploration holes have been drilled in the Western Coompana Province. The EIS-funded 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 2016–17

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

- the understanding that the Madura and Coompana Provinces are dominated by Proterozoic oceanic basement
- 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
- completion of the ARC Linkage passive seismic project, the ‘ALFREX’ array, which has defined 3D crustal features including a linear section of deeper Moho between the Yilgarn Craton and the Fraser Zone. This highlights differences in 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.
- New detailed structural mapping and sampling in the east Albany–Fraser Orogen, with emphasis on the Fraser Zone, is unravelling the complex structural architecture and timing of events.
- In the Fraser Zone, ongoing collaborative work with Curtin University and industry including sulfur isotope, mineral and geochemical studies and P–T analysis of gabbroic rocks are helping determine the processes and tectonic environment of mineralization and prospectivity of the region.

Products released 2016–17

Geological interpretation of the Madura and Coompana Provinces along the Eucla–Gawler seismic and magnetotelluric line 13GA-EG1 (Non-series map)

Record 2016/2 Extended abstract Structural evolution of the S-bend region, east Albany–Fraser Orogen

Three external publications — see Appendix C

Planned work program and products 2017–18

- Work is focussed on detailed structural mapping and analysis in the Fraser Zone region and publishing significant datasets and their interpretations. These include: a

detailed comprehensive Report on the Eucla basement stratigraphic and co-funded drilling

- update and expand the contributions in the Explanatory Notes online database
- structural and metamorphic analysis of the Fraser Zone and adjoining regions; includes 1:100 000-scale series mapping, detailed structural mapping and analysis, sampling, microstructural work, P–T work, routine and non-routine geochronology).

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 GS61 program is integrated with the Minerals Research Institute of Western Australia (MRIWA) M470 project, which is a collaboration between exploration industry sponsors and Curtin University (led by Associate Professor Chris Kirkland,) 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 (Assoc. Prof. Katy Evans) and metamorphic work on the Fraser Zone (Dr Tim Johnson, Curtin University). The metamorphic work 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 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 now complete. This was set up to examine the 3D structure of the crust and lithosphere of the Albany–Fraser Orogen and adjacent Yilgarn Craton through passive seismic data acquisition and analysis. The results and interpretations have been published in two journal articles, and a GSWA Report is due to be released early in 2017–18.

Interpretations of the Eucla–Gawler seismic line 13GA-EG1, MT data along the same line, and potential field data modelling were presented at a dedicated session at the

Australian Earth Sciences Convention (AESC) in June 2016. This work will be published in a co-branded GSWA–Geological Survey of South Australia– GA Record this year. The work also links the GS61 program with GS62 3D Geoscience, which includes further interpretations of the Albany–Fraser seismic and MT lines, potential field data modelling, and construction of 3D models.

Work has commenced on understanding connections between the west and east Albany–Fraser Orogen, and a geochemical and isotopic sampling traverse is planned. This work will link to geochemical analysis in the Southwest and Youanmi Terranes of the Yilgarn Craton.

A pre-conference fieldtrip to the Albany–Fraser Orogen, as part of the Specialist Group in Tectonics and Structural Geology (SGTSG) of the Geological Society of Australia (GSA) will be led by members of the GS61 team in November 2017. Field guides for this trip and also for the mid-conference fieldtrip in the Denmark–Albany region and post-conference fieldtrip to the Leeuwin Province will be published by GSWA.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

Stratigraphic and co-funded drilling of the Eucla basement — the Proterozoic geology beneath 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 (Report)

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

Structural evolution of the S-bend region of the east Albany–Fraser Orogen (Report)

Explanatory Notes of selected units of the Albany–Fraser Orogen (database)

Fieldguide for the SGTSG pre-conference fieldtrip, Albany–Fraser Orogen (Record)

Fieldguide for the SGTSG mid-conference fieldtrip, Denmark–Albany region (Record)

Fieldguide for the SGTSG post-conference fieldtrip, Leeuwin Province (Record)

SGTSG program and abstracts (Record)

External publications — see Appendix C

Planned work program, products 2018–19 and beyond

The focus for 2018–19 will be the release of the first IBG map at 1:250 000 scale of the Eucla basement to the South Australian border, as part of a Geological Exploration Package (GEP). The IBG will use the results of the Eucla basement stratigraphic drilling, new stratigraphic drilling by the Geological Survey of South Australia, and interpretation 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 continue on linking the west and east Albany–Fraser Orogen.

Products planned for release 2018–19

1:100 000 series digital map package of the southern east Albany–Fraser Orogen

1:250 000 IBG and GEP of the Eucla basement

Explanatory Notes of selected units of the Albany–Fraser Orogen, Madura and Coompana Provinces

Structural and metamorphic evolution of the east Albany–Fraser Orogen (Record)

Geochemistry of the west Albany–Fraser Orogen (Record)

GS62 3D Geoscience

Manager: Klaus Gessner

*Team members: Ruth Murdie, Lucy Brisbout, Elle Rakich, Huaiyu Yuan
(Macquarie University), Joel Burkin (CET)*

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 2016–17

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 2016–17

Geological interpretation of the Madura and Coompana Provinces along the Eucla–Gawler seismic and magnetotelluric line 13GA-EG1 — Map

Ten external publications — see Appendix C

West Gawler 3D model

Specifications for submission of 3D Models to GSWA

Rocklea Dome 3D Model

Planned work program, products 2017–18 and beyond

The 3D Geoscience section will continue to contribute to regional mapping project teams. The team will also contribute to a number of regional 3D modelling studies, potential field interpretations of the Yilgarn Craton, the Capricorn Orogen, the Albany–Fraser Orogen, and the Canning Basin.

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 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

COPA passive seismic array (Report)

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)

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, 10GA-CP1, 10GA-CP2, 10GA-CP3 (Geophysical Modelling Reports)

Geophysical Modelling Reports for GSWA map sheets ATLEY, BADJA, BUNGAR, DIORITE, DRYSDALE, GOLDEN POINT, LAKE PERCY, MEEKATHARRA, RICHENDA, SANDSTONE/GUM CREEK, THUNDELARRA, WARBURTON RANGE, WEBB, YALGOO, YOUANMI

3D index for geophysical modelling reports
Hamersley Basin and Merlinleigh 3D models
Nine external publications — see Appendix C

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, a total of 581 km of deep seismic reflection data were 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 2017–18 and beyond

The main objective of the project, which started in 2017–18, 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):
 - establish which of the mafic intrusive rocks of the region are related to the Fortescue and Hamersley Groups
 - establish the geochemical relationship between felsic igneous rocks of the Fortescue and Hamersley Groups and the associated mafic and ultramafic rocks
 - use litho-geochemistry 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 data collection, including the collation of available legacy data from the Fortescue and Hamersley Groups and HyLogger scanning of selected drillcore from the Hamersley Basin. These data will be used in a study of hydrothermal alteration. The initial fieldwork has been aimed primarily at validating existing mapping and identifying areas for detailed future work. Systematic outcrop and drillcore 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

Compilation of legacy data (aerial photographs, field notebooks, and samples), imagery for the project area and reinterpretation of the bedrock geology of the southwestern Hamersley Province at 1:250 000 scale (Geological Information Series)

Products planned for release 2018–19 and beyond

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)

YARRALOOA 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), Darren Wallace, Bhumita Fadadu, Marie Ferland, Kiran Gavni, Kay Greenberg, Gary Hartley, Bec Hitchings, Arthur Hoffman (Manager GS85), Joe Hogen-Esch, Stewart Jefferys, Jean Johnston, Annick Francois, John Kirk, Tom Lenane, Irena Lesiak, Frank Matera, Tuyen McDonald, Sue Mulligan, Margie Nash, Mittal Patel, Joyce Peng, Michael Prause (Manager GS82), Bernd Striewski, Adam Symonds, Daniel Then (Manager GS83), Brad Tapping, 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 and GIS specialists.

These program areas reside in the Geoscience Information Branch (GIB), which 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 2016–17

There was continued focus on the management and delivery of geoscience data. Major outcomes of the work program included:

- promotion of Western Australia’s prospectivity at international and national conferences, and trade shows
- Release of a number of digital data layers downloadable from Data and Software Centre and through GeoVIEW.WA
- Continued to provide GSWA online systems training in Kalgoorlie and Perth
- Ongoing updates to a number of web-based applications

Products released 2016–17

Products released in 2016–17 were:

- 38 manuscripts
- 5 Geological Series maps (1:100 000 and 1:250 000 scale)
- 10 geological maps at other scales
- 16 digital products
- completed Native Title South West Settlement final assessment system tool across the Department of Lands and DMIRS
- First release of the digital 1:10 million tectonic map as a data layer and through GeoVIEW.WA
- Release of two virtual tours — the mafic–ultramafic intrusions of the Youanmi Terrane and Meteorite impact structures of Western Australia
- Release of a new version of WA Geology application
- Released a spatial tool for MRIWA website
- Release of a new version of GeoVIEW.WA
- The launch of a new Data and Software Centre web site.

Planned work program and products 2017–18

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

- 40 manuscripts
- 6 Geological Series maps (1:100 000 and 1:250 000 scale)
- 18 geological maps at other scales
- 18 digital products
- MINEDEX2018 redevelopment
- further develop ENS to include regolith, geochronology and mineral systems.
- WAPIMS CO2 enhancements

GS91 Mineral Exploration Information Management

Acting manager: Ann Fitton

Team members: Monique Brouxhon, Subashni De Biran, Joyce Edmonds (retired December 2016), Fiona MacCorquodale, Robert Pizzi, Christine Suchodolski, Julia Thom

The department has a statutory obligation to manage the collection, storage, and release of company exploration reports containing geoscience information on mining tenements in Western Australia — and this function is performed by GSWA. 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, which minimizes duplication of exploration effort and enables more efficient exploration.

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

Outcomes of work program 2016–17

The online report-writing application for mineral exploration reports was launched in February 2015. It has been available for just over two years during which time companies have had an opportunity to use it for the compilation of their annual reports. Its use is still optional and at end June 2017, more than 2363 reports had been submitted online representing 81% of the reports submitted. Current plans are for use of the online report-writing application to be mandatory from mid-2018.

The tenth annual release of exploration reports, after an advertising and objection period on the website in early 2017, was completed in May 2017 — and 1079 reports were released. This consisted of reports submitted to the department in 2011 and released under the provisions of the Mining Regulation 96(4), commonly known as the ‘sunset clause’. In addition, 1826 reports were released to open file as part of the normal cancellation process of dead tenements. At the end of June 2017, more than 86 000 reports were accessible to the public on the department’s website.

The mineral drillhole and surface geochemistry database was maintained. It now contains around 2.7 million drillholes and 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 2016 and March 2017. Charts illustrating the annual number of drillholes, amount of metres drilled, and number of surface geochemistry samples analysed are included as Figures 30–31, respectively.

<i>Outcomes 2016–17</i>	<i>Current status</i>
The online report-writing application for mineral exploration reports has been available for two years	It has generally been well received. At the end of June 2017 more than 2363 reports had been submitted via the system
Bi-annual updates of mineral drillhole and surface geochemistry database	Updates were released in August 2016 and March 2017
Annual release of reports under the ‘sunset clause’ legislation	The tenth annual release of exploration reports under the ‘sunset clause’ was successfully completed in May 2016, with release of 1079 reports
Release of reports on dead tenements	A total of 1826 reports was released under the normal cancellation process. At end of June 2016, more than 86 000 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 2016, March 2017, and June 2017)
Identification of mineral exploration core suitable for inclusion in the Perth and Kalgoorlie core libraries	Donations of mineral core continued in 2016–17 with the extended downturn in the industry. Under the circumstances, company geologists were very keen to find a good home for their valuable core.

Planned work program and products 2017–18

Planned activities and outcomes are to:

- formalize the online report-writing application for mineral exploration reports to become mandatory by mid-2018
- review and release surrender reports and their associated annual reports as they are received, together with the 11th 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
- amend the Guidelines for Mineral Exploration Reports on Mining Tenements to include:-program of works number (POW) and whether a drillhole has been rehabilitated in the collar table of drillholes, adopt a unique sample ID for mineralogical samples and make digital submission of reports mandatory by mid-2018
- continue bi-annual releases 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 to enable better searching of the drillcore
- continue to identify and collect historical drillcore suitable for the Perth and Kalgoorlie core libraries. It was successful in 2016–17 and, under the continued industry downturn, is likely to continue to be successful during 2017–18
- 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, the department 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 department is also assisting NOPTA and GA develop and maintain NOPIMS, with very close links to WAPIMS and the Core Library database (CIMS).

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 2016–17

Outcomes 2016–17

Implemented Petroleum Online data submission module through PGR interface

New functionalities and enhancement added to the WAPIMS (e.g. historical permits layer on the GIS Map)

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

Work in collaboration to NOPTA and GA on the successful release of the new NOPIMS based on WA system (WAPIMS)

Catalogue and archive petroleum data collections donated to DMIRS from industry and academia

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 2017–18

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.

Planned activities and outcomes are to:

- continue the testing and create enhancements to the new WAPIMS in collaboration with NOPTA and GA
- create forms and public reports to release online all the public geoscientific data captured in WAPIMS (State and Commonwealth)
- assist Petroleum Division in capturing data submitted for Gorgon CO₂ injection project and Tubridgi gas storage project
- assist the Basin and Energy Geoscience section in creating Digital Core Atlas for Theia 1 and other projects as required (geochemical data capture, reprocessing)
- publish a new 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
 - For State surveys, start planning and transcribing the 3480/3590 seismic data cartridges into a new media (3592 cartridges)
 - 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

Manager: Paul Stephenson

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

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, petroleum industry onshore and offshore 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 from around Australia. 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.

The core libraries at Carlisle (Perth) and Kalgoorlie also house the extensive core generated since 2009 from the EIS co-funded drilling program. This core, after a short 6-month confidentiality period, is a great boost to explorers and academia, providing new core from greenfield areas and allowing testing of new ideas and concepts.

Outcomes of work program 2016–17

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 steady during 2016–2017 relative to 2015–16— this continues the decade-long trend (Figs 33, 34). 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 — a total of 96 km of core was laid out and 2005 pallets accessed at Carlisle during 2016–17 (Figs. 33, 34).

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 led by DMP’s Facilities Services group.

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.

All works have now been completed, and the core library extensions were officially opened in November 2016.

Planned work program and products 2017–18

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

- Upgrade the Carlisle site security with new swipe entrance gates for May–June 2018.

- Install a crash barrier at the corner of Harris and Briggs Street by May 2018.
- Place Nodding Donkey acquired from AWE Ltd erected at the Harris St entrance by June 2018.
- Exxon Mobil is in discussions with us at present about donating its core and cuttings from Victoria and Tasmania (around 250–300 pallets worth).

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Team members: Edward Rogers, Michael Wawryk

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. The 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. Full datasets are also available upon request.

Outcomes of work program 2016–17

For the year ending 30 June 2017, the GSWA HyLogger facility collected and processed VNIR–SWIR–TIR spectral data for 42 692 m of core from 155 drillholes. These comprised 69 EIS co-funded holes, 72 historical and donated mineral holes, and 14 petroleum wells. The amount of core scanned is the second largest in the facility’s eight years of operation (Fig. 35).

For 2016–17, about 55% of the scanned core was derived from EIS co-funded drilling, whereas ‘other’ scanned core was mostly legacy mineral exploration core in GSWA archives in both Kalgoorlie and Perth Core Libraries, plus a small amount of from petroleum exploration projects. During the year, more of the historical core and EIS core from Kalgoorlie Core Library was freighted to Perth for re-scanning using upgraded technology and data interpretation methodology. The project is partly funded by AuScope as part of an NCRIS grant scheme.

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

- regional stratigraphy and hydrothermal alteration assemblages of the Fortescue Group, Hamersley Basin 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)
- Hyperspectral characterization of Li mineralization in Londonderry pegmatite deposit, Yilgarn Craton REE mineralization identified by hyperspectral and XRF methods (MSc, Curtin University) depositional history of several regions in Northern Carnarvon Basin (BSc Honours, UWA) sedimentology and geochemistry of source rocks in Perth Basin (PhD, UWA)

Other activities that involved HyLogger staff included:

- provision of a first batch of five new GSWA HyLogger Record that summarizes drillhole metadata and basic mineralogical interpretations
- provision of a two-day GSWA–CSIRO workshop showcasing the utility of the HyLogger for understanding mineral systems to industry clients and users of the data. This followed successful workshops delivered in May 2014, April 2015, and May 2016
- upgraded the drillhole database ‘HyMeta’ with options to have links to additional HyLogging publications, levels of data processing, and release dates
- upgraded the ‘HyLogger’ layer within GSWA’s GeoVIEW.WA map-based interface showing colour-code for different levels of data interpretation and the links to the HyLogging summary reports
- commissioning of a new portable/desktop SEM instrument for mineral validation work
- collaboration with CSIRO staff at the Earth Sciences Centre in Sydney and the Australian Resources Research Centre in Perth 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 facility in the extended Perth Core Library.

Products released 2016–17

Five new GSWA HyLogger records of summary drillhole metadata and basic mineralogical interpretation. Links to the summary records are available through the HyLogger layer in GeoVIEW.WA

Record 2016/16: Mapping iron ore alteration patterns: Beebyn deposit, Yilgarn Craton

Record 2016/17: Mapping iron ore alteration patterns: Windarling iron camp, Yilgarn Craton

Record 2016/18: Mapping iron ore alteration patterns: Drillhole PK11DD001, Mt Richardson, Yilgarn Craton

Record 2016/19: Mapping iron ore alteration patterns: Drillhole PK12DD001, Mt Richardson, Yilgarn Craton

AJES, 2016, v. 63: Reflectance spectroscopic characterisation of mineral alteration footprints associated with sediment-hosted gold mineralization at Mt Olympus, Ashburton Basin, Western Australia

Planned work program and products 2017–18

The facility will continue to collect and interpret spectral data from drillcore that contributes directly to increasing the knowledge of Western Australian geology and mineral/petroleum systems. 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 in order to balance the competing objectives, demands and priorities of users.

Other regular activities for 2017–18 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 department's GeoVIEW.WA 'HyLogger' layer. Short GSWA reports of data processing and interpretation will be included in the final products. In addition, links to other related publications will be available through GeoVIEW.WA HyLogging layer.

HyLogger staff will collaborate lead several special projects in 2017–18 to:

- develop procedures for using the portable/desktop XRD and SEM 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 2017–18

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

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

Planned work program, products 2018–19 and beyond

Maintenance of the HyLogging facility, 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

ES20 Government Co-funded Exploration Drilling

Manager: Margaret Ellis

Team member: Jane Forsey, Monique Brouxholm**

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 geoscience information and discoveries.

The program is preferentially funding high-quality, technical and soundly 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.

A formal advisory committee, chaired by the Director General or Deputy Director General of the department and consisting of representatives from the main industry representative groups and research sector, provides advice to the department 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 capped at \$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 completed (Fig. 36). 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

* Part year

the department before payment of the refunds, and the final report and core are released to open file after a six-month confidentiality period.

Outcomes of work program 2016–17

During 2016–17 drilling from three rounds was undertaken by exploration companies. As can be seen highlighted by the red rectangle in Figure 37, three rounds overlapped the reporting year. Round 12 projects covered the 2016 calendar year, with a number of projects drilled between July and December 2015. Round 13 projects were drilled between July 2016 and June 2017, and Round 14 covered projects drilled during the 2017 calendar year. There a number of Round 14 projects drilled in the first six months of 2017.

Successful drilling projects usually cannot be deemed to be so after just one drilling campaign. The successes listed below are some of those announced for drilling projects that have received co-funding in 2016–17 or in previous years.

Highlights of the 2016–17 program include:

- Breaker Resources orientated EIS diamond drill holes, the first into the 2.2 km-long Bombora gold discovery provided important information on the mineralised structures, host rock geochemistry and has reinforced the continuance of in-fill aircore and reverse circulation drilling to provide a maiden JORC Resource in late 2017. Assay results from diamond drilling has included 21.3 m at 5.10 g/t (BBDD0006), 3.55 m at 7.77 g/t and 2.55 m at 10.65 g/t (BBDD008).
- Drilling at Lake Wells by Australian Potash (formerly Goldphyre Resources) has continued and has now identified a deeper Tertiary paleochannel aquifer. A successful scoping study released in March 2017 indicated a possible mine life of 20 years, with premium-priced sulphate of potash in years 1–5 at a production rate of 150 000 tpa (stage 1) and years 6–20 at a production rate of 300 000 tpa (stage 2).
- Sipa Resources 4500 metre plus aircore program extended a previous one-hole copper–gold anomaly to a strike-length of >4km at its Paterson North Project. Multi-element results indicated the presence of significant copper–gold–silver–molybdenum–tungsten over a strike of 1.5 km, with gold values of up to 1.26 g/t. A co-incident magnetic and gravity anomaly along the mineralised strike referred to as

'Obelisk' has been the focus of deep RC drilling and early assay results returned 46 m at 0.12% Cu, 0.4 ppm Ag, 16 ppm Mo and 178 ppm W within a broader 62 m anomalous zone.

- Panoramic Resources announced a maiden Ore Reserve of 6.65 million tonnes at 1.42% Ni, 0.61% Cu and 0.10% Co for 94 500 t nickel, 40 900 t copper and 6700 t cobalt for its Savannah North deposit. A mine life of 10 years has been estimated.
- Sirius' Nova nickel mine, which was a discovery using GSWA precompetitive data and support from co-funded drilling, and subsequent mine development by Independence Group has resulted in the production of nickel and copper concentrate and export. From discovery (2012) to mine start-up (2015) was achieved in record time of only three years.

The following outcomes were also achieved during the year:

- completion of 49 exploration drilling projects by successful recipients between July 2016 and June 2017
- drilling of 27 919 m of diamond drilling and 54 380 m of non-cored drilling
- call for applications for the 2017 round of drilling, and evaluation of applications for co-funding
- announcement of successful applications, including from prospectors, for Round 14 of Government Co-funded Exploration Drilling to be undertaken during the 2017 calendar year, and distribution of those agreements (Fig. 38); Table 15)
- call for applications for the 2017–18 round of drilling (Round 15), and evaluation of applications for co-funding
- announcement of successful applications for Round 15 of Government Co-funded Exploration Drilling for projects to be drilled during the 2017–18 financial year (Fig. 39); Table 16). The distribution of those agreements was slightly delayed because of the State election, change of government, and delay in delivery of the State Budget.

Figure 40 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 2017. A total of 732 projects have been offered co-funding up until 30 June 2017, and drilling has been completed on 371 projects. Another 42 projects have

until the end of December 2017, and 43 projects have until the end of June 2018 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 41.

Planned work program 2017–18 and beyond

The drilling projects that were successful in gaining co-funding in Round 15 will be undertaken during the 2017–18 financial year. All relevant data and core will be submitted and subsequently released to open file.

Round 16 of the Co-funded Drilling program will be advertised, with an application period between September and early October 2017. This round is offering about \$5 million to support drilling projects undertaken during the 2018 calendar year.

Round 17 will be open for applications in late February 2018 for applications for drilling projects to be drilled during the 2018–19 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 2016–17

In 2016 –17, the project planned and coordinated the Director General's promotional visit (July 2016) to Beijing, China. Key activities during this trip were:

- Attending China International Gold Conference, with presentation of a keynote address at the Conference reaffirming relationships with major investors and potential investors; promoting Western Australia's track record in resource development and

investment attractiveness; and meeting major resource investors and key industry leaders

- visit China SOEs and potential major investors — meeting with the China National Administration of Coal Geology (CNACG), China National Nuclear Co (CNNC), and Beijing Research Institute of Uranium Geology

In 2016–17, 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
- the 13th International Mining & Machinery Exhibition (IMME), India
- 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 2017–18

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 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. The objective of the initial phase 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 (Fig. 23).

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). The Capricorn Orogen survey was flown and this complements the earlier reconnaissance AEM surveys undertaken by GA (Fig. 24).

Airborne gravity surveys are included and described 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 2016–17

No airborne magnetic, radiometric or electromagnetic surveys were planned for 2016–17 with funds and efforts being concentrated on the airborne gravity program reported under ES32 Regional Gravity Surveys.

No surveys are currently 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 and program priorities. Currently no airborne surveys other than gravity (see ES32 for details) are under consideration.

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 this project (i.e., 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.

Passive seismic studies have commenced with UWA to investigate the feasibility of using the ambient noise and receiver function techniques in the Perth Basin, including a novel project that explores how the Metropolitan Fibre Optic Network can be utilised to achieve this. These projects aim to detect both the shallow and deep velocity structure beneath the Perth Basin.

Outcomes of work program 2016–17

During 2016–17 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. 42). Two targeted passive seismic arrays continued to be deployed in 2016–17 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.

Products released 2016–17

West Gawler 3D model

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)
11 external publications — see Appendix C

Planned work program and products 2017–18

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 also continue to support the deployment of the COPA passive seismic array in the Capricorn Orogen. 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 resolving seismic anisotropy structure for long-operating stations.

Local ambient noise and receiver function studies with UWA will continue to investigate the shallow and deep velocity structure beneath the Perth Basin.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

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

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)

Albany–Fraser Orogen 3D Model

Perth Basin passive seismic study (Report)

Geophysical Modelling Reports for Seismic Surveys 10GA-YU1, 10GA-YU2, 10GA-YU3, 11GA-SC1 , 10GA-CP1, 10GA-CP2, 10GA-CP3

Four external publications — see Appendix C

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 2016–17

Data from the 2.5 km grid survey that was completed between May and June 2015 in the Wiluna area were processed and released (4 454 new stations) (Fig. 25).

GSWA's first airborne gravity survey was completed in the East Kimberley and the data released (38 000 line-km) (Fig. 25).

Two Requests for Tender were issued and contracts awarded for additional airborne gravity surveys in the NE Canning – Tanami and Kidson areas (Fig. 25) for completion by the end of 2017 and publication of data anticipated for the first quarter of 2018.

<i>Products planned for release 2016–17</i>	<i>Current status</i>
Completion of the Wiluna survey in areas cleared for access.	Complete; data published
Completion of the East Kimberley airborne gravity survey.	Complete; data published

Planned work program and products 2017–18

Completion of the NE Canning – Tanami and Kidson area airborne gravity surveys.

Planned work program, products 2018–19 and beyond

Area prioritization for new surveys will be determined over the course of 2017–18.

ES33 Yilgarn Margin Geochemistry

Manager: Paul Morris

Team members: Nadir de Souza Kovacs, Sara Jakica

This program was originally formulated to generate regolith–landform maps and regolith geochemical data on the margins of the Yilgarn Craton, which has a well-established mineral endowment. The approaches taken at the inception of the program have been extended to areas with similar cover characteristics: that is variably thick, usually transported regolith in areas where there are little available data related to its mineral potential. Recently, this program has included the Ngururrpa area in the northeast part of the State, covering parts of the Murraba and Canning Basins. Over 600 regolith samples were collected at a density of one sample every 12.5 km². Regolith and spinifex samples were collected across two regional faults to test whether changes in chemistry of both media indicated that faults had acted as conduits to bedrock-derived fluids. Passive seismic data were collected along one transect to determine the thickness of regolith. Apart from providing a complement to regolith chemistry, the regolith–landform mapping carried out as part of the Ngururrpa program forms part of an update to the West Arunta geological information package (GIP). Additional regolith–landform mapping has now extended the coverage of this package south to include the Macdonald (SF52-14) 1:250 000 map sheet.

GSWA recognises that federal government agencies and tertiary institutions can make a valuable contribution to geoscience programs through collaboration. Regolith-related programs involve GSWA funding of and external co-operation with staff from CSIRO and Curtin University.

- GSWA has contributed to the funding of biogeochemical work carried out by CSIRO in the northwestern Yilgarn Craton – Gascoyne area. This work was completed in 2016–17, and will be published in 2017–18 as a GSWA record.
- GSWA has contributed to the further investigation of regolith fine-fraction chemistry to explore for buried mineralization through an industry–government–MRIWA project based at CSIRO. A development in this program is the potential use of

archived regolith material held in GSWA's core library for further testing of sample preparation and analytical approaches developed earlier in the program

- GSWA has been instrumental in developing the application of the single-station passive seismic approach to estimating regolith thickness. An important part of this approach is to determine the level of agreement between data generated by passive seismic, and those resulting from drilling or other techniques such as airborne electromagnetics (AEM). To test the effectiveness of different methods, GSWA is working with CSIRO scientists to evaluate data from the Gascoyne area, where passive seismic data have been acquired close to AEM flight lines, and drilling data are available. The passive seismic data program has been expanded by the purchase of four single-station devices, and entering an agreement with Curtin University to generate improved approaches to data reduction.
- Radiometric dating of ferruginous duricrust at Curtin University using the (U–Th)/He method has been undertaken on GSWA samples collected in the Kimberley and southwest Yilgarn Craton areas. Apart from providing valuable geochronological data, dating of these samples has contributed to further evaluation of developing an in situ approach to dating using this technique. The availability of these types of data will contribute to better regolith–landform maps, and an improved understanding of the more recent geological evolution of the State. Sample collection from the Gascoyne and Goldfields areas in 2016–17 will be used to expand this program.

Outcomes of work program 2016–17

- Co-sponsor and contribute a researcher to a CSIRO–MRIWA–industry project to examine the application of fine-fraction chemistry of regolith for mineral exploration in areas of transported regolith
- Contribution to the funding of a biogeochemical study carried out by CSIRO in the northwestern Yilgarn Craton and Gascoyne area.
- Extension of the west Arunta GIP regolith layer to include the Macdonald 1:250 000 map sheet (SF52-14)
- Dating of ferruginous duricrust from the Kimberley and Boddington areas
- Collection of ferruginous duricrust from the Gascoyne and Goldfields areas for further (U–Th)/He dating.

Planned work program and products 2017–18

- Carry out regional regolith-oriented programs in underexplored parts of the State, conditional on funding
- Collect representative samples of duricrust suitable for radiometric dating
- Dating of ferruginous duricrust from the Gascoyne and Goldfields areas by the (U–Th)/He dating method
- Acquire passive seismic data in areas of variable cover as a complement to regolith geochemical data, and with an aim to generate a third dimension for regolith–landform maps.

Products planned for release 2017–18

Regolith geochemistry of the Ngurrupa area (Record)

NW biogeochemistry and beyond project (GSWA Record)

(U–Th)/He dating of ferruginous duricrust (GSWA record)

Macdonald 1:250 000 geological map sheet (SF52-14)

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 2016–17

<i>Outcomes 2016–17</i>	<i>Status</i>
Implement an online search tool that interrogates the field observation database (WAROX)	Ongoing – USB released
Enhance ENS to include regolith and mineral systems	Ongoing
Redevelop the department's Data and Software Centre	Complete
Enhance geochemistry database (WACHEM)	Stage 1 complete
Develop methodology and application for Mining Act Section 16(3) and administrative referrals to/from Department of Lands	Complete

Planned products and outcomes 2017–18

<i>Planned outcomes 2017–18</i>
Implement an online search tool that integrates with the field observation database (WAROX)
Develop a new user interface for WAMEX
Enhance ENS to include regolith and mineral systems
Enhance geochemistry database (WACHEM) Stage 2

ES42 3D Geoscience

Manager: Klaus Gessner

Team members: Lucy Brisbout, Ruth Murdie, Elle Rakich, Huaiyu Yuan (Macquarie University), Joel Burkin (CET)

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 2016–17

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) investigated the lithosphere structure of the Albany–Fraser Orogen using a passive seismic array. Lucy Brisbout, Ruth Murdie and Klaus Gessner collaborated with Catherine Spaggiari (see also GS61) ANU seismologists Christian Sippl, Hrvoje Tkalčić and Brian Kennett on the geological interpretation, resulting in a GSWA Record (scheduled for publication in 2017–18) and two external publications.

Ruth Murdie and Huaiyu Yuan worked with Michael Dentith at UWA in installing a trial passive seismic array in the Perth Basin to investigate the feasibility of such studies in this area.

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'.

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 manuscript is scheduled for publication in 2017–18 in a Geological Society (London) Special Publication

Elle Rakich has worked with 3D Geoscience as part of her departmental Graduate Rotation from February to April 2017. During that time Elle worked in close collaboration with Mark Jessell and Vitaliy Ogarko (CET) on the application of graph theory algorithms to find a linear representation of the topology of geological networks and stratigraphy.

Joel Burkin (UWA) has worked on transforming external 3D models to GSWA standards.

Products released 2016–17

Record 2016/3: Integrated Exploration Platform v2.5

Record 2015/13: Saying goodbye to a 2D Earth

Record 2015/16: Second Lithosphere Workshop Abstracts

West Gawler 3D model

Record: Specifications for submission of 3D Models to GSWA

Ten external publications — see Appendix C

Planned work program, products 2017–18 and beyond

A key focus for 2017–18 will be on the collaboration with the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS) in Beijing, China, to carry out the first stage of passive seismic deployment in the coastal region of northern Western Australia (Fig. 42).

3D Geoscience staff will also contribute to a collaborative project with UWA on the crustal structure of the southwest Yilgarn Craton. 3D models and publications are also planned for the Albany–Fraser and further modelling work will be carried out on the Hamersley, Merlinleigh and Perth Basins.

Within the ARC CCFS Huaiyu Yuan (supported by an exchange student and a visiting Postdoctoral Research Fellow from the Chinese Academy of Sciences) will continue work on the architecture of the lithospheric mantle of the West and North Australian Cratons. A suite of passive source methods will be applied in conjunction with the COPA to develop a technical template for resolving both the isotropic and anisotropic seismic velocity models for both long-operating and the COPA stations. A 3D lithosphere-scale P-wave velocity model targeting the Capricorn region will be worked on by the exchange student, and a Yilgarn-wide crustal shear velocity model will be developed by the visiting postdoc using the data from both the Albany–Fraser and the COPA deployments and the GA permanent stations. Results of the seismic modelling will be published in peer-reviewed journals and as GSWA Records.

Local passive seismic studies with UWA will continue to investigate the feasibility of using the techniques in the Perth Basin and also against the Metropolitan Fibre Optic Network.

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 2017 Goldschmidt meeting in Paris, the 2017 conference of the Structural Geology and Tectonics Specialist Group of the Geological Society of Australia (SGTSG) in Denmark (WA), the 2018 ASEG meeting in Sydney, the 2018 AOGS Meeting in Singapore, the 2018 EGU Meeting in Vienna, the 18th Annual Conference of the International Association for Mathematical Geosciences (IAMG) in Fremantle, and the Third CCFS Lithosphere Dynamics Workshop at UWA.

Products planned for release 2017–18

Crustal and uppermost mantle structure of the east Albany–Fraser Orogen from passive seismic data (Report)

A magnetotelluric survey across the Albany–Fraser Orogen and adjacent Yilgarn Craton (Report)
Imaging the structure of Archean fault rocks with synchrotron X-ray microtomography (Record)
The Precious Earth – Understanding Hydrothermal Ore Forming Systems (Book)
Third Lithosphere Dynamic Workshop (Abstract volume)
SGTSG (Abstract volume)
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, 10GA-CP1, 10GA-CP2,
10GA-CP3 (Geophysical Modelling Reports)
3D index for Geophysical Modelling Reports
Merlinleigh and Hamersley Basin 3D models
Twelve external publications — see Appendix C

ES43 Mineral Systems Atlas

Managers: David Maidment, Trevor Beardsmore

Team members: Lauren Burley, Paul Duuring, Josh Guilliamse, Sidy Morin-Ka, Mark Hutchison, Wally Witt, CET UWA, CODES, CSIRO

Under this program, GSWA has entered 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. Many of these projects are managed or monitored by GSWA's Mineral Systems group, and in some instances have received in-kind funding from the GS20 recurrent budget, but the majority of these minerals-oriented research projects have been partly to fully funded by the Exploration Incentive Scheme (EIS). Some of the EIS-funded collaborative research projects have been or will soon be completed. Uncertainty on the long-term continuity of EIS has put a brake on initiating new research projects.

Significant projects recently coming to a conclusion 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
- diamond prospectivity of Western Australia

Outcomes of work program 2016–17

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 released early in 2016–17 (Report 158).

The EIS-funded collaborative study of the VMS fertility of Yilgarn volcano-sedimentary successions was completed in late 2015. The results of the analysis of then-existing public domain data were published in GSWA Report 165 and in the journal *Precambrian Research* during 2016–17. Studies of the litho-geochemistry and geochronology of a number of under-represented terranes using newly collected data have also been compiled and are to be published in another GSWA Report in the coming year; some of the new work on the Nimbus, Teutonic Bore and King VMS deposits has also been published in *Precambrian Research* and presented at a variety of international conferences (see Appendix C).

The EIS-funded government–academia–industry collaborative study of BIF-hosted iron ore metallogeny in the Yilgarn Craton (part of Project ES43) was 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 published in 2016–17 some of the results of mapping iron ore and associated alteration using HyLogging as a series of GSWA Records. An overall synthesis is to be published as a GSWA Report and series of external publications.

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 published as a co-branded GSWA Report 163 in early 2016–17 (at the expiry of the confidentiality period), and a presentation made at GSWA’s Annual Open Day (Record 2017/02).

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, together with the earlier-submitted interim Report and database, are being prepared for release as GSWA publications in 2017–18.

The mineral prospectivity analysis of the southeastern Capricorn Orogen by UWA’s Centre for Exploration Targeting was near completion at the end of 2016–17. The final

report documenting the study is being prepared for release in 2017–18. Three GIS datasets with prospectivity models and toolboxes will also be released, as well as a new time–space correlation chart for the Capricorn Orogen.

Dr Mark Hutchison neared completion of a database 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). Release of the Western Australian ‘diamond’ database and associated reports is scheduled for August 2017, at the 10th International Kimberlite Conference.

In a significant new initiative, the Mineral Systems Studies section commenced work to create an interactive, GIS-based Mineral Systems Atlas, which will deliver ‘mappable geological proxies’ for critical metallogenic processes, that are derived from systematic ‘mineral systems analyses’ of known or probable mineral systems in Western Australia (see Project GS20 for more details).

GSWA also began developing in-house knowledge and technological capacity to undertake multi-scale prospectivity studies. Staff from the Mineral Systems Studies section, the Mapping section, and the GIS section attended two training workshops provided by UWA–CET staff.

Product released 2016–17

Report 158: Yilgarn Gold Exploration Targeting Atlas – Volume 3

Report 163: MRIWA Report Project M426: exploration targeting for BIF-hosted Fe deposits in the Pilbara Craton, Western Australia

Report 165: VMS mineralization in the Yilgarn Craton, Western Australia: A review of known deposits and prospectivity analysis of felsic volcanic rocks

Record 2016/16: Mapping iron ore and alteration patterns BIF using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia

Record 2016/17: Mapping iron ore and alteration patterns in BIF using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia

Record 2016/18: Mapping iron ore and alteration patterns in BIF using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia

Record 2016/19: Mapping iron ore and alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia

Planned work program and products 2017–18

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:

- a series of Reports and Records detailing the results of mineralogical and metallogenic studies of Archean BIF-hosted iron ore deposits in the Yilgarn Cratons
- final Report and three GIS datasets for the mineral prospectivity targeting work in the 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.

The development and funding of new collaborative research projects will depend on continuation of the Exploration Incentive Scheme.

Products planned for release 2017–18

Report and database — Diamond and diamond-indicator mineral occurrences, and diamond prospectivity, in Western Australia (provisional title)

Mineral systems analysis of the Capricorn Orogen (provisional title) (Report)

Three GIS datasets with prospectivity models and toolboxes (Capricorn southern basins, Edmund-Collier basins and Ashburton Basin)

Metallogeny of Archean BIF-hosted iron ore deposits in the Yilgarn Craton, Western Australia (Report and external publications)

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 2018–19 and beyond

GSWA will negotiate new, relevant collaborative research projects that may be funded from the EIS — if EIS is funded beyond mid-2017.

ES45 Geological Mapping and Interpretation

Manager: David Maidment

Team members: Olga Blay, Nadir De Souza-Kovacs

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 several remote greenfields areas of Western Australia, including the Kimberley, Capricorn, west Arunta, west Tanami and Paterson regions. Large parts of these areas are underexplored due to remoteness, land access issues, and the lack of up-to-date pre-competitive geoscience datasets. This program is providing new mapping and interpretations, as well as making existing legacy data available in digital format.

Capricorn Orogen

In the Capricorn Orogen, the project has contributed to mapping of late Paleoproterozoic to Mesoproterozoic Edmund and Collier Basins, which contain Abra, Western Australia's largest stratabound Pb–Ag–Cu–Au deposit (see Project GS49). As part of this work, the WONYULGUNNA 1:100 000 Geological Series map was produced in 2016–17, completing 1:100 000 Geological Series mapping of these basins. Mapping in the region is now transitioning to the basins of the Eastern Capricorn Orogen, which include the Bryah, Earahedy, Padbury and Yerrida Basins. Reports detailing the results of focussed studies are also in preparation, including the geochemistry and geochronology of a newly identified dolerite suite and other dolerite suites within the basins.

West Arunta region

The West Arunta region incorporates poorly exposed metasedimentary and meta-igneous rocks of the Paleoproterozoic Arunta Orogen, which is overlain by Neoproterozoic sedimentary rocks of the Murraba and Amadeus Basins. The Arunta Orogen in Western Australia is underexplored, owing to the paucity of outcrop and remoteness, but several base metal prospects have been identified in areas of outcrops (e.g. Enceladus and Iapetus Zn–Pb), as well as a field of kimberlitic intrusions (Webb diamonds) under shallow cover.

The provision of new geological data for this geologically complex, but understudied region will assist mineral exploration targeting and reduce exploration risk in this greenfields domain.

Recent EIS-funded work by GSWA in the region has focused on the production of two Second Edition 1:250 000 Geological Series maps: WEBB (released in 2015–16) and MACDONALD (to be released in 2017–18). A Tanami–Arunta Geological Information Series digital product was released 2016, and will be updated in 2017–18 with the most recent mapping.

Paterson Orogen

The Paterson Orogen to the east of the Pilbara Craton includes polydeformed and metamorphosed Neoproterozoic to Paleoproterozoic rocks of the Rudall Province as well as overlying Neoproterozoic sedimentary rocks of the Yeneena Basin. These rocks are in turn overlain by Paleozoic sedimentary rocks of the Canning Basin and widespread surficial sediments that largely mask the Proterozoic units. The Yeneena Basin hosts several major mineral deposits and occurrences, including the Telfer Au–Cu, Nifty Cu, Kintyre U and O’Callaghans W (Zn–Cu–Pb) deposits. Most mineralization in the region formed during one of two major metallogenic events: 840–810 Ma (e.g. Nifty, Kintyre, Warrabarty); and coeval with deformation and granite emplacement at 655–605 Ma (e.g. Telfer, Magnum, O’Callaghans).

Recent EIS-funded work in the Paterson Orogen has included the publication of a Report in 2017 on the geochronology and evolution of the Rudall Province, in conjunction with Geoscience Australia. A collaborative study with Curtin University on the oxygen and Lu–Hf isotope compositions of zircon from Mesoproterozoic to Neoproterozoic magmatic rocks has recently completed the data acquisition phase.

Kimberley Region

In the Kimberley region, the project is contributing to the collection of geochronology, geochemistry and isotope data for metasedimentary and igneous rocks of the 1912–1788 Ma Lamboo Province to better constrain the timing and nature of tectonism and geodynamic models for the region (see Project GS56). SHRIMP U–Pb dating of detrital

zircons from 1880–1845 Ma metasedimentary successions is complete, which provides constraints on the nature of the western and central zones prior to their inferred collision with the North Australian Craton. Collection of Lu–Hf isotope data for these rocks is ongoing. The results of this study will be produced as a Record assessing the geodynamic setting of the region prior to the deposition of the Kimberley Basin. Geochemistry, geochronology and Sm–Nd data are also being collected for granitic rocks of the 1832–1808 Ma Sally Downs Supersuite to better understand the spatial and temporal variations in magmatism during the Halls Creek Orogeny.

West Tanami region

The West Tanami region incorporates the western part of the Granites–Tanami Orogen, a poorly exposed domain of Neoproterozoic to Paleoproterozoic metasedimentary and igneous rocks that host significant orogenic gold (e.g. Callie, Tanami Goldfield, Groundrush and Coyote) and REE deposits (Browns Range). The Granites–Tanami Orogen is overlain by Mesoproterozoic to Neoproterozoic sedimentary successions, including the Birrindudu and Murraba Basins, as well as widespread surficial cover that has hampered mineral exploration.

Recent work by GSWA in the West Tanami region has included production of several 1:100 000 geological series maps (SLATEY CREEK, BALWINA, WATTS, KEARNEY AND LEWIS), as part of an EIS-funded project compiling previous GSWA and GA mapping data. These maps, as well as recent regolith mapping, regolith geochemistry and gravity data in the Ngururrpa area between the Tanami and Arunta regions, have been released as part of the Tanami–Arunta Geological Information Series 2016 data package. A report on the results of SHRIMP U–Pb dating of zircon from the western Granites–Tanami Orogen is also in preparation, in collaboration with Geoscience Australia.

Outcomes of work program 2016–17

In the Capricorn Orogen, the 2016–17 work program focused on compilation and publication of the WONYULGUNNA 1:100 000 Geological Series map, under EIS funding. A 2016 update of the West Capricorn Geological Information Series data package incorporated data for the LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps, which were released in 2015–16. Geochemical and geochronology studies

have identified a previously unrecognized 1517–1505 Ma dolerite suite, which provides a minimum age constraint for Depositional Package 1 of the Edmund Group.

A Report on the geochronology and geochemistry of the Rudall Province of the Paterson Orogen was released in 2017. This study revealed the presence of possible Neoproterozoic metasedimentary rocks, widespread 1589–1549 Ma granitic magmatism in the eastern part of the Province and suggests that amalgamation of the West and North Australian Cratons might have occurred significantly later than previously thought. A collaborative study with Curtin University of Lu–Hf and O isotopes of Meso- to Neoproterozoic granitic rocks from the Paterson Orogen completed its data acquisition phase. The results reveal a range of isotopically evolved and primitive magma sources that provide insights into the geodynamic setting and crustal structure of multiple magmatic events.

Work in the West Arunta region focused on compilation of the MACDONALD 1:250 000 Geological Series Map. This has involved generation of a new regolith layer for the sheet as well as revision of the interpreted basement geology based on recent fieldwork.

In the Kimberley region, EIS-funded work in 2016–17 focused on acquisition of detrital zircon geochronology for 1880–1845 Ma metasedimentary units of the Lamboo Province. The results of this dating suggest that terranes previously thought to be exotic might instead have been part of the North Australian Craton and that geodynamic models might require revision. Lu–Hf isotope data for these rocks are currently being collected to test regional correlations. Geochemistry and Sm–Nd isotope data for the 1832–1808 Ma Sally Downs Supersuite were also collected during 2016–17 and incorporated into GSWA databases.

Products released 2016–17

WONYULGUNNA 1:100 000 Geological Series map

West Capricorn Geological Information Series update 2016 (including the LOFTY RANGE and ILGARARI 1:100 000 Geological Series maps)

Report 161: Geochronology of the Rudall Province, Western Australia: implications for the amalgamation of the West and North Australian Cratons

Planned work program and products 2017–18

In the Capricorn Orogen, EIS-funded work in 2017–18 will continue the compilation of legacy data for the basins in the eastern Capricorn Orogen project. Work will commence on the construction of seamless 1:250 000-scale digital geology layers with the progressive release of 1:250 000 mapping tiles each year as digital layers in the East Capricorn Geological Information Series data package.

In the west Arunta region, the MACDONALD 1:250 000 Geological Series Map will be published, with data incorporated into a 2018 update for the Tanami–Arunta Geological Information Series digital data package. This will complete Second Edition mapping of the Arunta Orogen in Western Australia.

A report on the volcanology and geochemistry of the c. 1795 Ma Hart–Carson large igneous province will also be released. This report will present the results of a collaborative study with the University of Tasmania examining the volcanology and geochemistry of this extensive mafic magmatism within the Kimberley Basin. Work will also include preparation of a report documenting the results of detrital zircon dating of the Lamboo Province. EIS-funded work will also contribute to the compilation of the LANSLOWNE 1:250 000 Geological Series map, scheduled for release in 2017–18.

Products planned for release 2017–18

Recognition of a new Mesoproterozoic mafic intrusive event in the Capricorn Orogen (Record)

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

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

MACDONALD 1:250 000 Geological Series map

LANSLOWNE 1:250 000 Geological Series map

Mineral prospectivity of the Southern Basin of the Capricorn Orogen (Yerrida, Bryah, Earraheedy and Padbury Basins) (GIS digital data package)

Volcanology and geochemistry of the Hart–Carson large igneous province (Report)

Detrital zircon geochronology and Lu–Hf isotope study of the Lamboo Province (Report)

Geochronology of the western Granites–Tanami Orogen (Report)

Oxygen and Lu–Hf isotope study of magmatic events in the Paterson Orogen (Report)

Planned work program, products 2018–19 and beyond

Work in the Capricorn Orogen will continue to focus on the compilation of legacy data for the basins in the eastern Capricorn Orogen and the progressive release of 1:2 500 000-scale mapping tiles as digital layers for the Eastern Capricorn Geological Information Series digital product. Work will also focus on the writing and update of explanatory notes for the Eastern Capricorn Basins.

Work in the Kimberley region will include evaluation of geochemical and isotope data of the Sally Downs Supersuite to produce a report on the implications for geodynamic models and mineral prospectivity.

Products planned for release 2018–19 and beyond

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

Eastern Capricorn Geological Information Series 2019 (including a digital compilation of the 250 000 IBG and associated digital layers, and Explanatory Notes for parts of the Padbury, Bryah, Yerrida and Earraheedy Basins)

Geochemistry and isotope study of Sally Downs Supersuite (Report)

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 continues to extend and enhance 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 additional isotope-related techniques (such as whole-rock Lu–Hf and Pb–Pb isotopes) conducted in collaboration with university research groups. These techniques enable construction of a range of isotopic maps at different scales, which are powerful in imaging lithospheric and crustal architecture, identifying metallogenic terranes and favourable geodynamic environments, and constraining the 4D evolution of the lithosphere. The resulting knowledge will greatly help focus exploration in prospective areas.

Variations of radiogenic isotope compositions (mainly Sm–Nd and Lu–Hf) provide information on the nature of the sources of magmatic rocks, allowing magmas derived from the mantle to be distinguished from those derived by reworking of older crust. Stable isotopes, mainly oxygen, are used to distinguish material derived from near-surface or supracrustal environments from mantle-derived material.

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 in controlling the fertility of a magma for ore formation. 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 2016–17

About 900 previously dated zircons from 24 samples were analysed for Lu–Hf isotopes during 2016–17. Following significant delays in the return of Lu–Hf data during 2016–17, we are expecting results for another 900 zircon analyses from 40 samples in the near future. The samples represent igneous, metamorphic, and sedimentary rocks selected from the Murchison Domain of the Yilgarn Craton, the Gascoyne Province, and the Kimberley

region. More than 100 samples were submitted in 2016–17 for Sm–Nd whole-rock analysis, mainly from the Eastern Goldfields Superterrane, the Murchison Domain, and the South West Terrane of the Yilgarn Craton, as well as the Kimberley region. About 830 previously dated zircons from 50 samples were analysed for oxygen isotopes during 2016–17, mainly from basement rocks beneath the Eucla Basin, and granites of the Pilbara and Yilgarn Cratons and the Capricorn Orogen (Fig. 43).

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, the GSWA Geochemistry (GeoChem Extract) web page, and within the annual compilation of geochronology information released on USB. 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 are described below.

Over 200 new samples have been collected for geochronology, geochemistry, and isotope analysis from igneous rocks in the South West Terrane of the Yilgarn Craton, a region with little pre-existing information. Geochemical (e.g. Eu/Eu*) and Nd isotope mapping using these new data, together with previously available data across the Yilgarn Craton, suggest the existence of east-trending basement structures that cut across current north-trending terrane boundaries. This discovery questions existing models of the structure of the Yilgarn Craton, and forces a rethinking of processes of craton formation and modification and crust amalgamation through time.

Zircons from about 40 previously dated samples from across the Yilgarn Craton have been analysed for trace element compositions. These new data indicate that Archean granites were mainly formed through lower crustal or infracrustal partial melting of mafic crust within the garnet stability field, whereas Phanerozoic Cu-fertile suites were formed by intracrustal amphibole-dominated fractionation of mafic magmas. This in turn suggests that Archean granite magmas are typically relatively dry compared to Phanerozoic Cu-fertile granite magmas. Granites formed by the first process have lower potential for porphyry Cu mineralization due to insufficient water and the lack of increasing copper and sulfur in the melt. Additional data are needed from mineralized Archean granites to determine whether they have different genesis from non-mineralized Archean granites.

The 2013–16 ARC Linkage project ‘Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: constructing a geological framework for understanding mineral systems’, which involved collaboration between GSWA and Curtin University, was completed at the end of 2016. This project used 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 close to completion. One result from this project is the discovery of c. 2400 Ma mineralization and hydrothermal alteration at the Paulsens mine, southern Pilbara Craton. This age does not correspond with any known deformation event in the region, and suggests a significantly different and more complicated low-temperature tectonothermal evolution for the southern Pilbara region than previously recognized.

A three-year research project commenced in 2015 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 presents Hf isotope data from the East Pilbara Terrane that indicate increased reworking of existing crust during the Paleoproterozoic and Mesoproterozoic. Another article in review uses Lu–Hf and oxygen isotope data for Proterozoic granites in the Rudall Province to understand the genesis of Archean TTGs in a non-subduction setting. Finalising the interpretation of Lu–Hf and oxygen isotope data for basement rocks beneath the Eucla Basin is still underway.

Two MRIWA-administered projects continued in 2016–17. The first project, ‘M448: Rutile – Pathfinder to Ores’ 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. Rutile U–Pb ages from previously dated GSWA sandstone samples in some cases show very different age spectra compared to those based on zircon U–Pb ages, indicating that detrital zircon, monazite, xenotime, and rutile may have originated from different sources, and in combination provide the best constraints on maximum deposition ages. In addition, the chemistry of coarse rutile grains can preserve a gold ‘fingerprint’ that may be used to point towards another Tropicana or Big Bell gold deposit.

MRIWA project ‘M446: Re–Os sulphide geochronology’ uses the Re–Os isochron dating of sulfide minerals to determine precise ages for two classes of metal deposits in Western Australia: VMS Zn–Pb–Cu deposits and orogenic gold deposits. For each class of deposit, reviews of geology and geochronology were used to guide sulfide sampling. Minerals such as molybdenite, arsenopyrite, and pyrite are the best minerals for Re–Os geochronology given their high-Re and high Re/Os.

A three-year MRIWA project, ‘M470: Mineral systems on the margin of cratons: Albany–Fraser Orogen / Eucla basement case study’, commenced in May 2016. This project integrates Lu–Hf, Sm–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 to highlight areas of enhanced mantle input within the eastern Albany–Fraser Orogen and adjacent Eucla basement rocks. Three PhD projects at Curtin University are focusing on crustal evolution, petrochronology, and sulfide sources and budgets, respectively.

Products released 2016–17

Lu–Hf data released as part of the Compilation of geochronology information 2017

Lu–Hf and Sm–Nd datasets released to online applications (GeoVIEW.WA and GeoChem Extract)

Ten external journal articles and two conference abstracts (see Appendix C)

Planned work program and products 2017–18

Analyses of Lu–Hf, Sm–Nd, and oxygen isotopes will continue in 2017–18. 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. Existing and new zircon oxygen isotope data will be released for the first time in tabular form via GeoVIEW.WA and in the annual compilation of geochronology information. 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.

MRIWA project ‘M448: Rutile – Pathfinder to Ores’ will continue to develop and test the “small spot” LA-ICPMS method for analysing small rutile grains, to build the geochemistry database on rutiles from ore environments, and to better understand how rutile geochemistry and age are preserved and modified by secondary events. MRIWA project ‘M446: Re–Os sulfide geochronology’ will continue acquisition of sulfide Re–Os and sericite Ar–Ar geochronology at the Nimbus VMS deposit and the Boddington and Big Bell gold deposits. Sulfide Os–Pb isotopes will also be conducted to fingerprint metal sources at these deposits. MRIWA project ‘M470: Mineral systems on the margin of cratons’ will continue to acquire new Hf–Nd–O–S isotope data, and LA-ICPMS trace element and U–Pb data from TIMA mounts and drillcore samples from the Albany–Fraser Orogen and Eucla basement.

Planned work program and products 2018–19 and beyond

The planned work program for 2018–19 and beyond will be similar to that for 2017–18. New samples will be collected during the normal course of GSWA fieldwork to address specific geological problems.

ES47 Petroleum, Coal and CO₂ Geosequestration

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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 gas fields 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; the agency estimated that the Canning Basin 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 possible viable future addition to the State's domestic gas market.

During the last decade, shale has become an important supply of natural gas and oil in the US. Interest in exploring shale 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 tight and shale hydrocarbon potential of the Canning and northern Perth Basin. The results of the Canning Basin project to date include recognition of a new potential petroleum source rock in the Ordovician Nambett Formation; improved correlation of conodont age dating with international time scales using new geochronology (CA-IDTIMS) and chemostratigraphy (carbon isotope curves) results; better estimation of thermal maturity combining geochemistry and several methods of converting organic petrology of bitumen, graptolites and other bioclasts to an equivalent vitrinite reflectance; and the development of a new digital product (called the Digital Core Atlas) to interactively display large data sets from

core analysis results. The first Digital Core Atlas was for the well Olympic 1 and has received wide acclaim from industry, academia and international geological surveys.

Geophysical projects being undertaken that will provide new pre-competitive data and aim to improve the structural and stratigraphic definition of the Canning, Carnarvon and Perth Basins include:

- contribution to a project involving the acquisition of new passive seismic data in the Perth Basin (ES31) with results expected in 2017–18
- reprocessing of selected 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and northwestern Canning Basin
- reprocessing of selected 2D seismic lines in the southern Carnarvon Basin and the Coolcalalaya Sub-basin of the northern Perth Basin
- completion of a revised SEEBASE (depth to basement) product over the Canning Basin by FrogTech Geoscience
- new regional deep crustal seismic survey of almost 900 km in the Kidson Sub-basin of the Canning Basin is currently being planned to be undertaken in winter 2018, jointly funded by GA and GSWA. Following on from the seismic acquisition, stratigraphic drilling is planned for mid-2019 on a location along the new seismic line, to improve understanding of the stratigraphy and petroleum potential of the Kidson Sub-basin and the underlying basement. The stratigraphic hole will be largely funded by GA through its 4-year *Exploring for the Future* project in Northern Australia.

A project to document the coal resources of Western Australia is underway. The first two records to be released in 2017–18 review the exploration history and estimated lignite resource volumes in the southwestern Western Australia including the Eucla Basin; and the Mesozoic coal seams of the northern Perth Basin. Work has commenced on the next two Records which focus on the coal resources of the Canning Basin and the Permian coal resources of the Carnarvon and Perth Basins.

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, with the Canning Basin project 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, DMIRS.

Outcomes of work program 2016–17

Canning Basin

Some of the main outcomes from studies in the Canning Basin in 2016–17 were:

- completion and publication of an interpretation of the Canning Basin deep crustal seismic survey (data acquisition funded by EIS and data processing by GA)
- GSWA continued participation in core analyses of the Lower Ordovician cored in Olympic 1 and Senagi 1, drilled by Buru Energy Ltd; and Theia 1, drilled by Finder Exploration Pty Ltd in 2015. The core analysis is now complete and work on interpreting the results and incorporating the implications into the regional prospectivity assessment and geological framework of the Canning Basin is continuing into 2017–18
- a new interactive digital product has been developed during the last two years, 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. The first atlas covered the core in Olympic 1 and was published during 2016–17. Work continues into 2017–18 on compiling a core atlas for each of Theia 1 and Senagi 1.
- publication of GSWA Report 169 on petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1
- publication of GSWA Report 170 on assessment of thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Olympic 1, Canning Basin
- publication of GSWA Digital Core Atlas: Olympic 1
- publication of GSWA Record 2017/05 on Canning Coastal seismic survey — an overview of the Canning Basin
- Work commenced on a Record assessing the coal resources of the Canning Basin.

- A project to update the SEEBASE product over the Canning Basin and the Western Australia portion of the Amadeus Basin commenced, with a draft of the product completed at the end of 2016–17.

Eucla Basin

The main outcome from studies in the Eucla Basin in 2016–17 was an assessment of the lignite resources of the Eucla Basin and southwest Western Australia, which was completed and will be published as a Record in 2017–18.

Perth Basin

Some of the main outcomes from studies in the Perth Basin in 2016–17 were:

- An assessment of the Mesozoic coal resources of the Perth Basin was completed and Record of the results will be published in 2017–18
- Work commenced in an assessment of the Permian coal resources of the Perth Basin, with a Record of the results expected to be published in 2017–18
- A collaborative core analysis project commenced with AWE Ltd on cores from the northern Perth Basin.

Products released 2016–17

Record 2017/05: Canning Coastal seismic survey — an overview of the Canning Basin

Report 169: Petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1

Report 170: Assessment of the thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Canning Basin

Digital Core Atlas: Olympic 1

Planned work program, products 2017–18 and beyond

Continue regional geological, geophysical and petroleum geochemical studies for the Canning, Perth and Carnarvon Basins during 2017–18 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 includes collaboration on core analysis with AWE Ltd of the core from the Waitsia 3 petroleum well, which was drilled in June 2017 in the north Perth Basin
- 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
- Interpretation of the new reprocessed seismic data
- completion of the SEEBASE product for the Canning Basin and the Western Australian portion of the Amadeus Basin.

Canning Basin

The planned outcomes from studies in the Canning Basin in 2017–18 are to:

- complete seismic reprocessing of vintage 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and the NW portion of the Canning Basin
- complete and release the revised SEEBASE product over the Canning Basin
- continue collaborative core analysis from recent and future wells drilled by petroleum companies in the Canning Basin including cooperative studies with CSIRO
- completion of digital core atlases for the Canning Basin petroleum wells Theia 1 and Senagi 1, which were included in the collaborative core analysis projects
- continue to investigate regional correlations and hydrocarbon potential of the lower to middle Ordovician Goldwyer and Nambeet formations
- define the Goldwyer Formation Reference Section
- complete and assessment of the CO₂ sequestration potential of the Ordovician in the Canning Basin based on the results from the collaborative core analysis project.

Perth Basin

The planned outcomes from studies in the Perth Basin in 2017–18 are to:

- undertake collaborative core analysis projects with AWE Ltd who have acquired core in

Waitsia 3 within 2016–17, with results feeding into regional studies

- release two GSWA Records on the coal resources of the Perth Basin; the first focusing on the Mesozoic and the second Record will document the Permian
- review results obtained from a passive seismic traverse

Southern Carnarvon Basin

The planned outcomes from studies in the Carnarvon Basin in 2017–18 are to:

- complete seismic reprocessing of vintage 2D seismic lines in the Southern Carnarvon Basin and the Coolcalalaya Sub-basin of the northern Perth Basin
- commence interpretation of the newly reprocessed 2D seismic lines and incorporate the results into a wider interpretation project to improve the definition of the stratigraphy and structure of the onshore portion of the basin.

Products planned for release 2017–18

Reference Section: Nambeet Formation, Canning Basin (Report)

Reference Section: Goldwyer Formation, Canning Basin (Report)

Digital Core Atlas, Theia 1, Canning Basin (interactive digital product)

Digital Core Atlas, Senagi 1, Canning Basin (interactive digital product)

Canning Basin Coal Resources (Record)

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

Mesozoic coal resources of Northern Perth Basin (Record)

Lignite resources of the Eucla/Bremer Basin (Record)

Permian coal resources of the Perth and Carnarvon Basins (Record)

Revised SEEBASE model for the Canning and western Amadeus Basins (digital product)

Reprocessed vintage 2D seismic data in the Canning and Southern Carnarvon Basins and the Coolcalalaya sub-basin of the Perth Basin

ES50 Strategic Industry Research Program

Manager: Margaret Ellis

This program has encompassed the following two activities:

- the expansion of research into greenfields exploration with funding support by EIS to the Minerals Research Institute of Western Australia (MRIWA) of \$350 000 per annum since 2009–10
- the Western Australia Regional Researcher Initiative.

This latter activity was 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 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, with the final report published in early 2017.

Outcomes of work program 2016–17

Several new MRIWA projects, which are supported directly or indirectly by GSWA, received approval by the MRIWA Board this year. They were:

- **M493** – Don't bury Western Australia's geophysical data: uncovering prospective mineral terrains with regional potential field, seismic and MT transects through cooperative inversion
- **M494** – Mapping chemical architecture of gold camps
- **M509** – MinEx CRC

In addition, seven more EIS-and GSWA-supported projects were already in progress:

- **M462** Multiscaled 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
- **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 is due for publication next year:

- **M424** Multiscale dynamics of hydrothermal mineral systems

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 first two Reports listed below were published prior to 2016–17, whereas the third (Report 165) was published during 2016–17.

- GSWA Report 144: Greenfields geochemical exploration in a regolith-dominated terrain: the Albany–Fraser Orogeny/Yilgarn Craton margin
- GSWA Report 145: High-grade gold deposits: processes to prediction
- GSWA Report 165: VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks.

Planned work program and products 2017–18

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 2019. The situation after that is subject to review and is dependent on future funding arrangements of EIS. Currently, EIS funding is forecast to terminate in June 2019.

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Appendices

Appendix A: 2017 WA Labor Platform

The following is a partial extract from the 2017 WA Labor Platform (<https://www.walabor.org.au/platform>) . The WA Labor State Platform is set and revised by each State Conference and it outlines WA Labor’s core beliefs and policy priorities. The Platform does not contain specific election promises or commitments. For ease of reference to the original document, headings and reference numbers below are as per the original Platform document. All of the wording below is directly quoted from the original document.

CHAPTER 3: CONSERVATION, THE ENVIRONMENT AND CLIMATE CHANGE

ENVIRONMENT

1. WA Labor believes that:

- a) A strong economy and environmental sustainability are mutually compatible;
- b) The Western Australian Government’s responsibility is to ensure that the present needs of everyone in our community are met without compromising the ability of future generations to meet their needs;
- c) Committing to sustainability will create jobs, improve living standards, support regional development and encourage growth in new industries;
- d) Environmental sustainability requires a whole of government approach and that all government decision-making should consider the need for a sustainable future;
- e) Biodiversity is crucial to environmental sustainability and must therefore be protected; and
- f) Aboriginal people have a relationship with the land that gives them the right to determine and implement environmental policy for that land, subject to the determinations of the Environmental Protection Authority.

CLIMATE CHANGE & CLEAN ENERGY

2 WA Labor recognises the science demonstrating that Human induced climate change is real and Western Australia's natural environment, public health infrastructure and economy are all vulnerable to its impacts.

3 WA Labor supports the need for Western Australia to develop strong mitigation and adaptation plans to deal with the consequences of climate change.

4 WA Labor supports the need for a comprehensive Energy, Jobs and Community Transition Plan to smoothly and fairly transition WA's energy sector from fossil fuel based energy production to renewable based energy production.

5 WA Labor believes that:

- a) Responding to climate change presents Western Australia with an opportunity to diversify our economy, create jobs and enhance our social fabric;
- b) Reducing energy use and improving energy efficiency is the most economically viable and cost effective way to reduce greenhouse emissions;
- c) A market-based mechanism is a highly effective method to reduce carbon emissions on a large scale; and
- d) The Western Australia Government must establish and work towards renewable energy targets for Western Australia, consistent with target commitments made by Federal Labor.
- e) The WA Government should have a dedicated office tasked with implementing and monitoring climate change policies.

6 In Government, WA Labor will:

- a) Consider legislation that includes:
 - i. Implementing a mandatory energy efficiency scheme for large and medium electricity users;

- ii. Supporting mandatory renewable energy targets; and
- iii. Continuing to develop ways to reduce waste to landfill and increase recycling.

b) Monitor the effects of greenhouse offsets in reducing the carbon footprint of major projects;

6 q) Develop the legislation, policy and science necessary for the establishment of a commercial carbon sequestration industry in Western Australia's Rangelands, ensuring that a royalty is paid to government for use of this publicly owned resource.

9 c) Explore the relative costs and benefits of Pumped Hydro Storage at sites in the Collie Region, near the Perth Metro area, namely the Darling Range, population centres in the South West, namely the Stirling Range, and relevant sites in the North of the State, namely the Super Pits.

FRACKING

WA Labor acknowledges that communities have expressed opposition to gas fracking development throughout the State, and that the previous Government failed to protect communities and the environment from the harmful effects of this industry.

WA Labor will immediately ban fracking in the SouthWest, Perth, Peel and Swan Valley Regions.

WA Labor supports a scientific approach to the regulation of fracking, and will conduct a public inquiry to examine environment, health, agriculture, heritage and community impacts prior to any fracking activity.

WA Labor will place a moratorium on the use of fracking until such an inquiry can demonstrate that fracking will not compromise the environment, groundwater, public health or contribute adversely to climate change.

Following the public inquiry into fracking and where supported by Traditional Owners, WA Labor will consider a permanent ban on fracking in any water reserves or

groundwater areas, productive farmlands, or areas with environmental, cultural heritage or tourism values which could be compromised by fracking.

WA Labor supports strong, enforceable measures to protect groundwater aquifers from pollution, contamination or depletion by industrial activities including the oil and gas industry.

WA Labor will target renewable energies in order to combat climate change and diversify regional economies to create employment opportunities.

REGULATION

18 b) WA Labor believes that: The long term legacy issues associated with the closure and rehabilitation of mining and other industrial sites in Western Australia must be addressed as a matter of urgency to ensure that proponents, and not taxpayers, pay the costs of closure and rehabilitation.

19 In government, WA Labor will:

b) Insist that mine closure plans and the capacity to finance and progressively implement those plans will be built into the assessment processes for mining proposals and developments;

c) Review and, where necessary, modify existing mine closure plans where the proponent's capacity to finance and progressively implement those plans is in doubt;

URANIUM AND THORIUM

20 WA Labor believes that:

a) Enriching uranium poses significant risks to human health, the natural environment and is not a solution to climate change; and

b) Thorium also poses significant risks to human health and the environment.

21 In Government, WA Labor will:

- a) Oppose the mining and export of uranium;
- b) Oppose nuclear enrichment, nuclear power and otherwise the production of dangerous radioactive waste;
- c) Oppose the storage of nuclear energy waste in Western Australia;
- d) Oppose the testing or use of nuclear weapons in Western Australia or near our coastline;
- e) Encourage local governments to declare themselves ‘Nuclear Free Zones’; and
- f) Ensure that the mining of thorium in Western Australia only occurs under the most stringent environmental conditions and oppose thorium exports to countries that do not observe the Nuclear Non-Proliferation Treaty.

RESOLUTIONS

29

WA Labor notes and congratulates the McGowan Government’s delivery of a core election promise to ban all future uranium mining applications in Western Australia.

WA Labor reaffirms its long and principled opposition to the mining and use of uranium due to the devastating effect it and its byproducts have on workers, the environment and communities.

WA Labor, in particular, notes that due to the location of uranium deposits in WA, any potential mining of uranium would likely have a disproportionate effect on Indigenous communities.

WA Labor also reaffirms its pre-election commitments to investing in renewable energy and leading the industry in the development and implementation of sustainable energy technology.

This Conference condemns the previous Liberal Government for its reckless approval of uranium mining projects within Western Australia.

WA Labor State Conference notes the legal advice that these approvals cannot be overturned without serious legal and financial ramifications for the State.

WA Labor cannot and will not use taxpayers' money to pay out projects which are not financially viable.

WA Labor commits to supporting and resourcing the Environmental Protection Authority, the Department of Mines and Petroleum, WorkSafe and any other relevant departments to ensure they have the capacity to guarantee strict compliance from any potential uranium mines to best practice in the environmental, industrial and community spheres.

CHAPTER 4: ECONOMICS, INDUSTRY AND REGIONAL DEVELOPMENT

PUBLIC SECTOR EMPLOYMENT

250: WA Labor will, in consultation with relevant unions of government employees, review the use of labour hire, independent contractors and consultants to ensure that such employment or contract arrangements are used only where necessary and in accordance with ALP policy on government and determine the need for amendments to the Public Sector Management Act or other relevant legislation.

MINERALS AND ENERGY

The Responsible Development of Western Australia's Resources

INTRODUCTION

266 Western Australia owns a rich and varied world class mineral endowment. The mining and energy industries developed around the extraction of these minerals are a major source of export earnings, direct and indirect employment. Labor recognises that Australia's minerals and energy industries are vital to the strength of our economy.

267 WA Labor believes that there is further potential for development of these industries. The greatest economic and social benefits from further development-will come from leveraging this development into high skills jobs.

268 WA Labor will ensure that any development or expansion of the mining and energy industries will only proceed in an environmentally sustainable way, with the highest standards for the health and safety of workers and their communities, and with protection for the native title rights of traditional owners.

PROMOTING DEVELOPMENT

269 WA Labor will:

- a) Maintain and encourage sound relations with our trading partners, between governments, and where appropriate, between government statutory authorities;
- b) Work to ensure that WA remains a desirable option for investment in minerals and energy exploration and development;
- c) Encourage mining companies and State and Commonwealth Governments to cooperate in international negotiations;
- d) Support efforts to provide a positive framework for the exchange of information and a forum for discussion on the industry, involving all industry players;
- e) Introduce changes to the Mining Act directed at harmonising its process with those of the Native Title Act with a view to ensuring mining titles are processed in the shortest practical time; and
- f) Investigate ways to increase ‘green fields’ exploration undertaken in the State.

BALANCING DEVELOPMENT

270 To ensure a proper balance between economic, social and environmental concerns in all developments WA Labor will:

Economic

- a) Encourage exploration and development of mineral and energy deposits;

- b) Promote Western Australia as an international centre for the mining industry and create a long term plan for the development of the industry;
- c) Promote the development of products and technologies which reduce pollution and greenhouse emissions and add to environmental sustainability;
- d) Promote research to improve the efficiency, safety and environmental performance of the minerals and energy sector;
- e) Promote the sourcing and purchase of locally manufactured and fabricated products and local services where possible, for use in every stage of a project;
- f) Promote downstream processing projects in Western Australia, including by ensuring there is adequate infrastructure and suitable sites for projects;
- g) Ensure that new developments optimise the use of existing infrastructure;
- h) Ensure that infrastructure agreements serve the financial interests of the State and that major projects entailing State Government or statutory authority infrastructure expenditure are subject to social impact, energy audits, economic and environmental cost/benefit analysis and public scrutiny;
- i) Ensure the industry contributes adequately to the cost of infrastructure requirements;
- j) Recognise that Western Australia's mineral resources are an important non-renewable asset which should only be exploited in a manner that maximises benefits to Western Australia;
- k) Ensure that the levels of royalties in minerals are at levels that ensure project economic viability while maximising returns to the community;
- l) Work to ensure that mining companies active in Western Australia do not use their place in the global market to drop the price of commodities in order to drive out other local mining companies, thus reducing employment, community and taxation returns;

- m) Insist that all existing and new mineral and energy developments enforce the highest possible standard of safe working practices;
- n) Ensure the mining and extractive industries adequately fund education and training for its workforce through an Industry Training Council involving key representatives from all levels of industry;

Social

- o) Ensure that all minerals and energy sector development proposals and plans are accessible to the public and subject to social and environmental impact assessments;
- p) Such assessments will include public review and community consultation;
- q) Ensure the protection of Aboriginal sacred sites and cultural heritage and that all reasonable demands by the local Aboriginal community for compensation, and participation in the benefits of developments, are met with a view to facilitating Aboriginal participation in the broader economy;
- r) Ensure that companies accept their financial and social responsibility towards:
 - i) People moving into an area of development;
 - ii) Development of independent communities; and
 - iii) Local governments, including ensuring costs incurred by local government as a consequence of development are met through appropriate mechanisms.

Environmental

- s) Ensure that mining has minimal adverse impact on water resources and that the public are informed and consulted about any changes that affect the quality of water;
- t) Ensure that emissions from refining and processing of mineral products are subject to rigorous environmental and epidemiological reviews.

- u) Ensure that occupational health and safety standards (where workplace radiation levels occur above background levels) are pegged to those of the International Commission on Radiological Protection (ICRP); and
- v) Continue to monitor the performance of all areas of the industry where any possible radiation risk to the public, or workers, exists, and ensure that industry complies with the stricter of the Australian Codes of Practice, or international standards for the separation, storage, transport and processing of these minerals and disposal of any waste products.

ENERGY

271 WA Labor recognises the importance of the provision of energy for economic development and householders. The provision of energy needs to balance a range of interests such as sustainability, affordability, available resources and latest technology. WA Labor will develop and implement a plan to generate 20% of Western Australia's energy production from renewable energy resources by 2020.

272 To achieve this goal, WA Labor will:

- a) Maintain a renewable energy buy-back scheme to require electricity suppliers to purchase from individuals;
- b) Promote fuel switching, energy efficiency and green power purchases among domestic and commercial users;
- c) Continue community service obligations by the utilities;
- d) Ensure that government policy incorporates the principles of energy efficiency particularly in respect of commercial and domestic construction, urban planning and transport;
- e) Promote Western Australia as an international centre for research and development in energy technologies in both conventional and renewable sectors;

- f) Labor is committed to the long term future of the Collie coalfields as a source for base load electricity, until viable alternative base load energy sources become available. In this framework, Labor will ensure that the future of coal is developed within a framework using clean coal technology; and
- g) Maintain the Domestic Gas Reservation policy so that there is an oversupply of gas into the Western Australian domestic market. An oversupply of gas will lead to lower gas prices in the domestic market, and innovative uses of the gas, as has occurred in the United States in response to their domestic gas reservation policy.

ENERGY UTILITIES

273 WA Labor is committed to the public ownership of energy utilities, but will ensure that energy generation, transmission and distribution industries, whether publicly or privately owned, are independently regulated to provide a competitive market. WA Labor recognises the importance of reducing energy costs for business and householders as well as the need to retain natural monopolies as a publicly owned utility.

URANIUM MINING & NUCLEAR ENERGY

274 Recognising the problems, hazards and dangers of nuclear power, especially relating to:

- a) The safety of the nuclear fuel cycle;
- b) The unsolved problems pertaining to the reprocessing and storage of radioactive wastes and spent plant;
- c) The growing concern about the biomedical effects of even low radiation;
- d) The coupling of nuclear energy and nuclear weapon development;
- e) The added danger of a future plutonium economy and the threats to civil liberties involved in a nuclear economy; and
- f) The fact that Labor policy contained herein on fossil fuels, energy conservation and renewable resources will ensure Western Australian energy self sufficiency.

275 WA Labor will:

- a) Reject nuclear power as an option for electricity generation in Western Australia;
- b) Oppose the establishment of a nuclear enrichment facility in the State;
- c) Reject the establishment of nuclear processing plants or the storage of nuclear wastes in the State;
- d) Allow no uranium mining or development in Western Australia; and
- e) Place thorium under the restrictions and conditions applicable to the mining, processing, sale and transportation of uranium currently mined in Australia as outlined in the Resources and Energy section of the National Platform, so far as they relate to nuclear non-proliferation.

276 The platform recognises WA Labor's long and continuous opposition to Uranium Mining. The commencement and continuation of any uranium project is inconsistent with WA Labor Policy. WA Labor will accept no obligation to complete approval processes or honour contractual arrangements entered into by a previous government where such approvals or contracts are directed towards an outcome inconsistent with WA Labor's platform.

SUSTAINABLE RESOURCE AND INDUSTRIAL DEVELOPMENT IN OUR REGIONS

300 WA Labor recognises both the existing and potential contribution of the resources sector to the development of our regions and will work to attract new investment in major resource and industrial development projects.

301 WA Labor recognises that periods of rapid industrial expansion place strain on regional communities and is committed to minimising the negative impacts of such periods, for the benefit of local communities and all Western Australians.

302 WA Labor will undertake strategic planning for major resource and industrial development sites on a regional basis. Such planning should be undertaken within a sustainability framework that assesses potential sites according to:

303 Economic factors, including the direct and indirect economic and employment benefits to both the State and Regional economies and the cost of economic infrastructure required:

- a) Social factors, including the capacity of government agencies to deliver services, the potential of regional communities to meet employment and skill demand, the availability of residential housing, community attitudes to development and Aboriginal heritage issues;
- b) Environmental factors, using strategic level EPA assessments that identify all environmental issues and the appropriate industrial capacity of locations; and
- c) Labor will encourage major resource and industrial development projects to locate where there is the optimum balance of economic, social and environmental factors, as identified in the strategic planning process.

304 WA Labor will examine local government, environment, planning, regional development and other relevant legislation to assess the extent to which these permit forward strategic environmental assessment and planning for major resource and industrial development projects within our regions. Where possible, WA Labor will amend legislation to facilitate strategic plans, thereby facilitating efficient assessment processes for major resource and industrial development proposals that comply with these plans.

305 WA Labor will establish or commit to economic infrastructure required in designated development locations and industrial sites as early as is consistent with sound financial management.

306 WA Labor recognises that existing Commonwealth / State financial relations result in a disproportionate amount of direct financial benefits from resources projects accruing to the Commonwealth Government and the limitation this places on the State in providing

the economic infrastructure required to attract investment to our regions. WA Labor will campaign for a new deal on Commonwealth / State financial relations to enable greater investment by the State in economic infrastructure and the attraction of increased levels of investment in major resource and industrial development projects within our regions.

307 WA Labor will make all available data on environmental values (ranging from endangered species' habitats to the management plans for maintaining the ambient quality of air, land and water) from formal strategic environmental plans, regional surveys and regional environmental management plans publicly available, so that project proponents can develop their proposals consistent with achieving government sustainability objectives.

308 WA Labor will investigate the establishment of a fund to assist regional communities to participate in the environmental impact assessment of major projects.

309 As part of a major project proponent's development application, WA Labor will require the proponent to develop a sustainability statement that addresses the economic, social and environmental impacts of the project during the construction and operations phases and following site rehabilitation, in a manner that enables the government to assess the overall cost benefit to both the region and the State from a sustainability perspective. This statement should be released in parallel with any formal document released for public review under the Environmental Protection Act.

CHAPTER 9: INTERNATIONAL RELATIONS

ASIAN ENGAGEMENT: A WHOLE OF GOVERNMENT APPROACH

1 WA Labor will appoint a Minister for Asian Engagement, charged with overseeing the implementation of an Asian Engagement Strategy

2 Develop a whole of government Asian Engagement Strategy to guide economic diversification and create jobs. The strategy will address the following issues and initiatives:

- a) Support WA small and medium-sized businesses engage Asia to attract capital investment and exploit export opportunities;

- b) Subsidise Asian language training to public servants and consider a small allowance to those who achieve a recognised standard;
- c) Help to establish a dedicated centre for Asian Engagement by competitive tender at a WA university;
- d) Commit to sending WA government delegations to at least one Asian country every year aligned with the Asian Engagement Strategy priorities and ensure gender equity of these delegations;
- e) Require every government department to develop a “Supporting Asian Engagement Plan” and manage its implementation;
- f) Host an annual ASEAN Dialogue, concurrently with a trade and investment show, and Asian Arts Festival. In similar vein a WA Labor government will conduct an annual high-level dialogue with the Indian Ocean Rim Association (IORA) as well as pursue other numerous opportunities to hold regional trade, political, cultural and social forums in Perth and encourage other similar forums to take place across Western Australia;
- g) Establish an Asian exchange program that will assist with members of the government, not-for-profit, and private sector to engage with our Asian neighbours; and
- h) Fund leading arts companies to tour Asian cities; and support Asian arts companies in touring Western Australia.

Appendix B: GSWA maps, books and datasets released 2016–17

Geological maps

1:100 000 Geological Series maps

MEEKATHARRA, WA Sheet 2544 by *Romano, SS, Ivanic, TJ and Chen, SF*

THUNDELARRA, WA Sheet 2340 by *Zibra, I, Chen, SF, Ivanic, TJ, Li, J and Gu, P*

UAROO, WA Sheet 1952 by *Cutten, HN, Johnson, SP and de Souza Kovacs, N*

WONYULGUNNA, WA Sheet 2848 by *Thorne, AM and Blay, OA*

WOODLEY, WA Sheet 2642 by *Ivanic, TJ*

Non-series maps

Aboriginal land, conservation areas, mineral and petroleum titles and geology,
Western Australia — 2017 by *Ridge, KJ*

Iron ore deposits of the Pilbara region 2017 by *Cooper, RW*

Layered intrusions of the Youanmi Terrane, Yilgarn Craton by *Ivanic, TJ*

Major resource projects, Western Australia — 2017 by *Cooper, RW, Wyche, NL,
Strong, C, Day, LJ, Jones, JA and Irimies, F*

Mineral deposits and petroleum fields 2017 by *Cooper, RW, Wyche, NL, Strong, CA,
Day, LJ and Jones, JA*

Mines — operating and under development, Western Australia — 2017 by *Cooper,
RW, Strong, CA, Wyche, NL, Day, LJ and Jones, JA*

Plates

Geological interpretation of the Canning Basin along Canning Coastal seismic lines
14GA-CC1 and 14GA-CC2 by *Zhan, Y*

Geological interpretation of the Madura and Coompana Provinces along the Eucla–
Gawler seismic and magnetotelluric line 13GA-EG1 by *Spaggiari, CV, Dutch,
RA, Doublier, MP, Pawley, MJ and Thiel, S*

Interpreted regolith–landform geology of the Dambimangari area, west Kimberley by
de Souza Kovacs, N

Publications

Bulletins

Mineral Resources Bulletin 25 Gemstones of Western Australia second edition by
Fetherston, JM, Stockmayer, SM and Stockmayer, VC

Reports

- Report 158 Deposit-scale targeting for gold in the Yilgarn Craton: Part 3 of the Yilgarn Gold Exploration Targeting Atlas *by Witt, WK*
- Report 161 Geochronology from the Rudall Province, Western Australia: implications for the amalgamation of the West and North Australian Cratons *by Maidment, DW*
- Report 163 MRIWA Report Project M426: exploration targeting for BIF-hosted iron deposits in the Pilbara Craton, Western Australia *by Duuring, P, Teitler, Y, Hagemann, S and Angerer, T*
- Report 164 Geology of the eastern zone of the Lamboo Province, Halls Creek Orogen, Western Australia *by Phillips, C, Orth, K, Hollis, JA, Kirkland, CL and Bodorkos, S*
- Report 165 VMS mineralization in the Yilgarn Craton, Western Australia: a review of known deposits and prospectivity analysis of felsic volcanic rocks *by Hollis, S, Yeats, CJ, Wyche, S, Barnes, SJ and Ivanic, TJ*
- Report 166 Thermo-mechanical evolution of orogeny in the Musgrave Province *by Walsh, A*
- Report 167 The geology, tectonic evolution and gold mineralization of the Lawlers region: a synopsis to 2001 *by Beardsmore, T*
- Report 169 Petroleum source potential of the Ordovician Nambheet Formation, Canning Basin: evidence from petroleum well Olympic 1 *by Normore, LS and Dent, LM*
- Report 170 Assessment of thermal maturity using bitumen, graptolite and bioclast reflectance in the Ordovician Nambheet Formation, Olympic 1, Canning Basin *by Dent, LM and Normore, LS*
- Report 171 The volcanology, petrogenesis, and economic potential of the Mesoproterozoic shallow-water, intra-caldera, lava-like rheomorphic Kathleen Ignimbrite, west Musgrave Province, central Australia *by Medlin, CC*
- Report 172 Petrogenesis of the mafic–ultramafic intrusions of the Mesoproterozoic Giles Event, Musgrave Province, central Australia *by Seubert, REB*

Records

- Records 2016/1 Geological Survey work program for 2016–17 and beyond
- Record 2016/12 Komatiites and associated rocks of the Kalgoorlie–Leonora region *by Barnes, SJ, Mole, D, Wyche, S and Dering, G*
- Record 2016/13 13th International Ni–Cu–PGE Symposium, Fremantle, Australia: Abstracts *by Godel, B, Barnes, SJ, Gonzalez-Alvarez, I, Fiorentini, ML and Le Vaillant, M*
- Record 2016/14 Mineralogy of gold from the Paulsens and Mount Olympus deposits, northern Capricorn Orogen, Western Australia *by Hancock, EA and Thorne, AM*
- Record 2016/15 Regolith chemistry of the Dambimangari area, west Kimberley *by Morris, PA, Scheib, AJ and de Souza Kovacs, N*

- Record 2016/16 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: Beebyn deposit, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/17 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: Windarling iron camp, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/18 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: drillhole PK11DD001, Mt Richardson, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/19 Mapping iron ore alteration patterns in banded iron-formation using hyperspectral data: drillhole PK12DD001, Mt Richardson, Yilgarn Craton, Western Australia *by Duuring, P and Laukamp, C*
- Record 2016/22 Petrology and geochemistry of the Eoarchean Manfred Complex: origin and components *by Rowe, ML*
- Record 2017/2 GSWA 2017 Extended abstracts: promoting the prospectivity of Western Australia
- Record 2017/3 Provenance, depositional setting and regional correlations of the Ordovician Carranya Formation, Canning Basin *by Normore, LS*
- Record 2017/4 Geological reconnaissance of the southern Murraba Basin, WA *by Haines, PW and Allen, HJ*
- Record 2017/5 Canning Coastal seismic survey — an overview of the Canning Basin *by Zhan, Y*
- Record 2017/6 TARGET 2017, Perth, Australia: abstracts *by Wyche, S and Witt, WK*
- Non-series books*
- An Early Devonian fish fauna from an unnamed sandstone in petroleum exploration well Wendy 1, northern Perth Basin *by Martin, SK*
- Calendar 2017: Geological Survey of Western Australia
- Fieldnotes: A Geological Survey of Western Australia newsletter 2017 January issue 81
- Fieldnotes: A Geological Survey of Western Australia newsletter 2017 April issue 82
- Fieldnotes: A Geological Survey of Western Australia newsletter July 2016 number 79
- Fieldnotes: A Geological Survey of Western Australia newsletter October 2016 number 80
- GSWA guide to editing digital products 2017–18
- Petroleum prospectivity of State Acreage Release Areas L17-1, L17-2, L17-3, L17-4 and L17-5, Canning Basin, Western Australia
- Specifications for 3D models submitted to GSWA *by Murdie, RE and Lindsay, MD*
- WA unearthed series: A Paleozoic perspective of Western Australia *by Mory, AJ*

Western Australia atlas of mineral deposits and petroleum fields 2017

Datasets

Geological Information Series

East Yilgarn Geological Information Series 2017

Kimberley Geological Information Series 2017

Murchison Geological Information Series 2017

Western Capricorn Geological Information Series 2016

Data packages

Compilation of geochronology information, 2017

Compilation of WAROX data, 2017

GSWA Open Day 2017

Iron ore deposits of the Pilbara, 2017

Manganese deposits of the Pilbara and Capricorn regions, 2016

NAPE 2017

Olympic 1, 2017: Digital Core Atlas Series

Rocklea Inlier, 2016: 3D Geomodel Series

State Acreage Release May 2017

Virtual tour of the mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton

West Musgrave GIS 2017

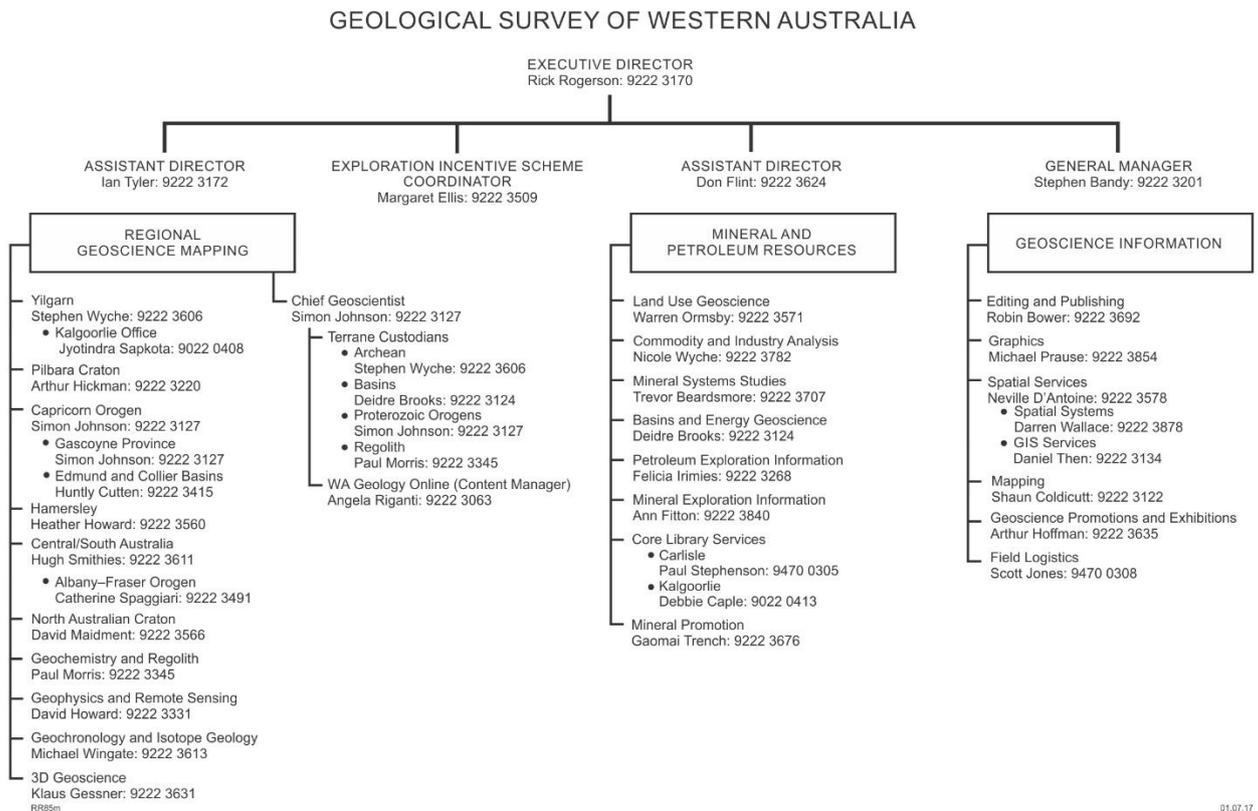
Explanatory Notes System

Murchison Explanatory Notes System 2017 (which is delivered online via ENS)

Posters

58 scientific posters

Appendix C: Organisational structure — 30 June 2017



01.07.17

Appendix D: GSWA external publications on Western Australian geoscience 2016–17

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- Donskaya, TV, Gladkochub, DP, Ernst, RE, Pisarevsky, SA, Mazukabzov, AM, Soderlund, U, **Wingate, MTD**, Hamilton, MA, and Demonerova, EI 2016, Age and geochemical characteristics of major mafic dyke swarms in the southern part of the Siberian craton: *Acta Geologica Sinica*, v. 90, p. 6–7.
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- Fielding, I**, **Johnson, SP**, Rasmussen, B, Muhling, JR, Dunkley, DJ, Zi, J, Sheppard, S and **Wingate, MTD** 2016, In situ SHRIMP geochronology to reduce the search area for orogenic gold exploration: 35th International Geological Congress, Capetown, South Africa.
- Gessner, K**, **Murdie, R**, Yuan, H, **Brisbout, L**, Sippl, C, **Tyler, I**, Kirkland, C, **Wingate, MTD**, **Johnson, S**, **Spaggiari, C**, **Smithies, RH**, **Lu, Y**, Gonzalez, C, Jessell, M, Holden, EJ, Gorczyk, W, and Occhipinti, S 2017, Continental geodynamics and mineral exploration — the Western Australian perspective: *Geophysical Research*

Abstracts, v. 19.

- Ghori, KAR** 2016, Shale petroleum resources of Western Australia: Australian Organic Geochemistry Conference, Fremantle, Western Australia, 4 December 2016.
- Ghori, KAR** 2017, Petroleum system modelling of the Perth Basin, Western Australia: AAPG Datapages/Search and Discovery Article #90217.
- Ghori, KAR** 2017, Petroleum systems modelling of the Perth Basin, Western Australia: American Association of Petroleum Geologists.
- Gladkochub, DP, Donskaya, TV, Ernst, RE, Pisarevsky, SA, **Wingate, MTD** and Soderlund, U 2016, Proterozoic Dyke Swarms of the Siberian Craton and Their Geodynamic Implications: *Acta Geologica Sinica (English Edition)*, v. 90 (supp. 1), p. 6–7.
- Guilliamse, JN** and **Beardsmore, TJ** 2017, Is there an unrecognised c. 1800 Ma mineral system in the northern Capricorn Orogen, Western Australia, *in* Future Understanding of Tectonics, Ores, Resources, Environment and Sustainability *edited by* JM Huizenga et al.: Economic Geology Research Unit, James Cook University, p. 50.
- Haig, DW and **Mory, AJ** 2017, Middle Permian (Roadian) Foraminifera from mudstone facies of the type Baker Formation, Southern Carnarvon Basin, Western Australia: *Journal of the Royal Society of Western Australia*.
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- Haines, PW**, Kirkland, CL, **Wingate, MTD**, **Allen, HJ**, Belousova, EA and Gréau, Y 2016, Tracking sediment dispersal during orogenesis: A zircon age and Hf isotope study from the Amadeus Basin, Australia: *Gondwana Research*, v. 37, p. 324–347.
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**Appendix E: Current collaborative research projects at 1 July
2017**

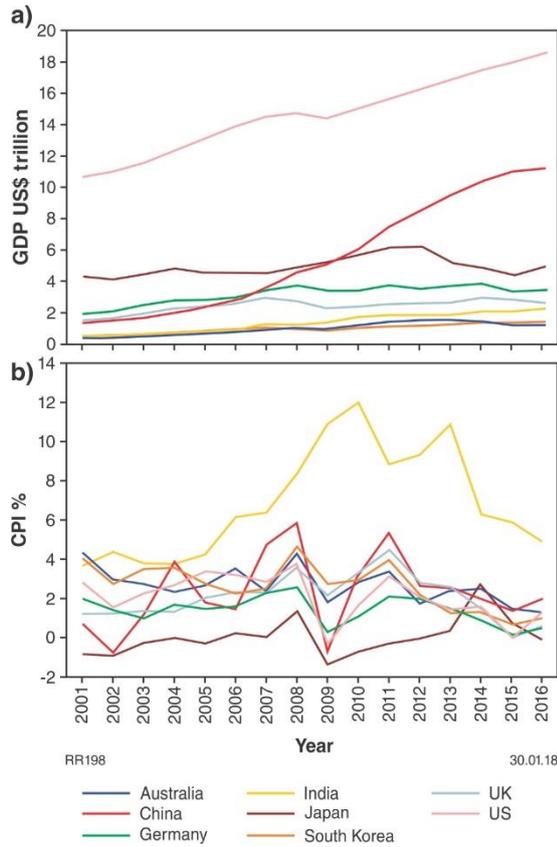
<i>Project cost centre</i>	<i>Collaborating entity</i>	<i>Project title</i>
ES31	ANU	ARC Linkage Project LP130100413: Craton modification and growth: The East Albany–Fraser Orogen in 3D
ES31	Centre for Exploration Targeting UWA	Fraser magnetotelluric survey
ES31	Geoscience Australia, Geological Survey of South Australia, AuScope Earth Imaging	Eucla–Gawler seismic, gravity and MT survey
ES31	MRIWA	M476: An integrated multi-scale study of crustal structure and prospectivity of the eastern Yilgarn Craton and adjacent Albany–Fraser Orogen
ES33	CSIRO	Eucla hydrogeochemistry of WA
ES33	MRIWA, CSIRO	MRIWA M462: Ultrafine fraction geochemistry
ES42	AMIRA – DET CRC	Deep Exploration Technologies Cooperative Research Centre
ES42	Centre for Exploration Targeting UWA, MRIWA	ARC Linkage Project LP100200785: Multiscale dynamics of ore-body formation - project extension through the MRIWA Project M424, multiscale dynamics of hydrothermal mineral systems
ES42 & ES46	Macquarie University, Curtin University and UWA	ARC Centre of Excellence CE11E0070: Core-to-crust fluid systems
ES43	Centre for Exploration Targeting UWA	Mapping sulfur sources in selected Precambrian terranes of Western Australia to enhance predictive targeting for gold and base metal mineralization
ES43	Centre for Exploration Targeting UWA	Predictive exploration for BIF-hosted Fe deposits in the Yilgarn Craton, Western Australia
ES43	Centre for Exploration Targeting UWA	ARC Linkage Project LP140100267: Reducing 3D geological uncertainty via improved data interpretation methods
ES43	CSIRO	Integrated spectral mapping of Au-hosted mineralisation, Nanjilgardy Fault
ES43	CSIRO, CET, Curtin	The distal footprints of giant ore systems: UNCOVER Australia project RP04-063
ES43	Northern Minerals Ltd, Curtin University	Geological studies of the Browns Range HREE mineralization
ES43 & ES31	Centre for Exploration Targeting UWA	Second generation regional targeting products: data generation and integration

ES43 & GS20	CRC for Metals Discovery – University of Tasmania	Yilgarn pyrite fingerprint database
ES43 & GS20	KalNorth Gold Mine	Provenance fingerprinting of gold from Kurnalpi Goldfield
ES43 & GS20	Northern Star Resources Ltd, Curtin University, UWA	Determining the age of gold mineralisation at the Paulsens mine, northern Capricorn Orogen, using monazite and xenotime geochronology
ES45	Centre for Exploration Targeting UWA	Stratigraphic contact analysis tool
ES45	Macquarie University (Sandra Piazzolo)	Yalgoo Dome structural project
ES45	MRIWA, Curtin University, CET (Chris Kirkland)	MRIWA M470: Mineral systems of the margin of cratons: Albany–Fraser Orogen/Eucla Basement case study
ES45	Uni of Sydney (Associate Professor Derek Wyman)	ARC Linkage Project: LP130100722: Earth's best-preserved Archean boninites: do they finally resolve the Archean mantle plume – plate tectonics controversy?
ES45	Johannes Gutenberg University Mainz, Germany (Prof Cees Passchier)	Narryer Terrane structural project
ES45	UWA (Tony Kemp)	Narryer Terrane isotopes project
ES46	Curtin University	ARC Linkage Project LP130100922: Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: providing a framework for understanding mineralizing systems
ES46	Curtin University (Chris Kirkland)	Crustal evolution of Western Australia
ES46	Curtin, MRIWA, Thermo Fisher Scientific	MRIWA M446: 4D Evolution of WA ore systems: Re-Os sulfide geochronology
ES46	Curtin, MRIWA, Thermo Fisher Scientific	MRIWA M448: 4D evolution of WA Ore systems: rutile pathfinder to ores
ES46	John de Laeter Centre	Contribution to funding for Centre Directorate
ES47	Frogtech Geoscience	SEEBASE project — Canning Basin
ES47	Geoscience Australia	Seismic reprocessing project — Canning, Carnarvon and North Perth Basins
ES50	AMIRA	AMIRA UNCOVER stage 2: Unlocking Australia's hidden mineral potential, Stage 2: Implementing the roadmap findings. AMIRA P1162A
ES50	CSIRO (Steve Hollis)	Volcanic hosted massive sulphide (VHMS) exploration in the Yilgarn Craton
GS20	Centre for Exploration Targeting UWA	Yilgarn gold exploration targeting atlas
GS53	National Geographic Society, Cambridge Uni	First footfall - the colonization of land

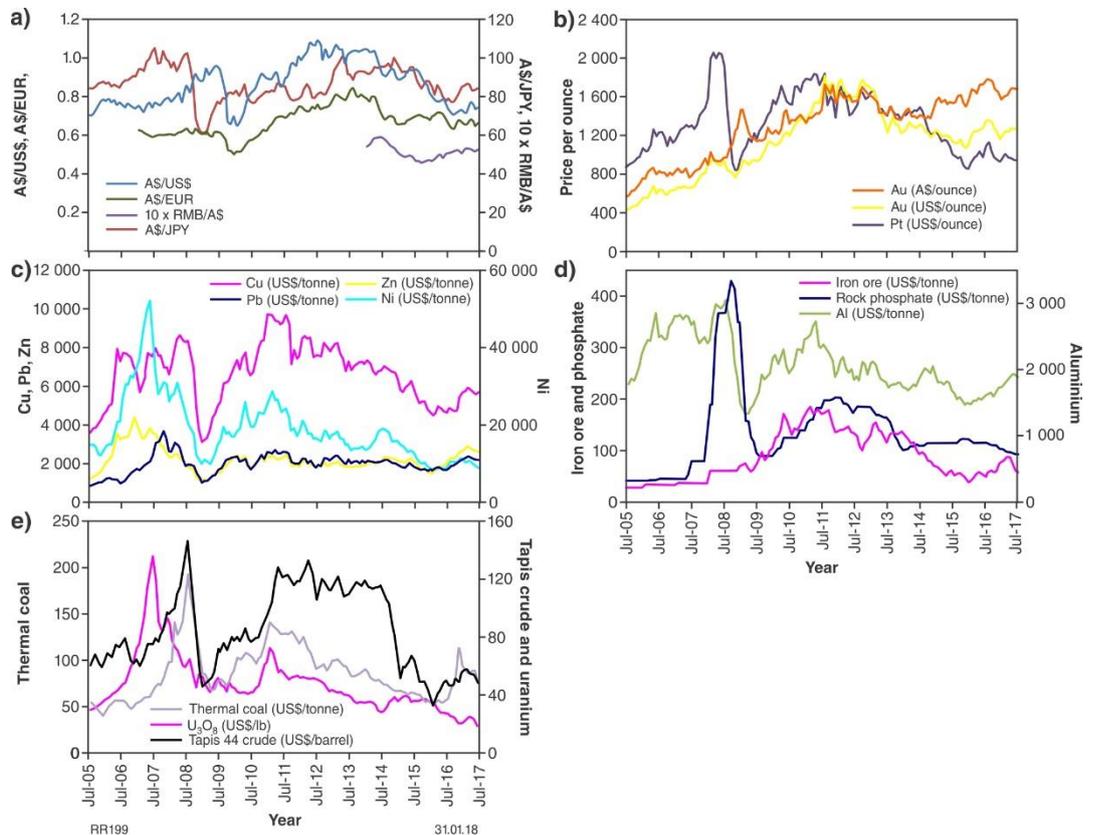
GS61	Curtin University	Geological studies of gabbroic rocks intruding the Arid Basin
GS95	Auscope with NCRIS funding, CSIRO	Virtual Core Library project - Auscope Agreement
KS02	UTAS (Dr. K Orth)	Paleoproterozoic mafic magmatism of the Kimberley Basin, Western Australia

Figures

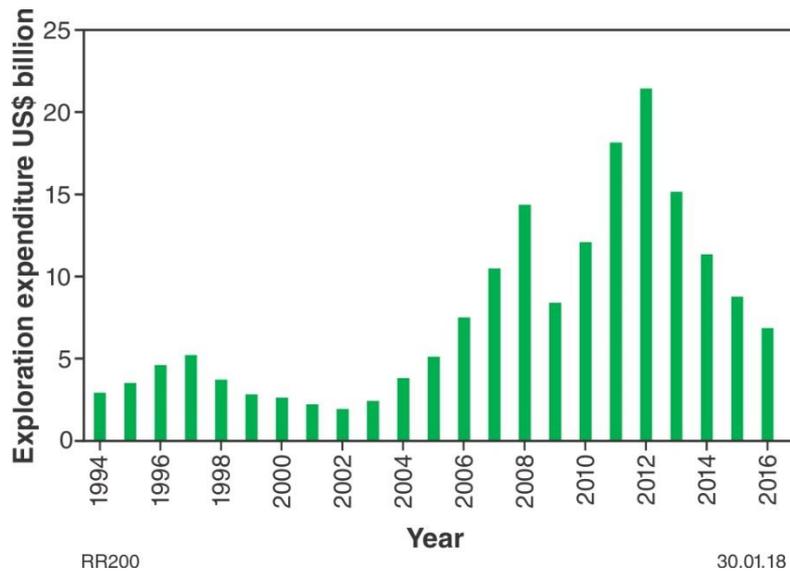
1. World economic volatility



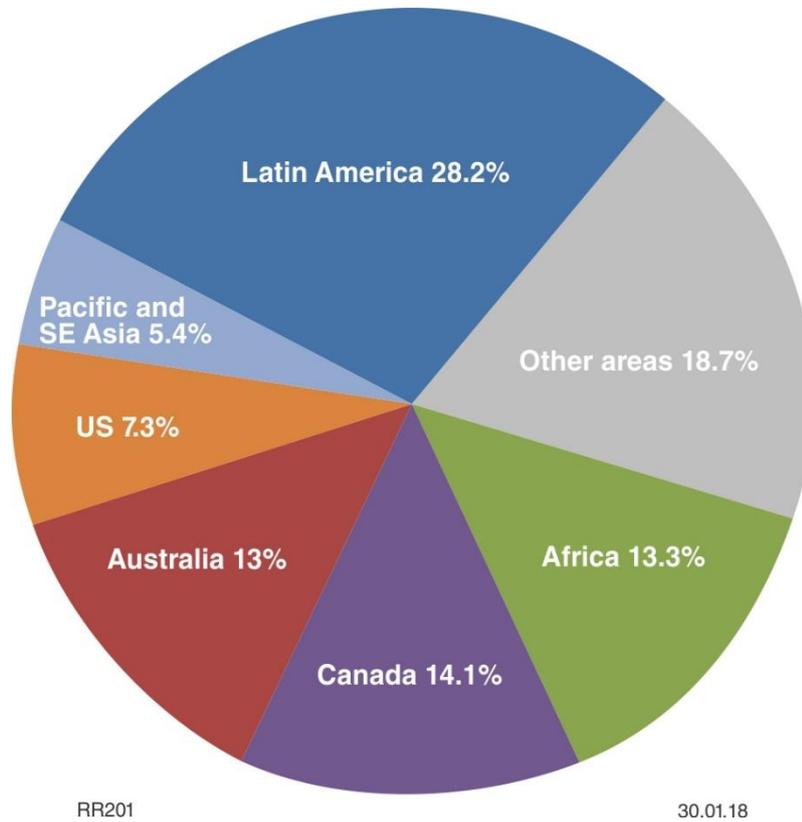
2. Average monthly commodity prices — July 2004 to June 2017 (dollars of the day)



3. Global exploration budgets 1994–2016

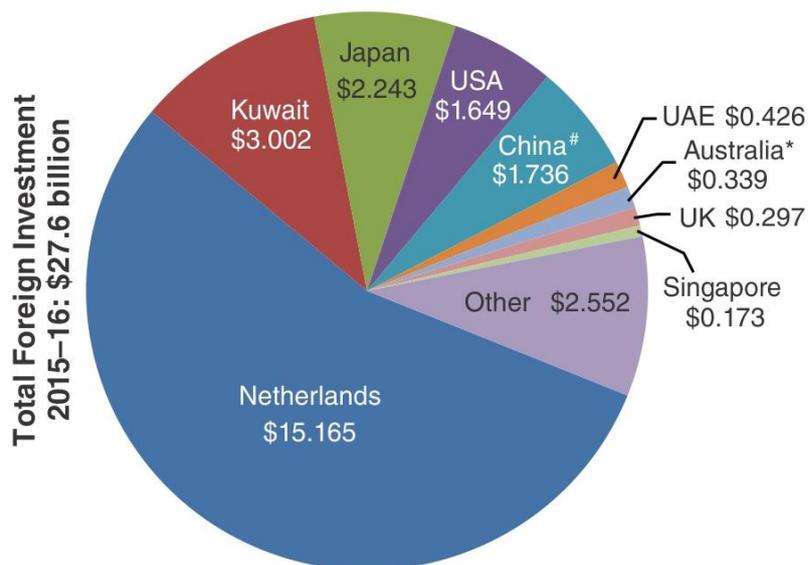


4. Worldwide non-ferrous exploration budgets by country or region for 2016



5. Sources of foreign investment into Australia's resource sector for 2015–16

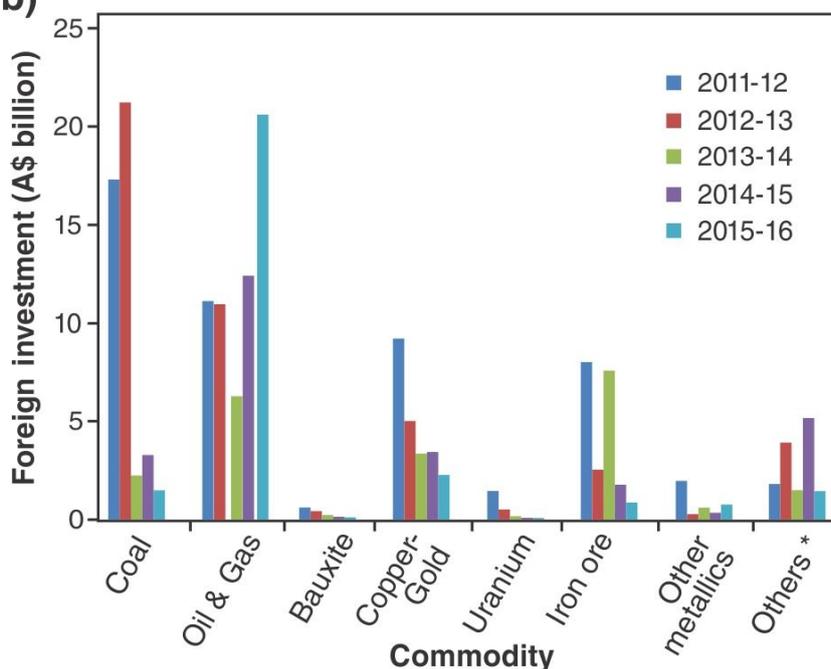
a)



* Investment by Australian investor with overseas partner or existing Chinese investor in Australia making additional investment.

[#] Includes Hong Kong

b)

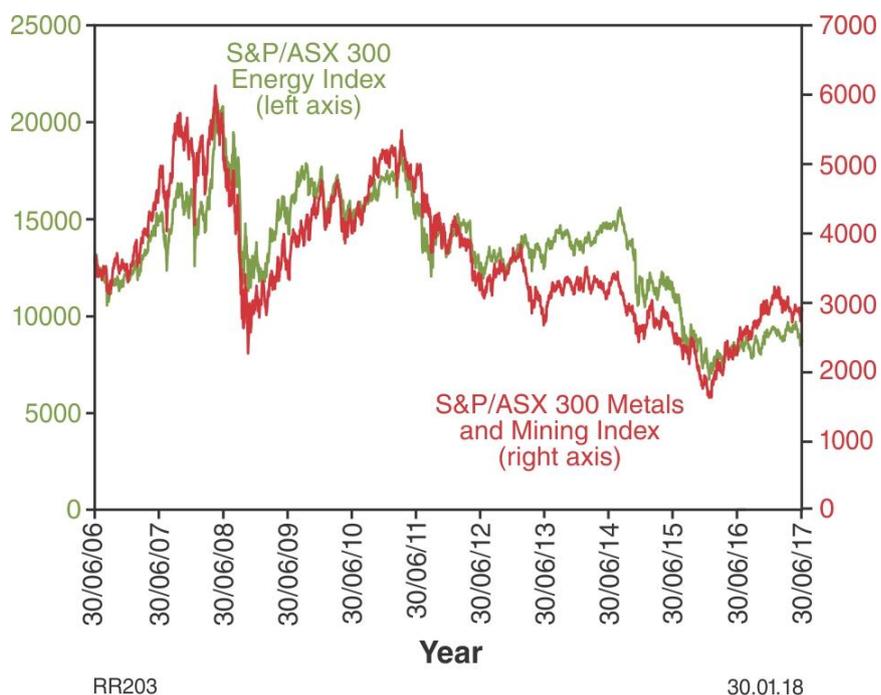


* Exploration and other support services; and other non-metallic minerals mining and quarrying

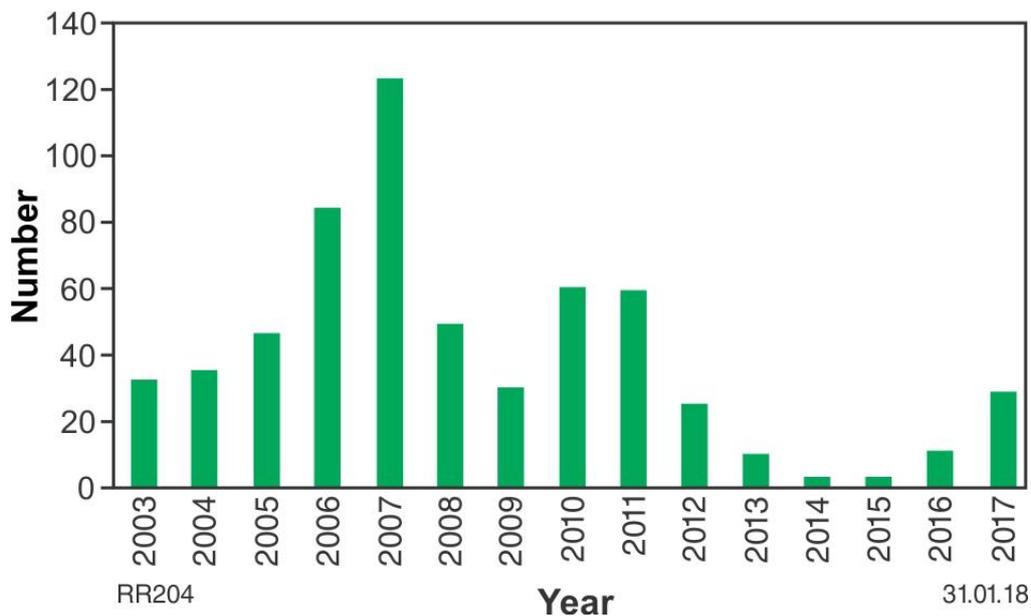
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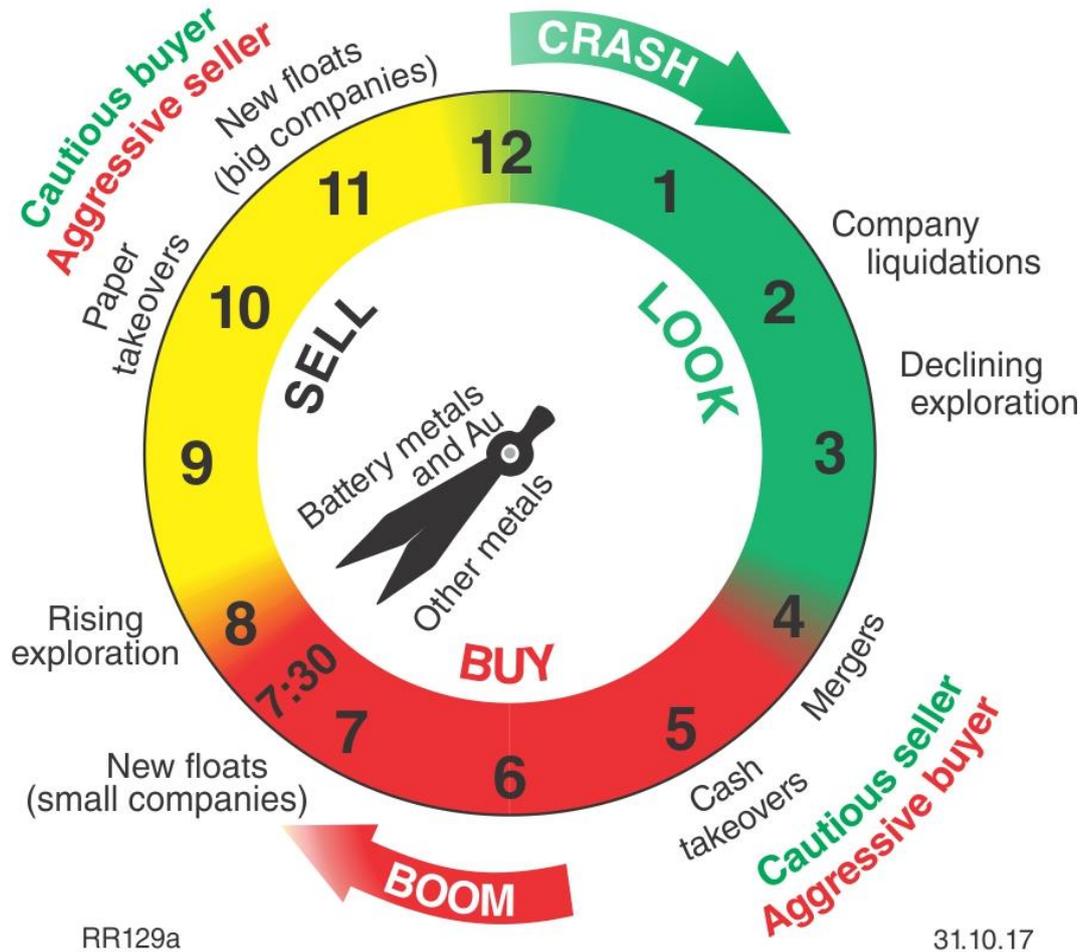
6. Metals and Mining Index and Energy Index — July 2006 to June 2017



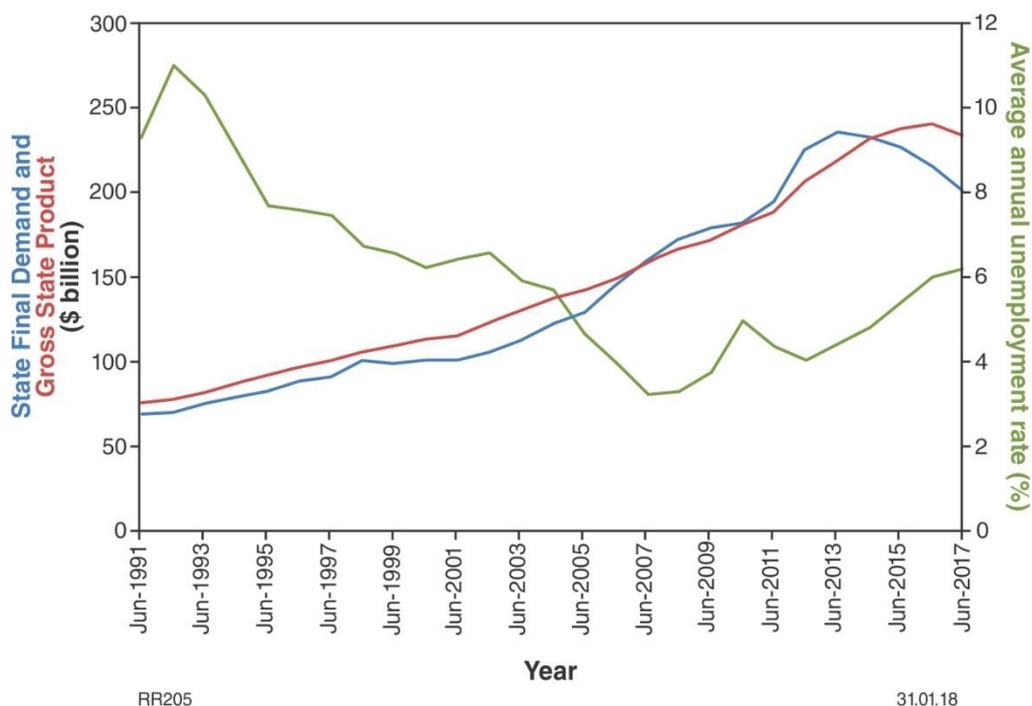
7. Mineral IPO (including coal) on the ASX by calendar year



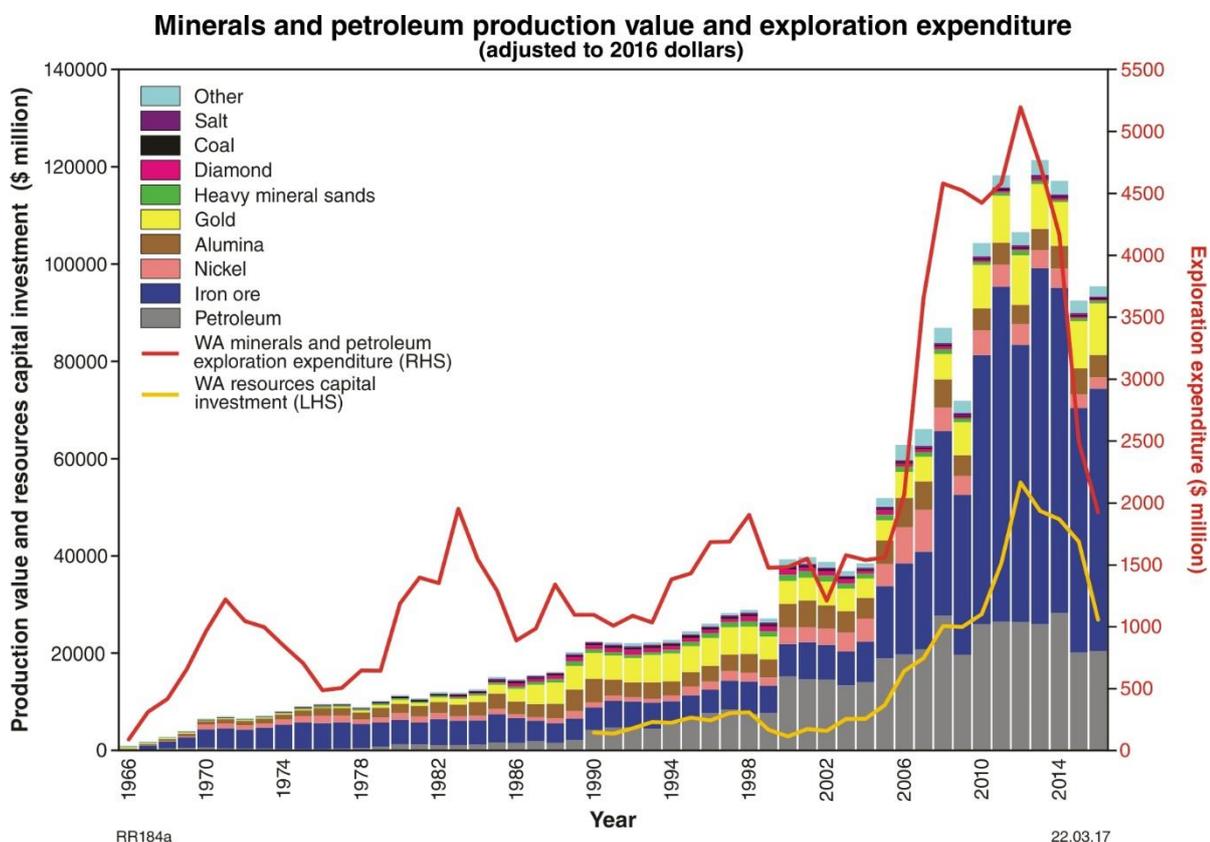
8. Lion Selection Group's well-known Widdup Cycle



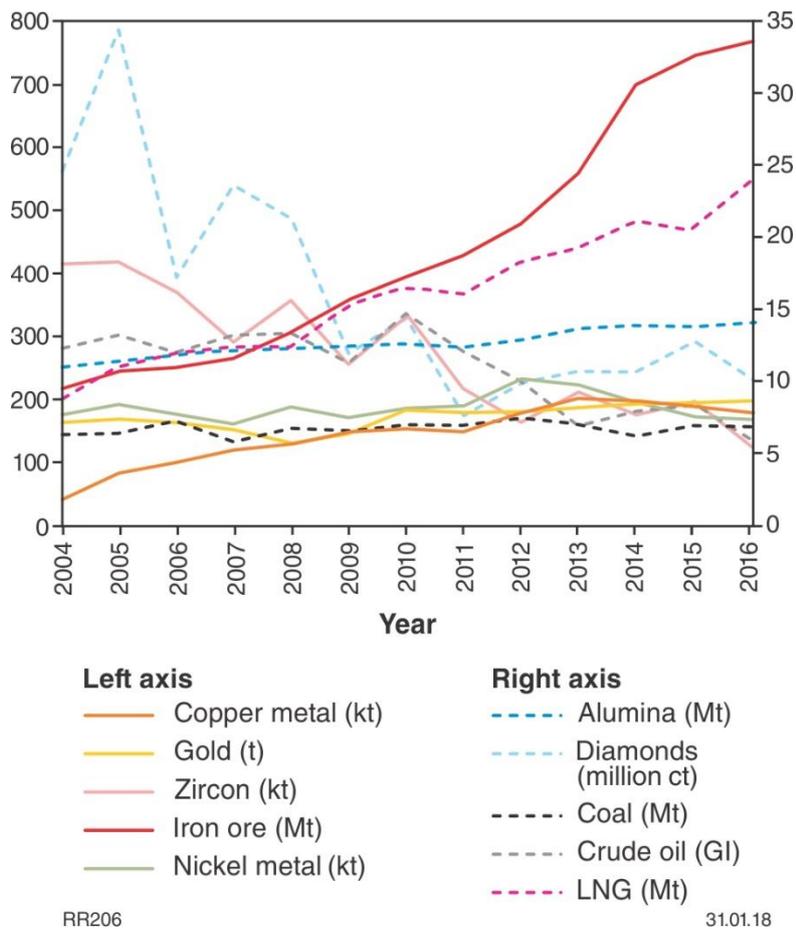
9. Macro-economic indicators and unemployment statistics for WA — June 1990 to June 2017 financial years



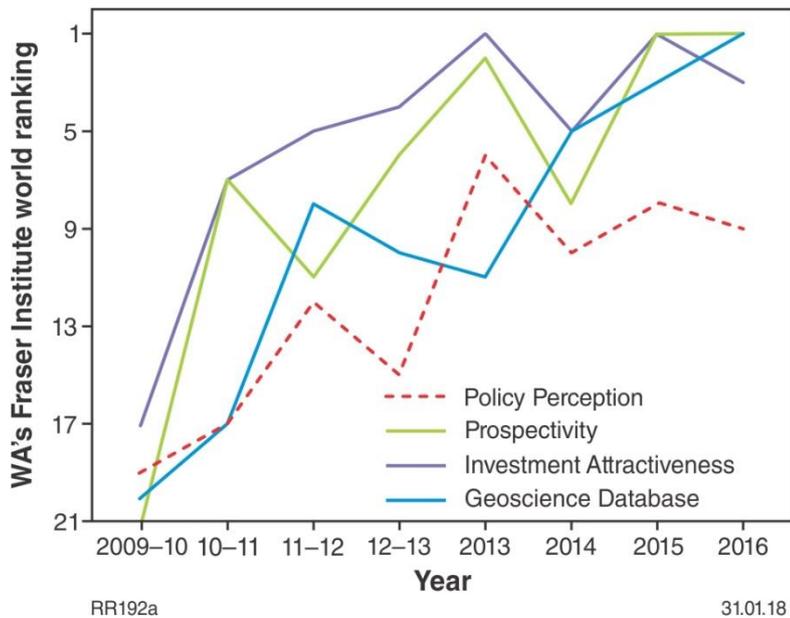
10. The three resources cycles in WA (2016)



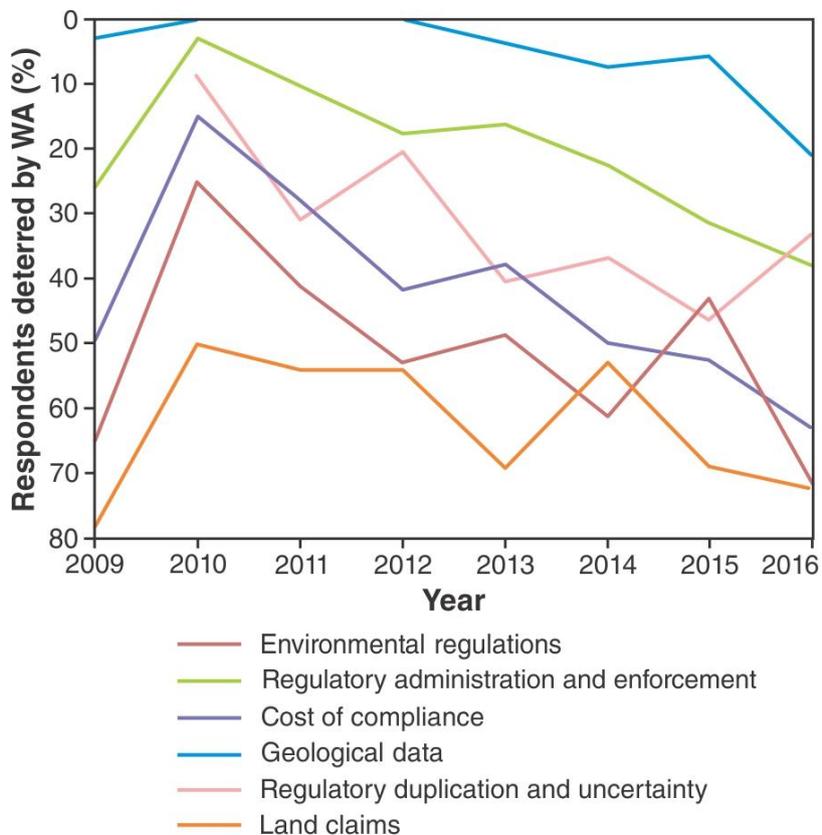
11. WA production quantity for major commodities 2015–16



12. WA's trend in the Fraser Institute's three critical mineral investor perceptions categories



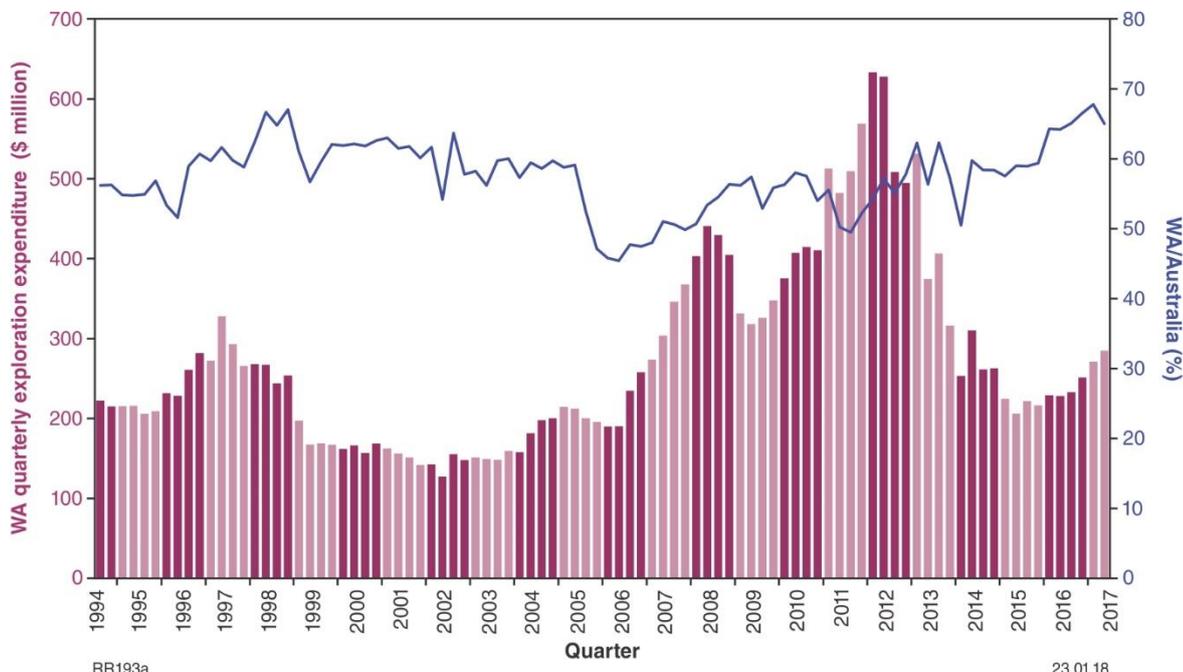
13. Selected factors contributing to Fraser Institute's petroleum PPI for WA



RR207

31.01.18

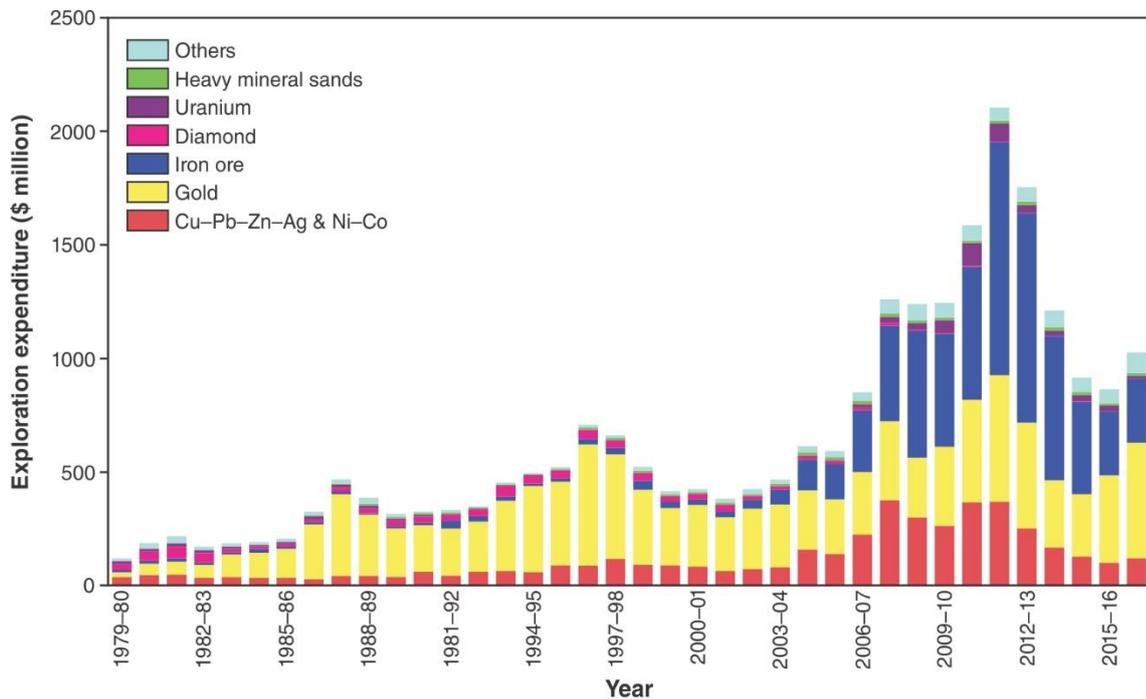
14. Quarterly mineral exploration expenditure in WA



RR193a

23.01.18

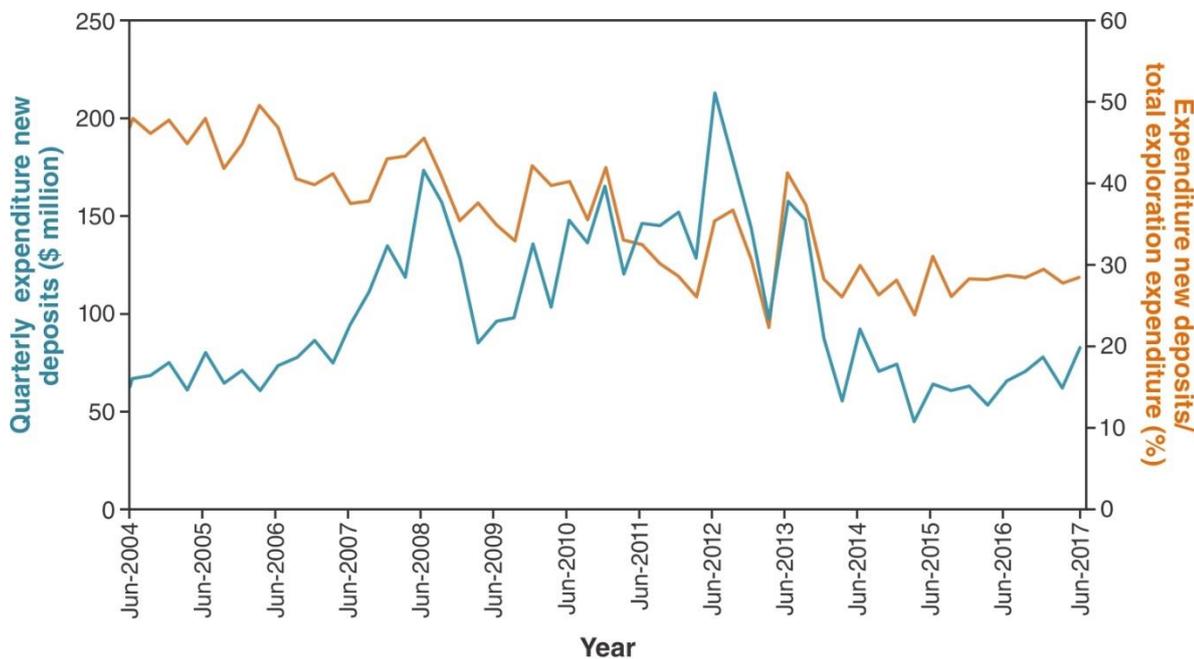
15. Exploration expenditure in WA by financial year by commodity



RR194a

23.01.18

16. Greenfields mineral exploration expenditure in WA

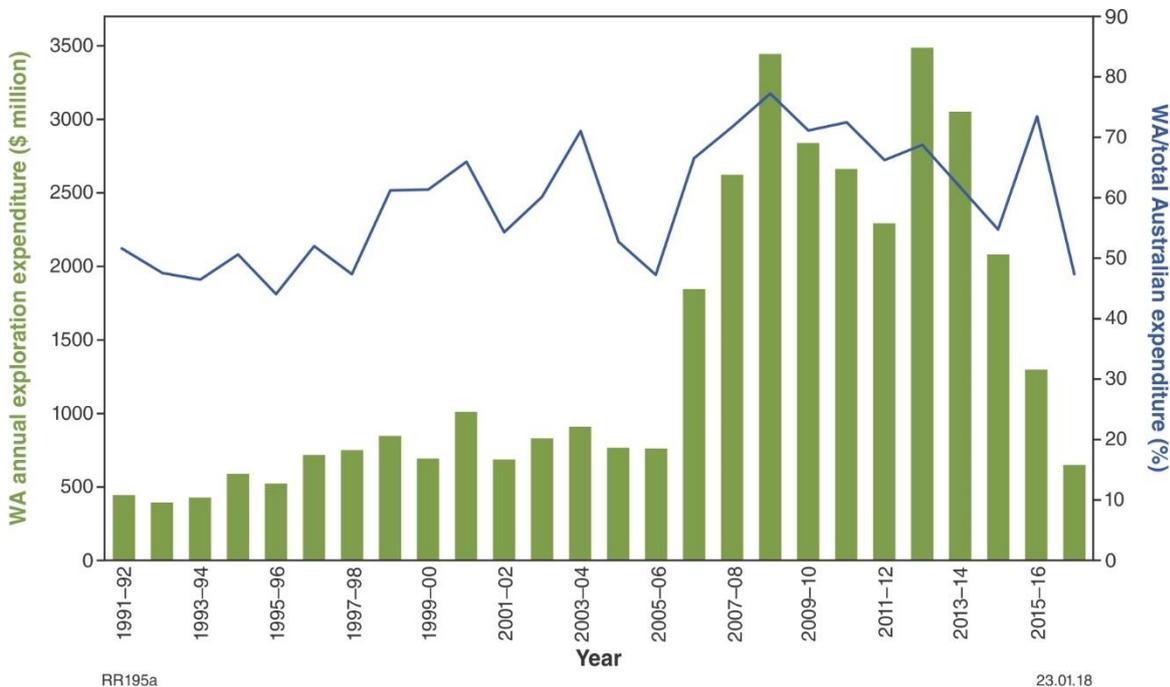


RR208

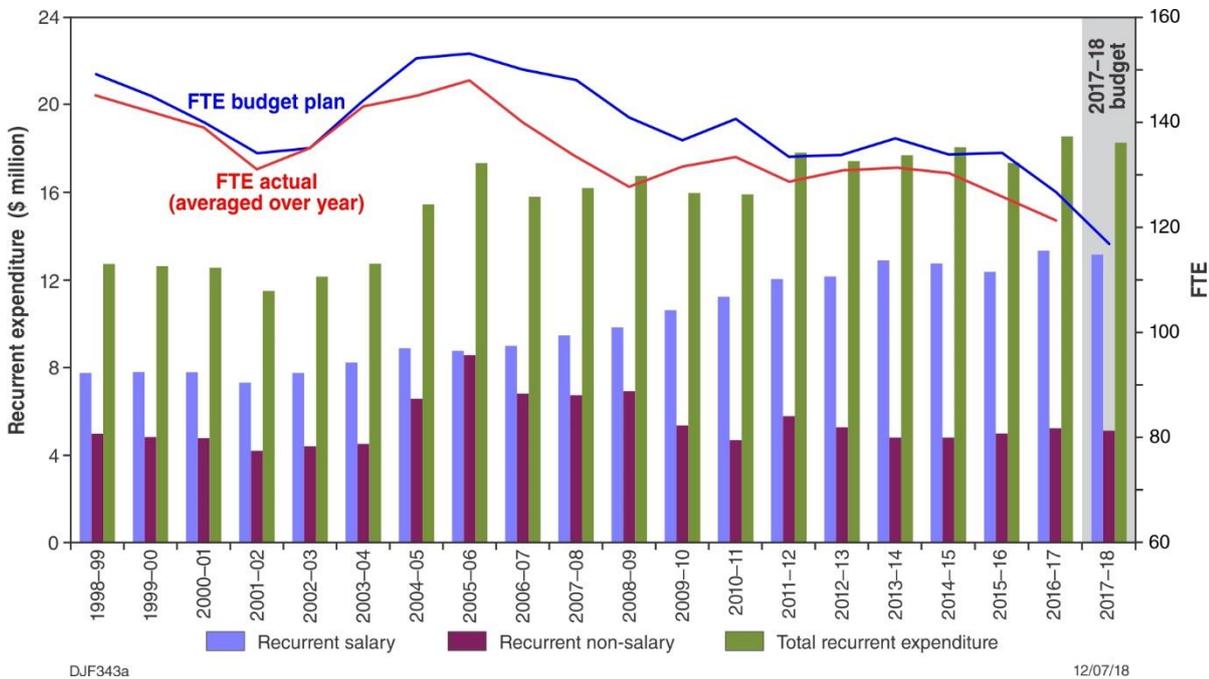
31.01.18

17. Annual petroleum exploration expenditure in WA and adjacent

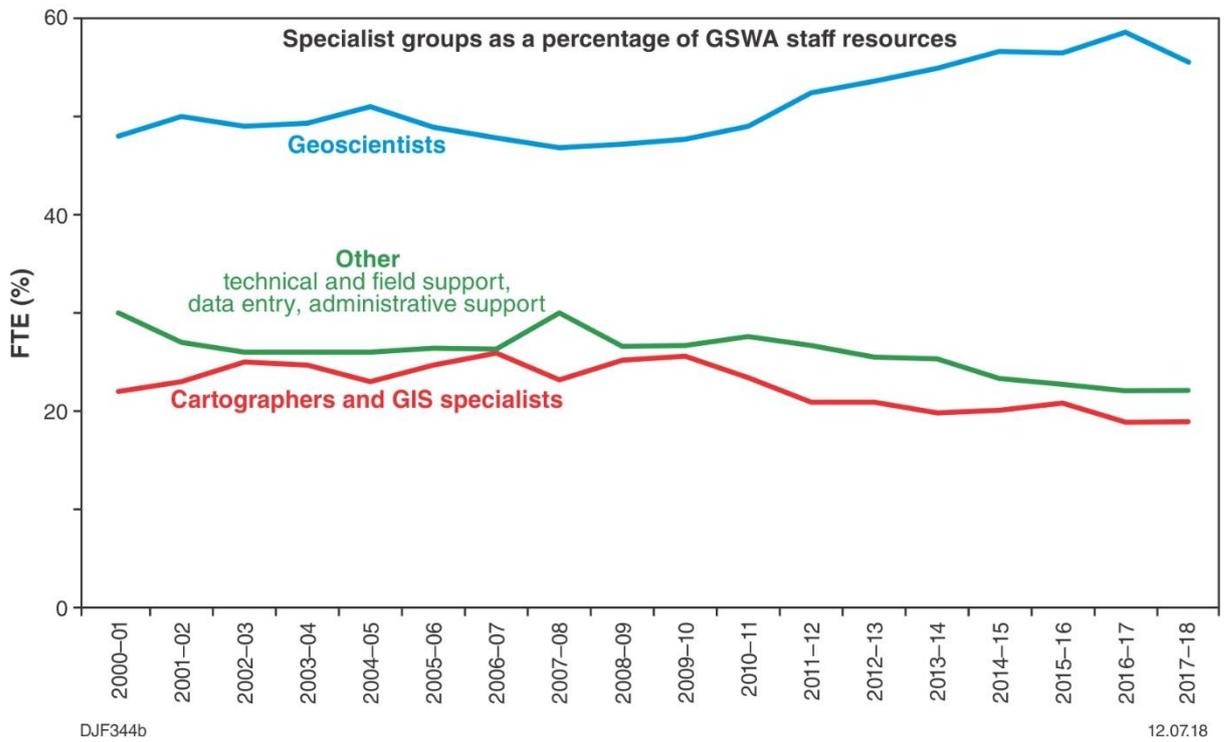
Commonwealth Waters



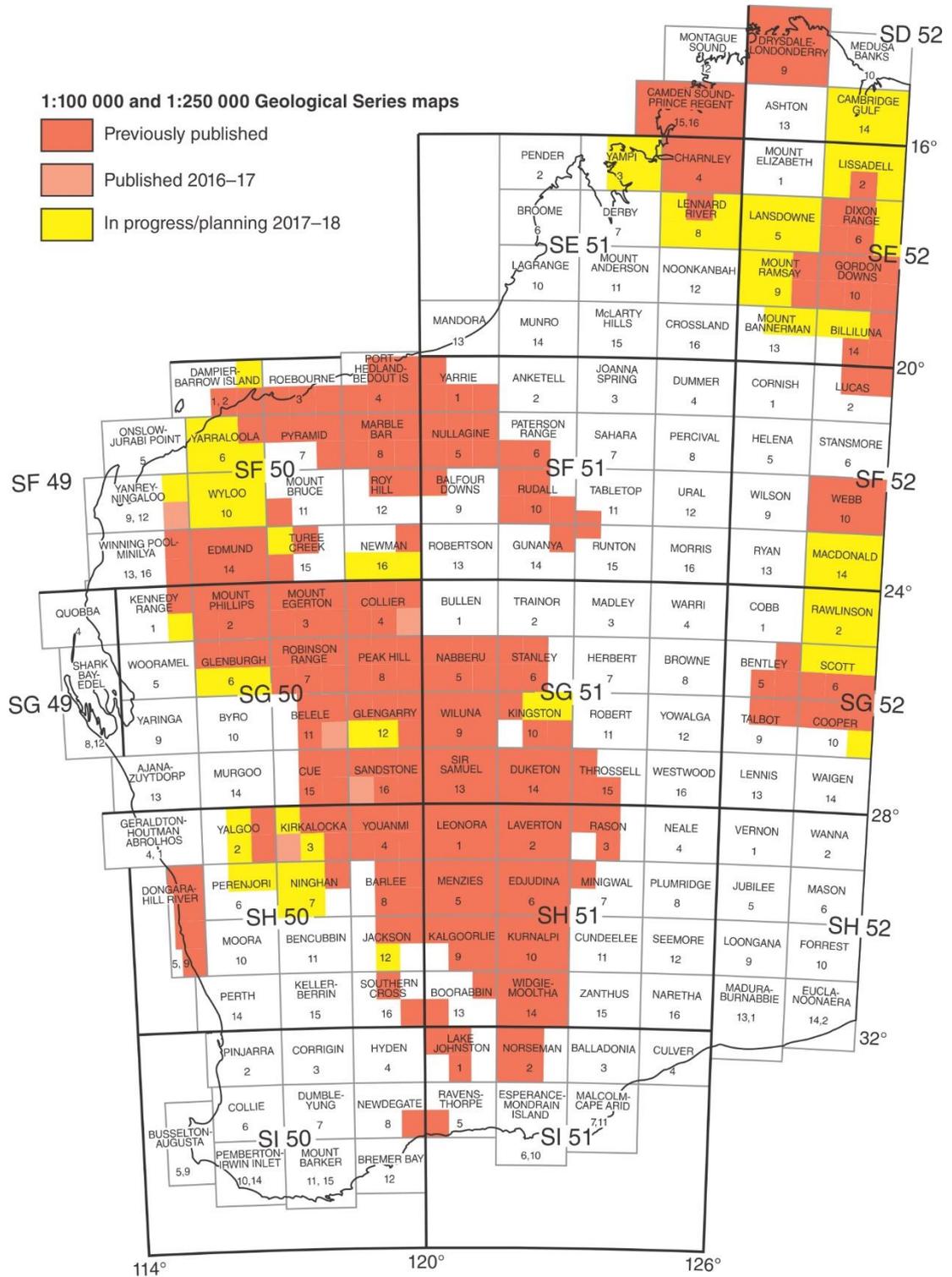
18. Long-term trends in GSWA's recurrent salary and non-salary expenditure



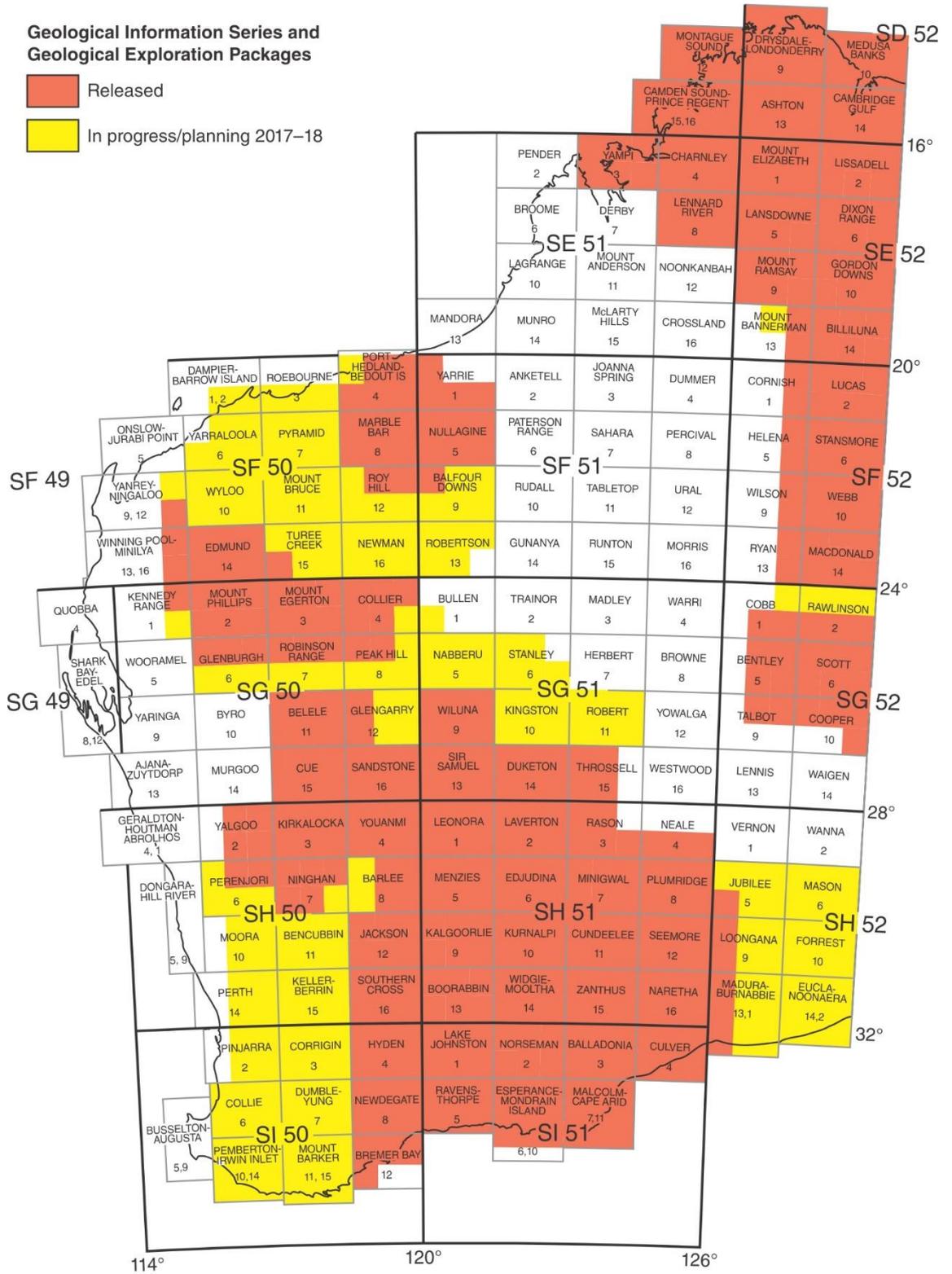
19. Specialist groups as a percentage of GSWA staff resources



20. Index map showing 2017–18 planned achievements — 1:100 000 Geological Series maps



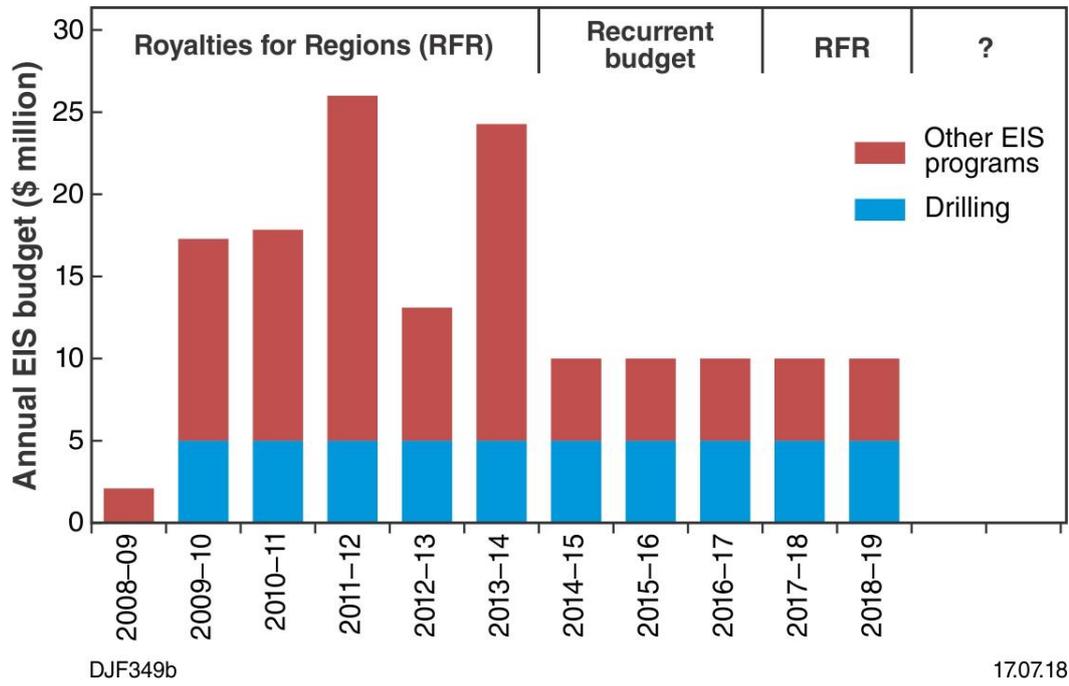
21. Index map showing 2017–18 planned achievements — 1:100 000 Geological Information Series (GIS) and Geological Exploration Packages (GEP)



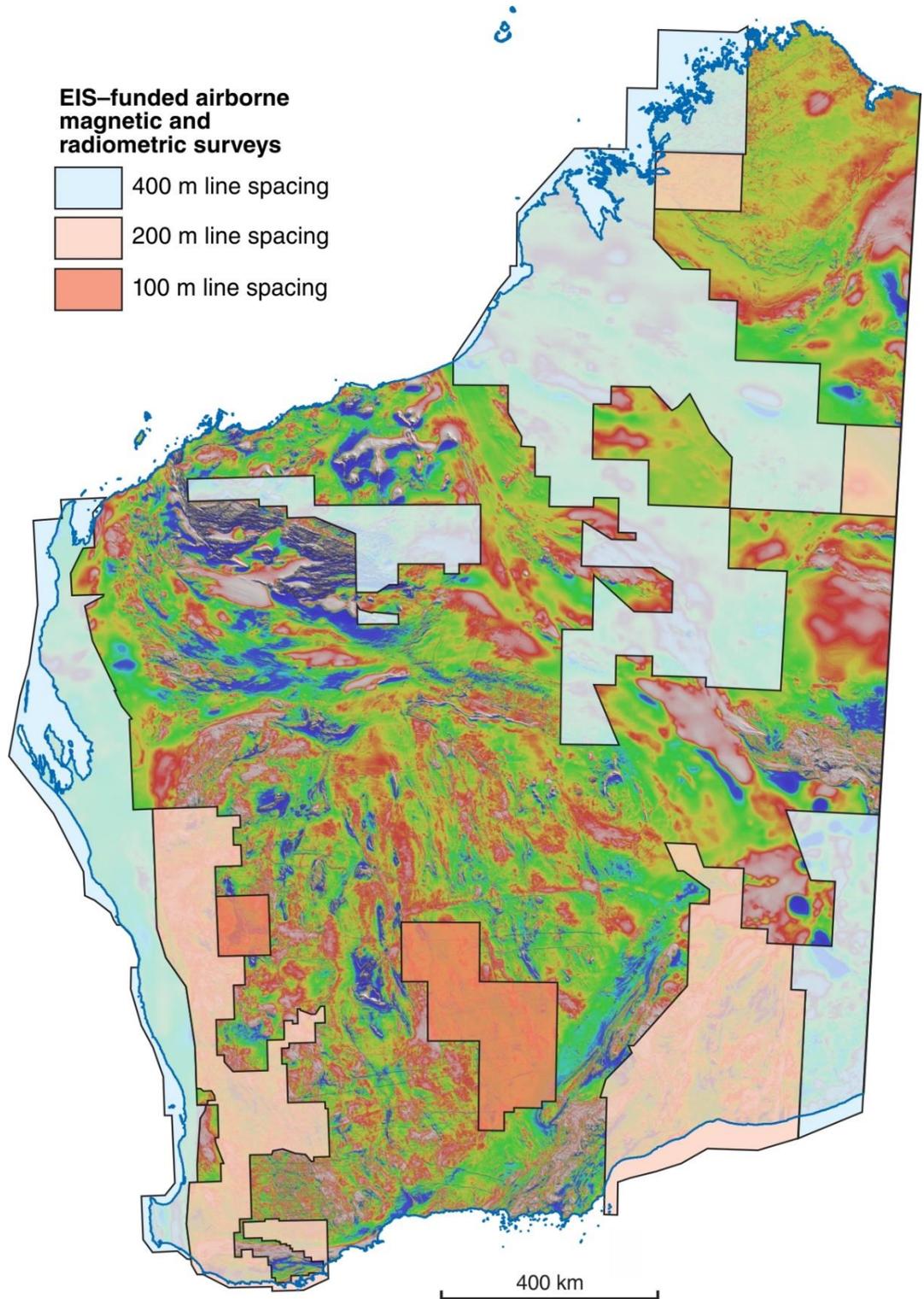
IMT176g

12/07/18

22. EIS budgets since 2008–09



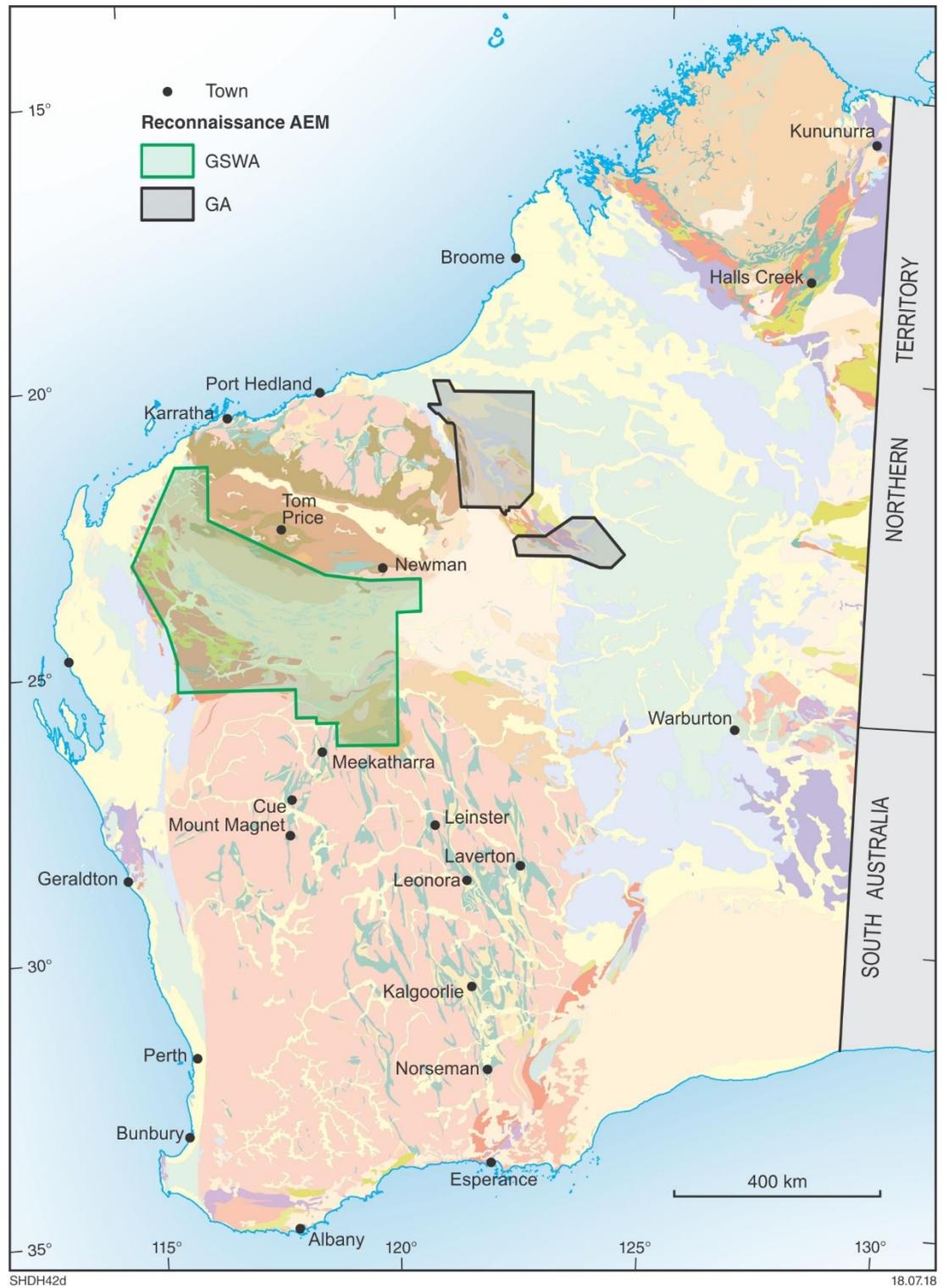
23. EIS-funded airborne magnetic and radiometric surveys



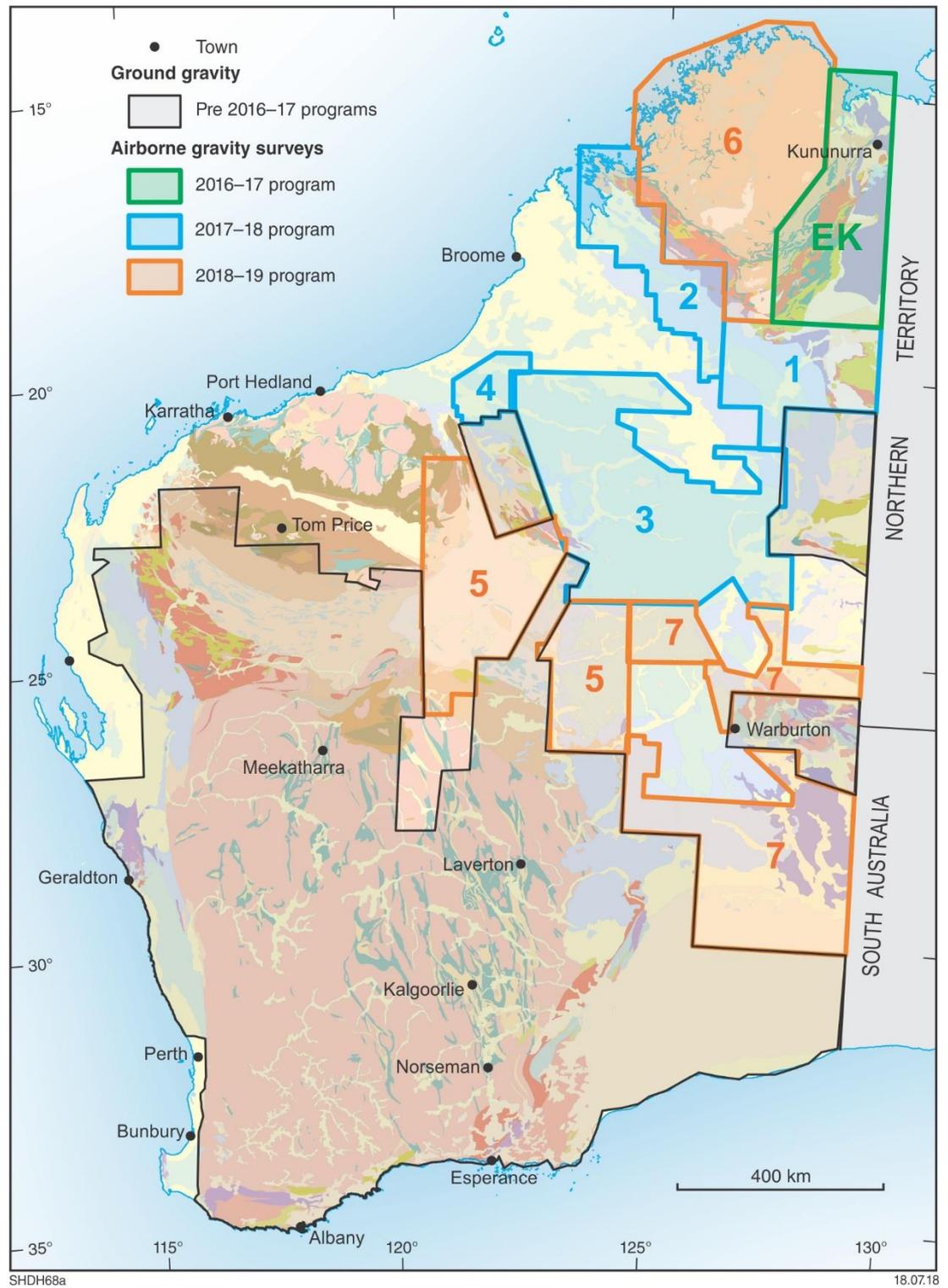
SHDH40b

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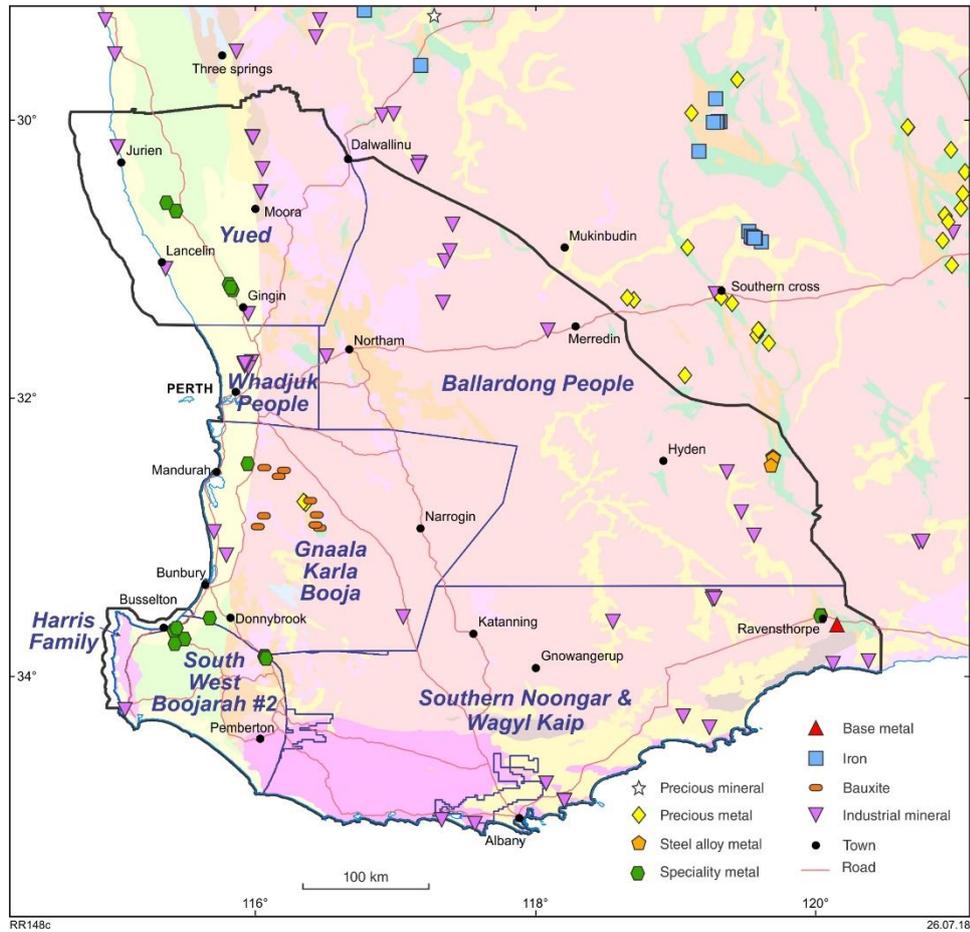
24. EIS-funded airborne electromagnetic surveys



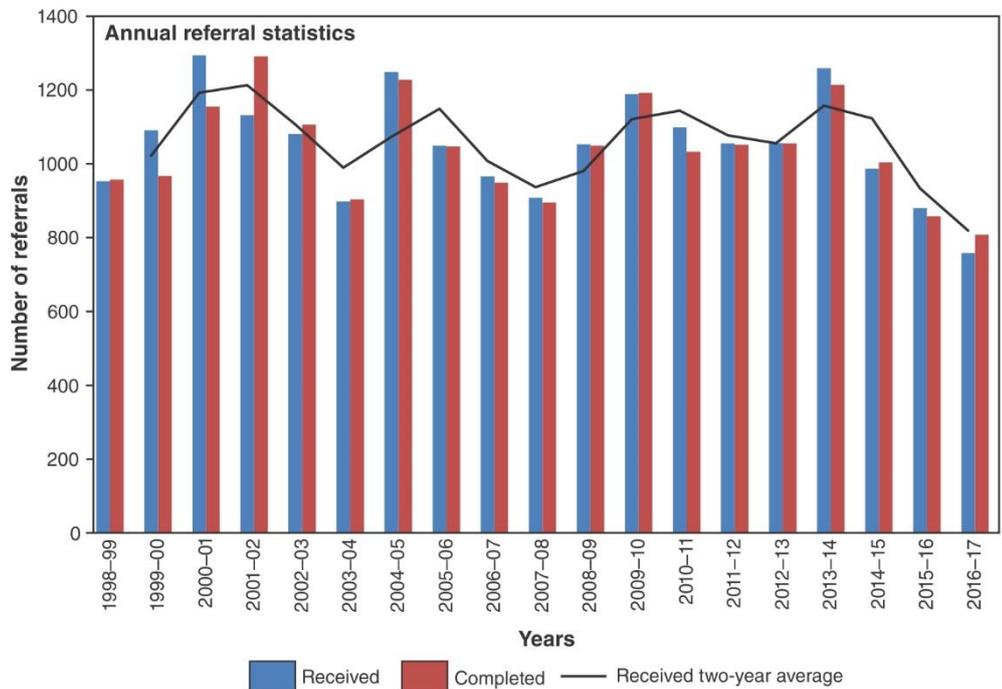
25. EIS-funded ground and airborne gravity surveys



26. South West Settlement project — location map



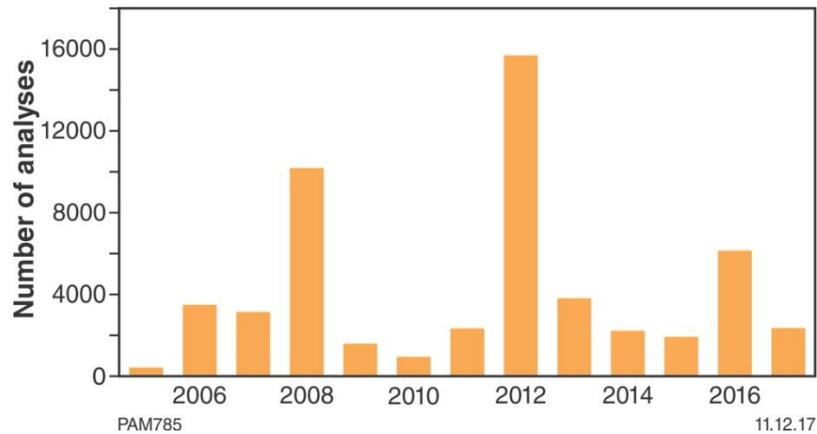
27. Land Use Geoscience section — annual referral statistics



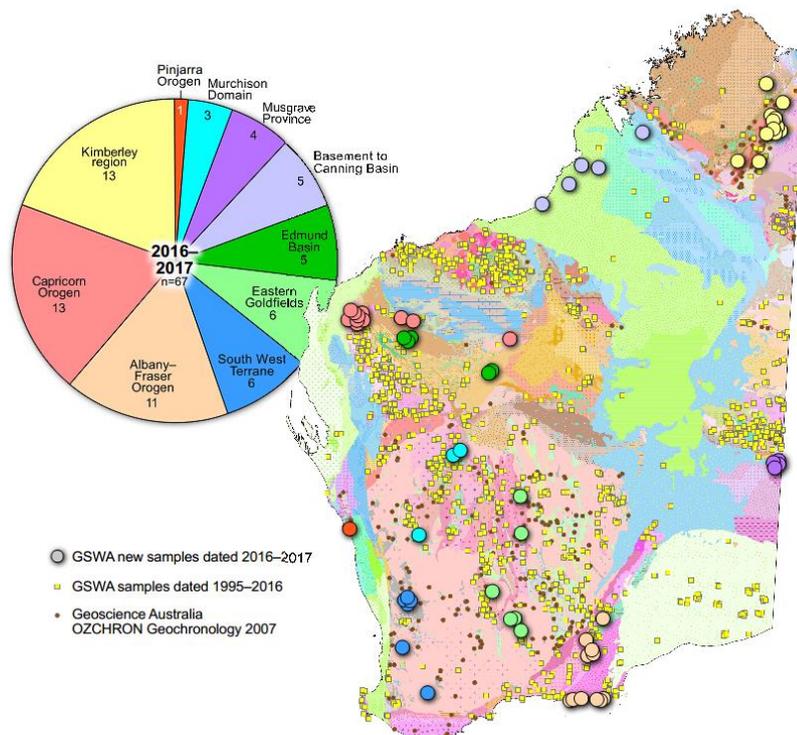
DJF360

29.05.18

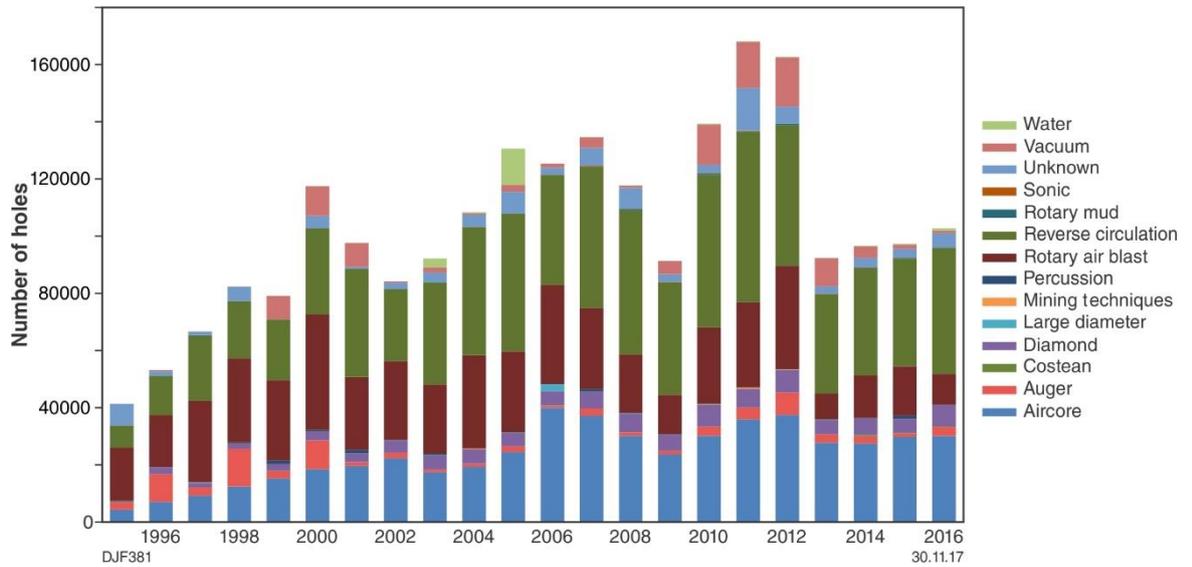
28. Histogram of samples loaded into the WACHEM database since its inception in 2005. The high number of samples in 2008, 2012, and 2016 correspond to importing of legacy data, the results of GSWA's 1994–2001 regolith geochemistry program, and analyses from the Albany–Fraser, Eastern Goldfields, and regolith geochemistry programs respectively



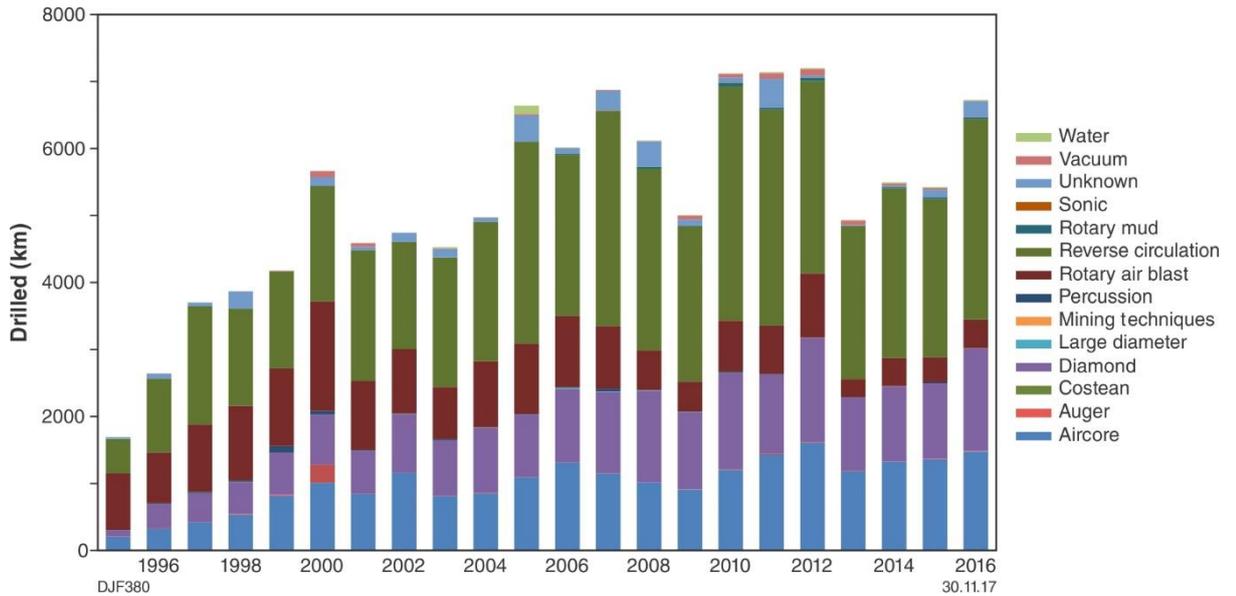
29. Geographical and tectonic distribution of GSWA samples analysed by SHRIMP ion microprobe



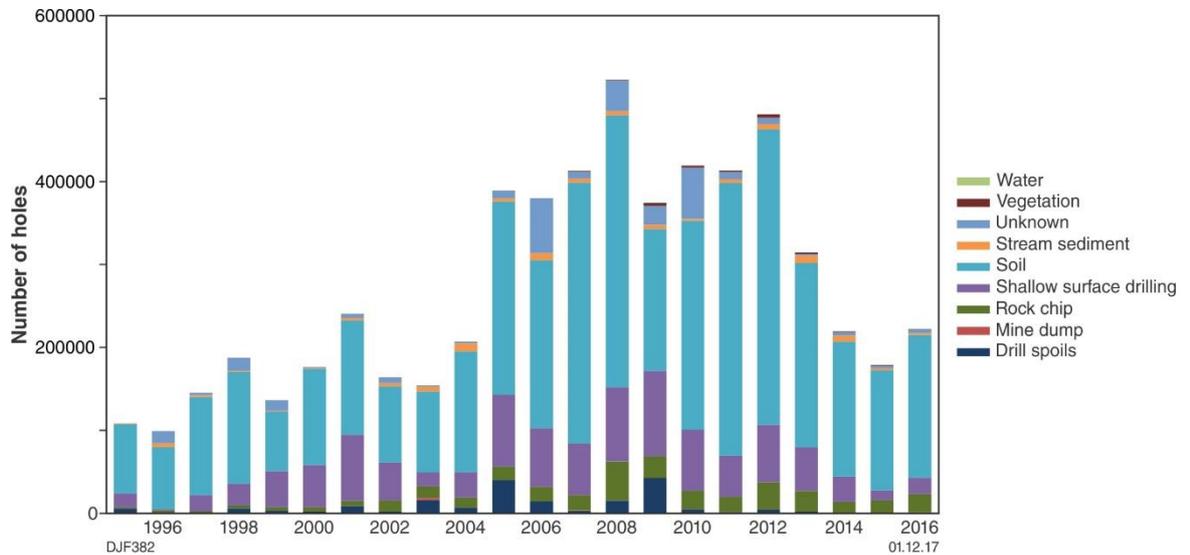
30. Drillhole database: number of drillholes recorded, by year of drilling and drilling type



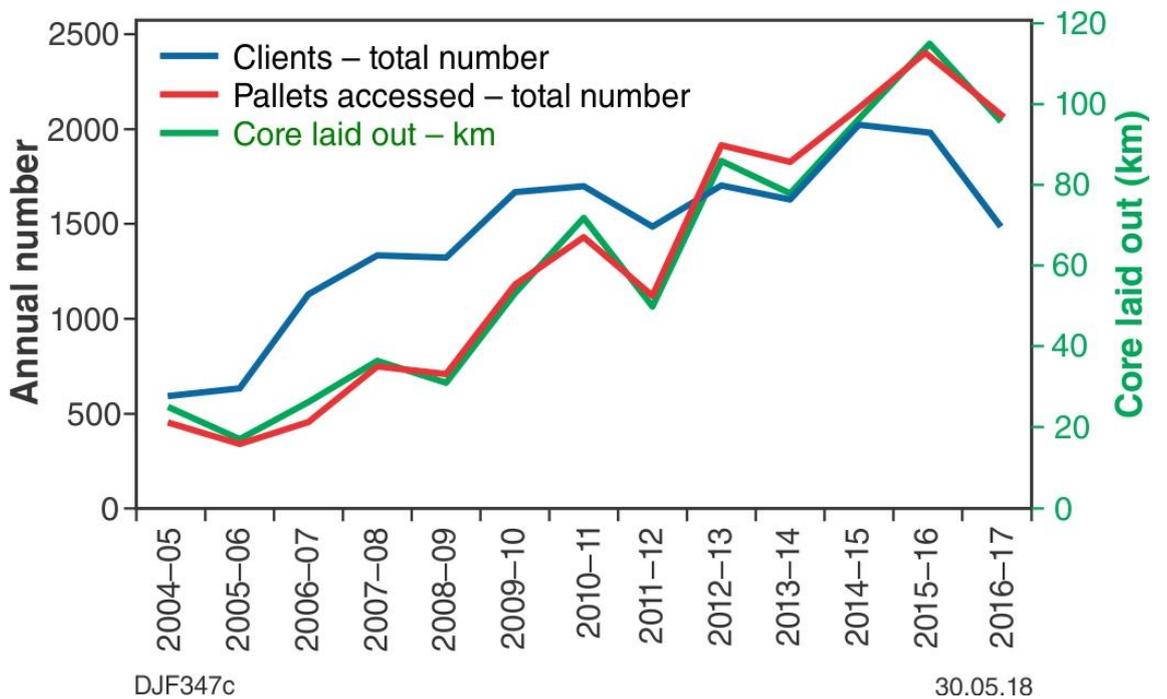
31. Drillhole database: amount of metres drilled, by year of drilling and drilling type



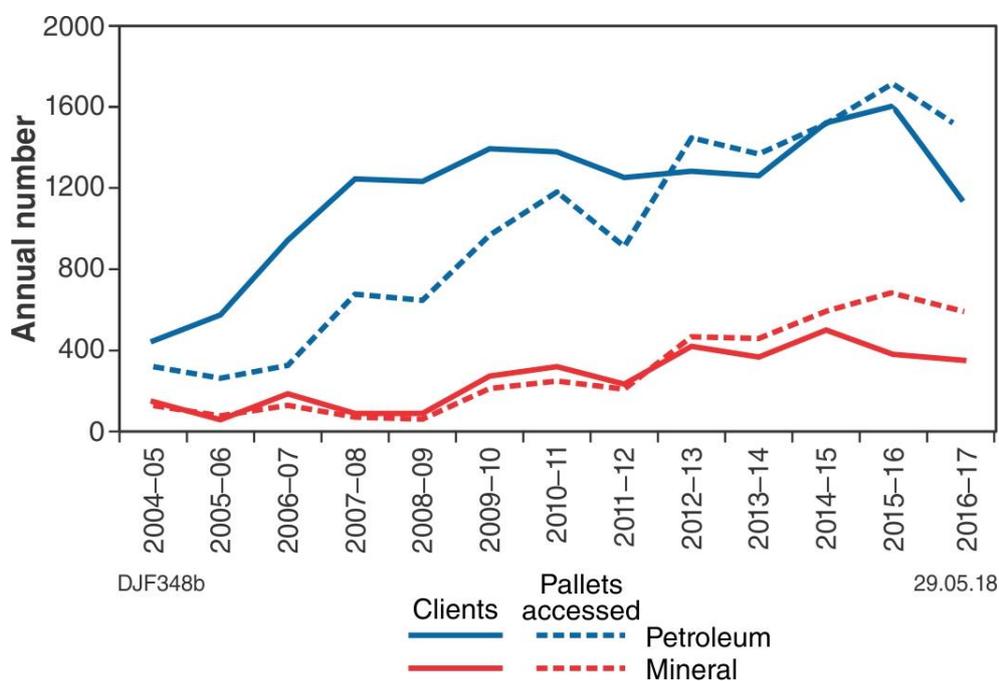
32. Drillhole database: number of surface geochemistry samples recorded, by year of drilling and sampling type



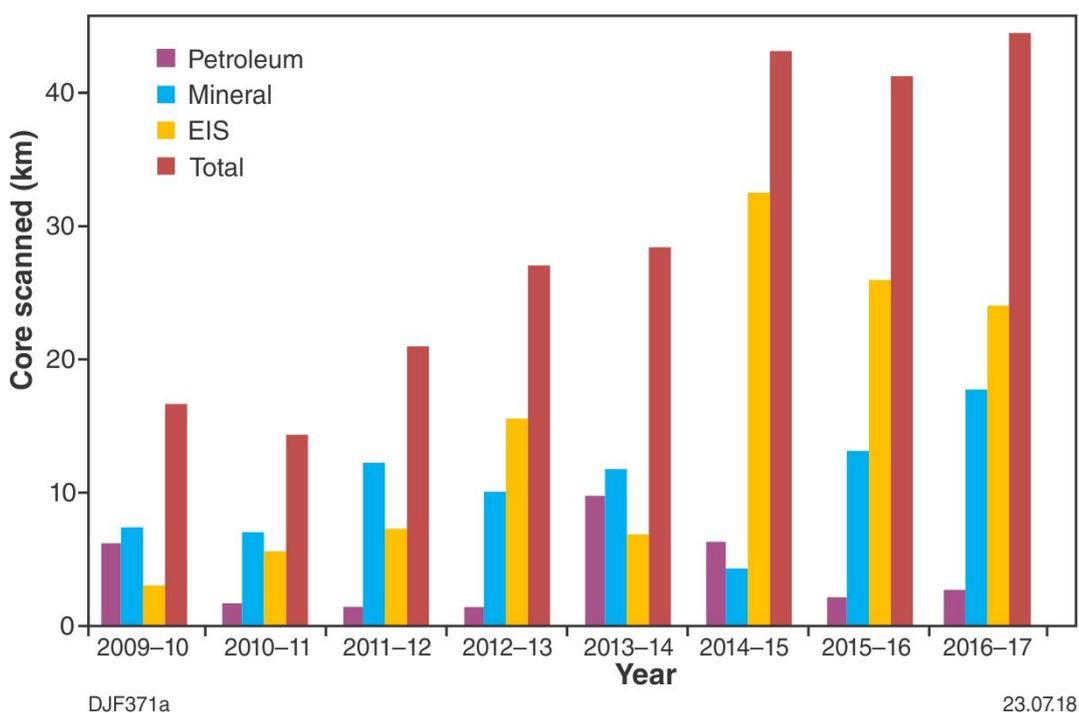
33. Perth Core Library usage statistics since 2004–05 for number of clients, pallets accessed, and core laid out



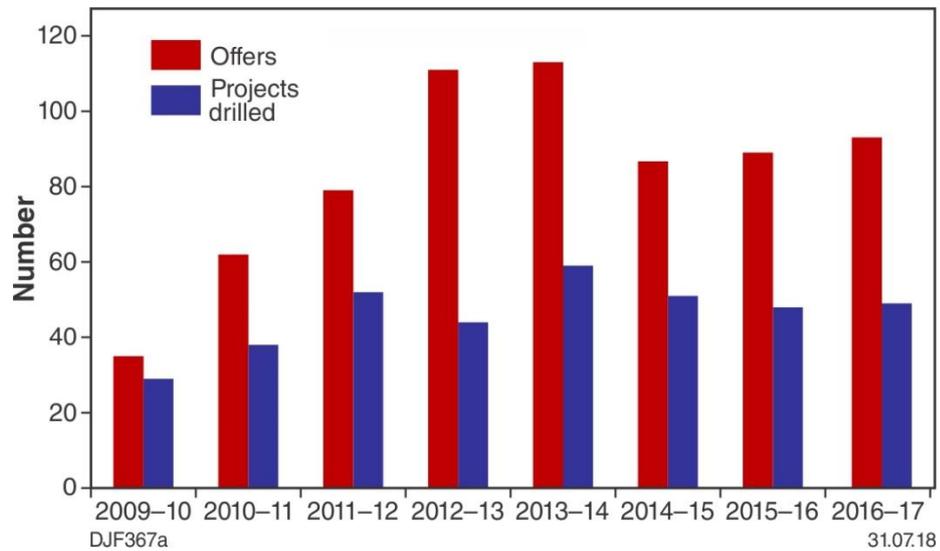
34. Perth Core Library usage statistics since 2004–05 for petroleum versus mineral clients



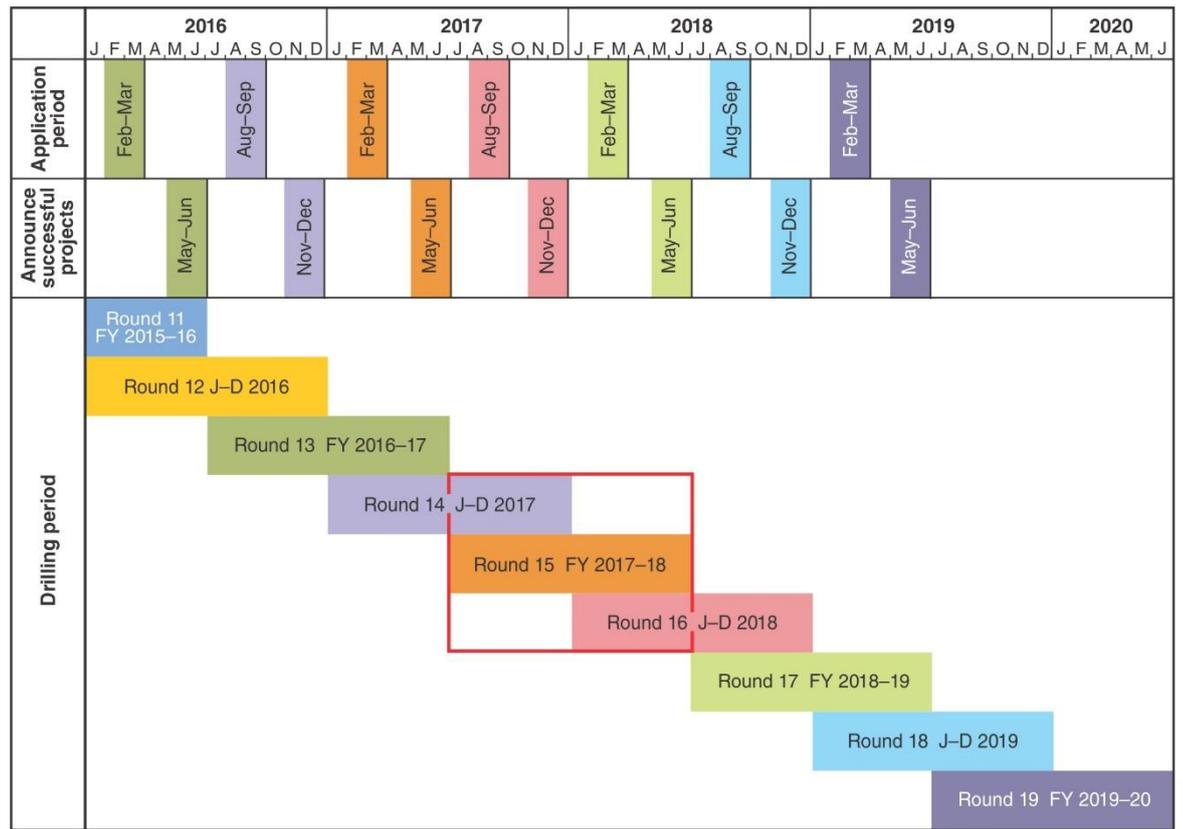
35. Spectral scanning of core through GSWA's HyLogger at Carlisle



36. EIS Co-funded Drilling program — projects offered funding versus projects actually drilled



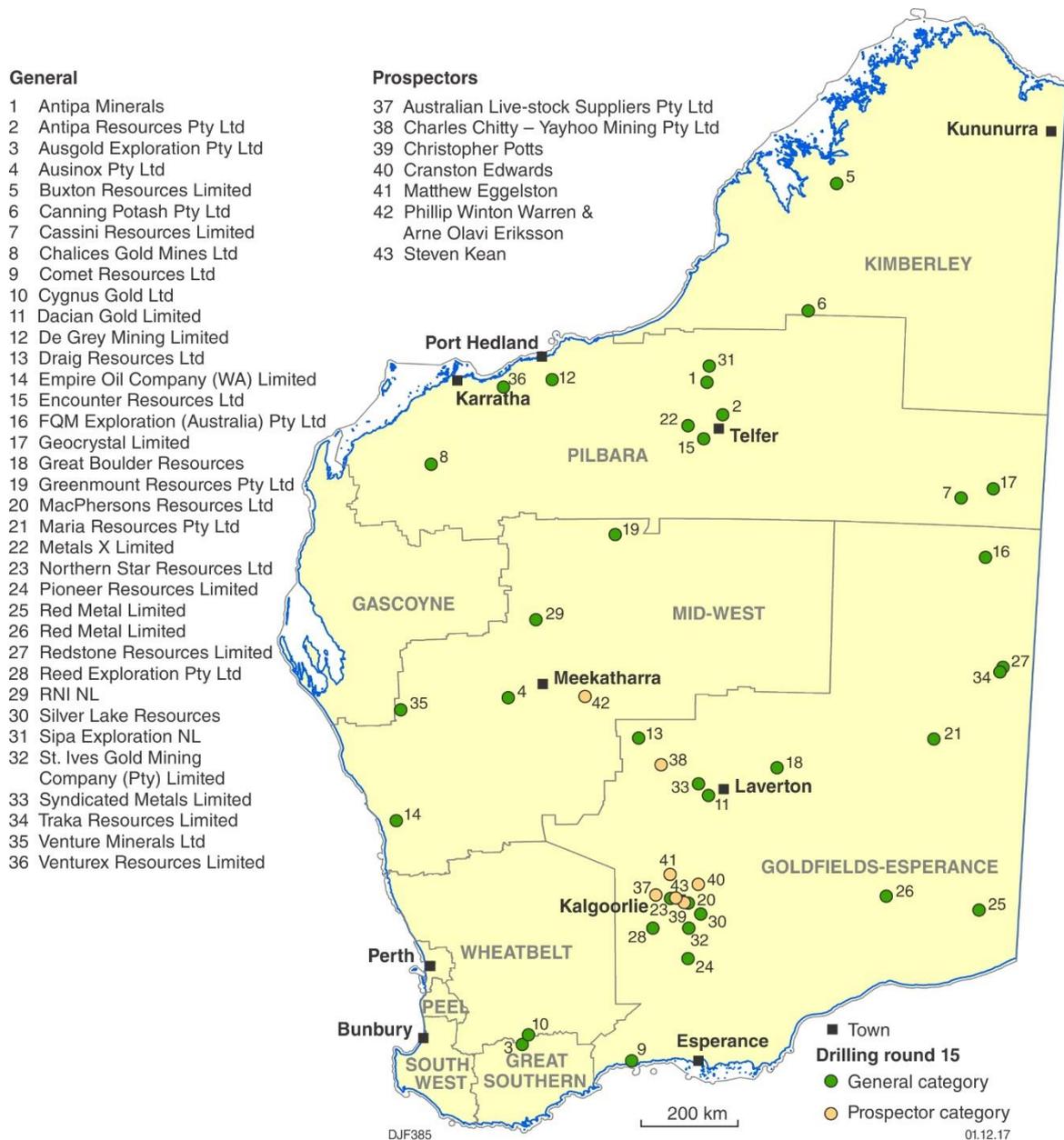
37. EIS Co-funded Drilling program — schedule of Rounds 6–16



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38. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 14



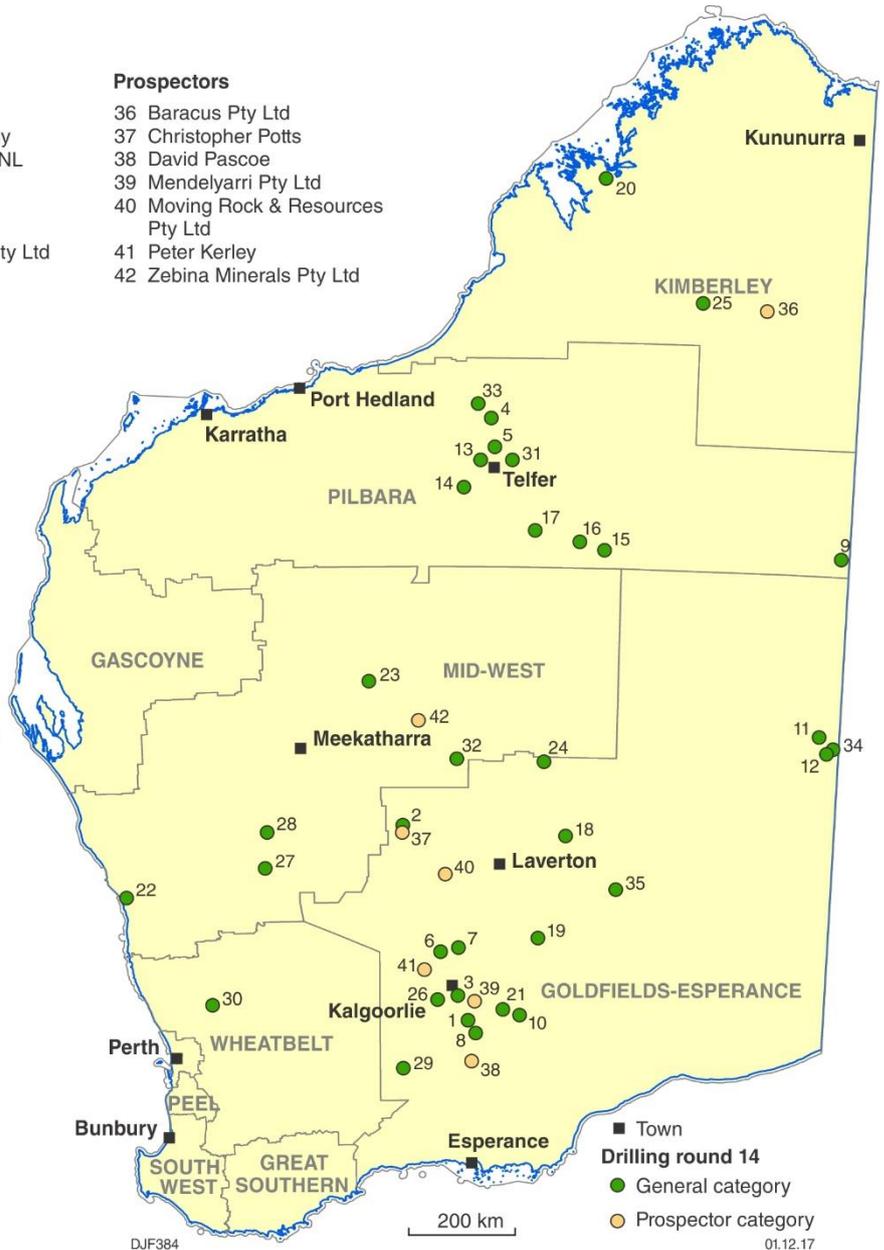
39. EIS Co-funded Drilling program — map showing distribution of projects offered funding in Round 15

General

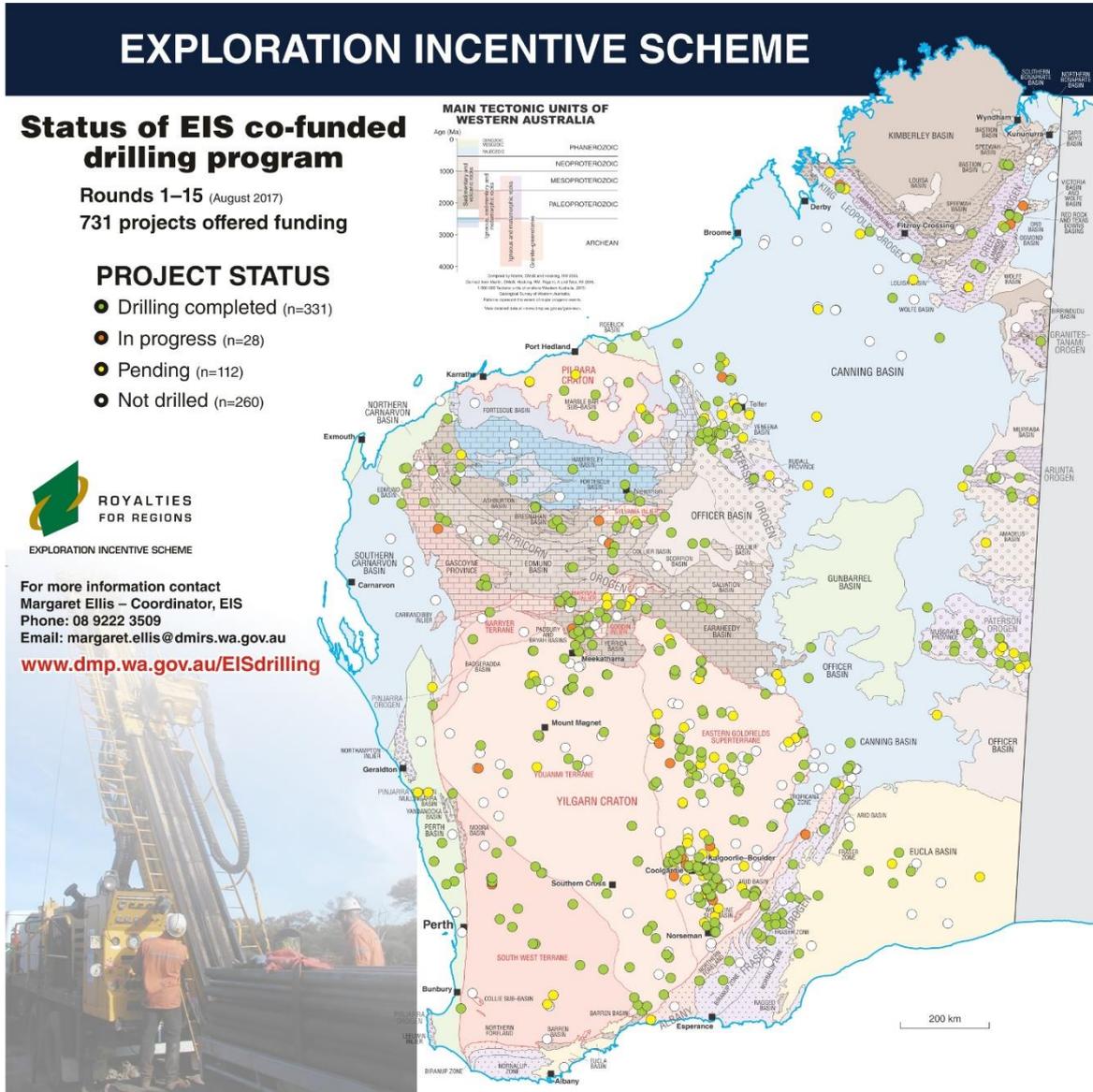
- 1 ACH Nickel Pty Ltd
- 2 Agnew Gold Mining Company
- 3 Anglo Australian Resources NL
- 4 Antipa Minerals
- 5 Antipa Minerals
- 6 Aphrodite Gold Ltd
- 7 Apollo Phoenix Resources Pty Ltd
- 8 Austral Pacific Pty Ltd
- 9 Australian Mines Ltd
- 10 Black Raven Mining
- 11 Chalice Gold Mines Ltd
- 12 Chalice Gold Mines Ltd
- 13 Encounter Resources Ltd
- 14 Encounter Resources Ltd
- 15 Fortescue Metals Group
- 16 Fortescue Metals Group
- 17 Fortescue Metals Group
- 18 Gold Road Resources
- 19 Impact Minerals Ltd
- 20 IronRinger (Tarraji) Pty Ltd
- 21 Kairos Minerals Ltd
- 22 Key Petroleum (Australia) Pty Ltd
- 23 Lodestar Minerals Ltd
- 24 MB Exploration Pty Ltd
- 25 Meridian (Lennard Shelf Project) Pty Ltd
- 26 Middle Island Resources Ltd
- 27 Minjar Gold
- 28 Mt Magnet Gold Pty Ltd
- 29 Poseidon Nickel Limited
- 30 Quadrio Resources Pty Ltd
- 31 Rio Tinto Exploration
- 32 Rox Resources Ltd
- 33 Sipa Exploration NL
- 34 Traka Resources
- 35 Ventnor Resources Pty Ltd

Prospectors

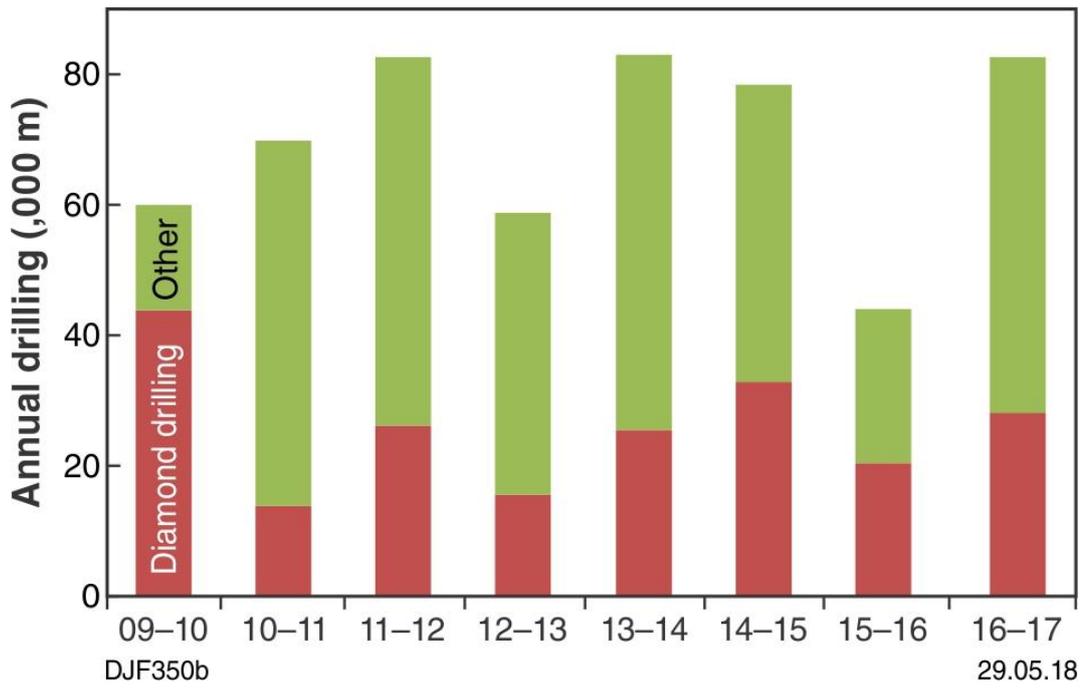
- 36 Baracus Pty Ltd
- 37 Christopher Potts
- 38 David Pascoe
- 39 Mendelyarri Pty Ltd
- 40 Moving Rock & Resources Pty Ltd
- 41 Peter Kerley
- 42 Zebina Minerals Pty Ltd



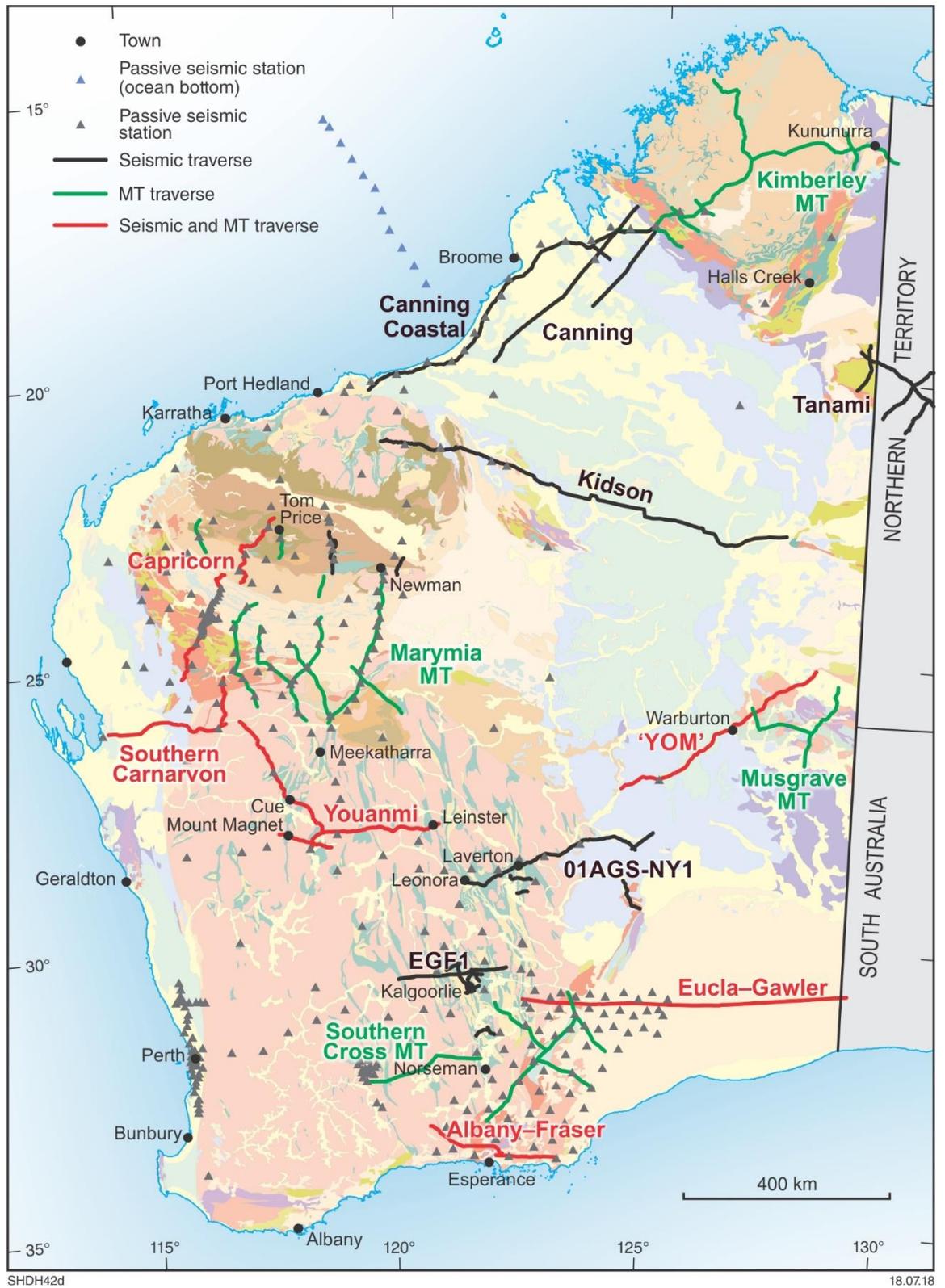
40. EIS Co-funded Drilling program — map showing projects offered funding in Rounds 1–15 inclusive



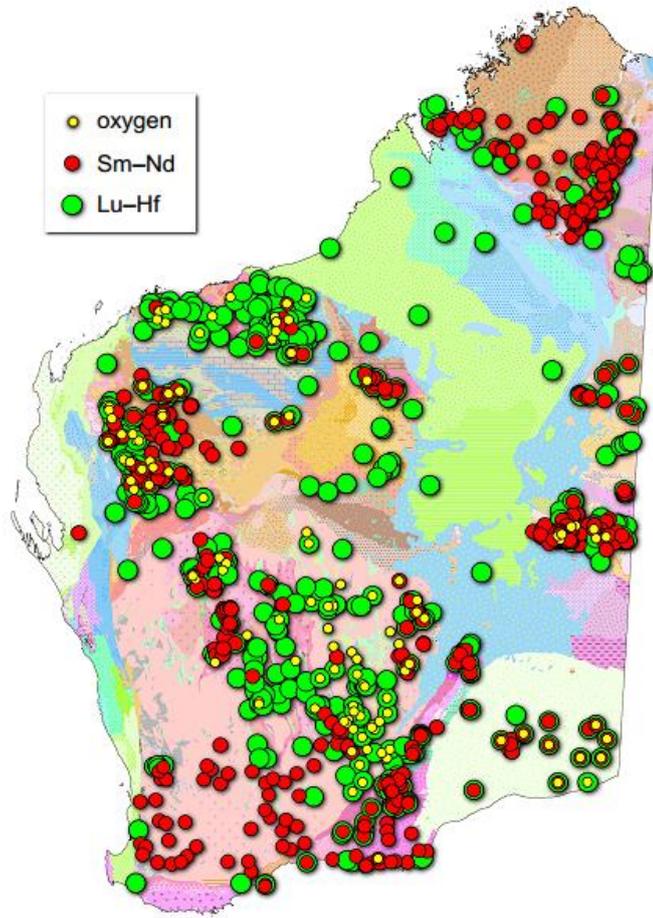
41. EIS diamond drilling versus all other drilling types, by year



42. EIS-funded deep crustal seismic and magnetotelluric, surveys



43. Locations of Lu–Hf, Sm–Nd, and oxygen isotope samples up to June 2017



Tables

1. Real local currency GDP in 2015 and 2016 for selected trading partners (IMF statistics)

<i>Country</i>	<i>2015 GDP (real, billion)</i>	<i>2016 GDP (real, billion)</i>	<i>GDP increase 2016/2015%</i>
Australia AUD	1,617.02	1,654.86	2.34%
China RMB	68,905.20	74,412.72	7.99%
Germany Euro	3,032.82	3,134.07	3.34%
India INR	136,820.35	151,837.09	10.97%
Japan JPY	530,545.20	537,369.90	1.29%
South Korea KRW	1,564,123.90	1,637,420.80	4.69%
United Kingdom GBP	1,872.71	1,939.64	3.57%
United States USD	18,036.65	18,569.10	2.95%

2. Quantity and value of minerals and petroleum production in WA 2016–17

COMMODITY	UNIT	Financial Year 2015-16		Financial Year 2016-17	
		QUANTITY	VALUE	QUANTITY	VALUE
ALUMINA AND BAUXITE	t	13,941,243	4,939,232,470	14,098,163	5,088,560,195
BASE METALS					
Copper Metal	t	190,298	1,180,826,384	170,601	1,237,682,406
Lead Metal	t	5,988	14,810,595	3,507	10,146,717
Zinc Metal	t	82,676	195,494,453	82,933	201,562,473
TOTAL BASE METALS			1,391,131,432		1,449,391,596
CHROMITE	t	0	0	0	0
CLAYS		21,969	1,104,708	20,865	1,390,448
COAL	t	6,890,951	336,466,825	6,806,389	338,435,045
CONSTRUCTION MATERIALS					
Aggregate	t	1,244,225	40,200,886	1,052,475	29,142,593
Gravel	t	200,934	2,264,091	261,219	1,652,110
Rock	t	304,395	4,685,177	390,243	5,234,964
Sand	t	3,537,282	38,325,803	2,560,475	24,306,381
TOTAL CONSTRUCTION MATERIALS			85,475,956		60,336,049
DIAMONDS	ct	13,869,547	354,047,664	12,607,032	268,383,094
DIMENSION STONE		4,113	2,205,326	4,795	1,823,218
GEM & SEMI-PRECIOUS STONES	kg	242,919	623,746	332,399	729,579
GOLD	kg	196,198	10,116,600,502	203,166	10,868,087,846
GYPSUM	t	551,910	13,724,991	531,399	12,980,853
MINERAL SANDS					
Garnet	t	251,162	n/a	565,618	n/a
Ilmenite	t	174,687	39,692,103	178,528	42,912,243
Leucoxene	t	18,137	16,452,584	5,892	5,364,559
Rutile	t	45,888	44,260,114	21,562	21,953,547
Zircon	t	191,551	151,297,003	184,700	101,083,491
Other	t	0	320,102,140	0	410,707,490
TOTAL MINERAL SANDS			571,803,944		582,021,330

IRON ORE	t	748,100,421	48,768,099,970	793,236,080	63,866,462,235
LIMESAND-LIMESTONE-DOLOMITE	t	4,509,980	44,279,689	4,094,677	25,896,887
MANGANESE ORE	t	425,303	146,188,090	236,565	n/a
NICKEL INDUSTRY					
Cobalt	t	5,479	174,846,826	4,732	238,867,102
Nickel	t	175,752	2,202,734,451	157,490	2,083,077,451
Palladium and Platinum By-Product	kg	687	16,656,441	783	21,808,381
TOTAL NICKEL INDUSTRY			2,394,237,718		2,343,752,934
PETROLEUM					
Condensate	kl	6,775,142	2,213,709,834	6,037,603	2,228,626,174
Crude Oil	kl	7,685,922	3,042,849,325	5,404,294	2,063,573,585
LNG	t	20,955,641	10,764,545,353	28,685,477	12,603,581,678
LPG - Butane and Propane	t	531,595	249,059,073	527,391	273,097,308
Natural Gas	'000m3	10,223,641	1,913,134,982	9,708,934	1,830,012,904
TOTAL PETROLEUM			18,183,298,567		18,998,891,650
SALT	t	10,974,721	336,253,755	10,874,279	292,285,826
SILICA-SILICA SAND	t	581,966	18,072,793	727,099	20,331,215
SILVER	kg	155,897	104,401,339	143,894	99,358,909
TIN-TANTALUM-LITHIUM		0	269,771,196	0	605,406,327
OTHER (Includes Vanadium, Manganese, Rare Earths, Spongolite and Talc)			199,236,526		242,499,614
TOTAL VALUE			88,276,257,207		105,167,024,848

Note: Quantities used in this table only apply to Minerals and Petroleum covered by the Mining Act 1978, the Petroleum and Geothermal Energy Resources Act 1967, the Petroleum (Submerged Lands) Act 1982, the Offshore Petroleum Act 2006 and relevant State Agreement Acts.

(r) Revised from previous edition

n/a Breakdown of chromite, garnet, manganese, talc, spodumene, vanadium, rare earths, tin, tantalite and lithium not available

3. WA's ranking in Fraser Institute mining company surveys for the period 2010–11 to 2016

	<i>Ranking relative to jurisdictions world-wide</i>							<i>Ranking relative to Australian jurisdictions</i>						
	2010–2011	2011–2012	2012–2013	2013	2014	2015	2016	2010–2011	2011–2012	2012–2013	2013	2014	2015	2016
<i>Number of jurisdictions surveyed</i>	79	93	96	112	122	109	104	7	7	7	7	7	7	7
Policy perception index	17	12	15	6	10	8	9	2	1	1	1	1	1	1
Best practices mineral potential index	7	11	6	2	8	1	1	1	1	1	1	1	1	1
Investment Attractiveness Index*	7	5	4	1	5	1	3	1	1	1	1	1	1	1
Quality of geological database	17	8	10	11	5	3	1	6	3	4	3	2	1	1

* Formerly "Composite policy and best practices mineral potential index"

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

Jurisdiction	Initiative	Funding
Queensland	Future Resources Program	\$30 million (4 years, ended in 2016–17)
NSW	New Frontiers Initiative (2012 – ongoing)	From licence rentals since 2012; \$41 million spent so far (to the end of 2016–17)
Victoria	TARGET: including \$12M co-funded exploration grants Victorian Gas Program	\$15 million over 4 years ending 2017–18 \$42.5 million over 3 years ending 2019–20
Tasmania	Northern Tasmanian Geosciences Initiative Mining Innovation Initiative	\$1.2 million over 4 years ending 2019–20 \$1.0 million over 4 years ending 2020–21
South Australia	<i>PACE</i> Discovery Drilling	\$5 million over 4 years ending 2020–21
Western Australia	Exploration Incentive Scheme Phase 3 South West Settlement Project	\$20 million over 2 years ending 2018–19 \$1.6 million over 5 years ending 2017–18
Northern Territory	CORE (Creating Opportunities for Resource Exploration)	\$23.8 million over 4 years ending 2017–18. Extension expected
Geoscience Australia	Exploring for the Future (aka “Northern Australia” geoscience program)	\$100.5 million over 4 years ending in 2019–20

5. Recommendations of the 2012 functional review of GSWA – implementation update 1 July 2017

<i>Recommendation</i>	<i>GSWA response</i>	<i>Implementation plan</i>
1. Develop a new funding model applicable beyond 2016 that recognises the dependence of the WA economy on the resources industry and the cost of modern geoscience programs	Accept	EIS3 funding for 2017–18 and 2018–19 approved in Budget forward estimates (from Royalties for Regions funding), but not beyond that. It remains a priority task to ensure long-term initiative funding.
2. Develop a staff development and recruitment strategy to address the age profile of GSWA with plans for succession	Accept	The graduate program (MSc) is finished. Budget and FTE limits imposed greatly restrict ability to employ new staff — as does the 60/40 harvesting rule when someone leaves the department.
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 Geoscience Australia's <i>Exploring for the Future</i> in northern Australia. The change of government following the State election in March 2017 has resulted in significantly different and new goals of a new government. DMP has merged with Department of Commerce to become the Department of Mines, Industry Regulation and Safety from 1 July 2017.
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. Note that within the new enlarged department (DMP has become DMIRS) there is the proposal to abolish the Petroleum Division in the structure from 22 January 2018.
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 (National Offshore Petroleum Data and Core Repository (NOPDCR)). GSWA's new WAPIMS system has previously displayed Commonwealth historical information. GSWA assisted the development of and helps maintain the new NOPIMS system.
6. Recruit a Chief Petroleum Geologist for the Executive Team	Accept	Chief petroleum geologist was recruited in early 2016 and remains with GSWA.
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/NOPIMS
8. More closely integrate the work of the Mineral Systems group with the regional mapping teams and research collaborators to produce integrated tectonic and metallogenic syntheses of terranes	Accept	Already implemented: review of Mineral Resources group in GSWA has resulted in a model involving assignment of a mineral geologist to most mapping teams
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. The 2017 update to the Canning Basin SEEBASE model does extend offshore for WA's jurisdiction.
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, but despite that about 80% of all reports are currently written and lodged online.
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 department's website, but specific applications are commercially sensitive to applicants and remain confidential. Applicants who were unsuccessful will be given, on request, reasons why they were

		unsuccessful. The award process is already externally audited.
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

6. GSWA products delivered 2008–09 to 2016–17

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
Books (Reports, Records, non-series books, etc.)	26	36	52	35	39	39	39	40	38
External publications	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	38.	54	52
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	8	10	5
Maps — other (includes Plates and geophysical maps)	17	11	8	14	17	20	19	18	9
Digital information packages	19	21	17	18	11	20	20	16	15
1000 line-km of airborne geophysical data (EIS) ^(a)	398	908	720	768	1157	588	0	110	38.4
Weighted Total Published Product	118	170	188	174	173	187	124	140	N.A. ^(b)
Days of effort to produce all GSWA product	N.A.	26 613 ^(b)							

(a) Plus release of 28 690 gravity points and 287 km of deep crustal seismic in 2015–16
Geophysical surveys in 2016–17 were airborne gravity

(b) Note that for 2016–17 the methodology for calculating the KPI-style 'Weighted Total Published Product' was discontinued and replaced by a measure of the total days of effort to produce all GSWA products — hence is fundamentally different and is not by itself a KPI measure. As such, it now also includes the effort to produce additional products not included this table.

7. GSWA high-level budget for geoscience information

	2013–14 \$M	2014–15 \$M	2015–16 \$M	2016–17 \$M	2017–18 \$M
Consolidated Revenue Fund					
Base funding (recurrent budget)	18.158	19.294	19.488	18.612	18.374
Kimberley Science and Conservation Strategy (KSCS)	1.039	—	—	—	—
Exploration Incentive Scheme*	24.194	11.075	10.000	10.000	10.000
Total budget	43.391	30.369	29.488	28.612	28.374

NOTE: * Budget allocation for GSWA for each financial year; excludes departmental corporate overheads; does not reflect final end-of-year actual expenditure. The base funding (recurrent budget) for 2017–18 includes a project-specific allocation from the Department of Premier and Cabinet of \$115 000 for the South West Native Title Settlement project. The 2017–18 budget allocation excludes the special allocation to the Carbon Strategy project, which covers the geosequestration project at Harvey in the State's South West, but which came under the control of the Geological Survey from 1 July 2017.

8. GSWA's 2017–18 recurrent budget for both projects and support activities

GEOLOGICAL SURVEY 2017–2018 PROJECT & SUPPORT BUDGETS

SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE - RECURRENT BUDGET ALLOCATIONS

2016–17 Budget \$,000	Project and Support Activities Operational Group/Cost Centres Description	2017–18 Allocations			Div
		Salary \$,000	Non-salary \$,000	Total \$,000	Plan FTE
	3101 - Executive and Administrative Support				
693	GS01 Executive Team	669	26	695	4.0
331	GS02 Executive Support	270	10	280	4.0
1024	Subtotal cost centre 3101	939	36	975	8.0
	3102 - Minerals and Petroleum Resources				
1656	GS10 Petroleum Geology	1306	209	1515	11.5
923	GS12 Land-use Geoscience	842	74	916	7.0
870	GS14 Commodity & Industry Analysis	501	312	813	5.0
679	GS20 Mineral Systems Studies	600	67	667	6.0
53	GS77 Mining Act Section 16(3) Referrals Information system development	0	0	0	0
105	GS79 MINEDEX/Royalties Information system development		37	37	0
4286	Subtotal cost centre 3102	3249	699	3948	29.5
	3103 - Regional Geoscience Mapping				
175	GS43 Geochemistry	151	34	185	1.0
151	GS45 Pilbara Craton	152	0	152	1.0
263	GS47 Gascoyne Province	132	25	157	2.0
140	GS49 Edmund and Collier Basins	0	0	0	1.0
430	GS52 East Yilgarn (Kalgoorlie Office)	211	217	428	2.0
554	GS53 Chief Geoscientist and Terrane Custodianship	730	82	812	5.0
737	GS54 Geochronology	493	234	727	4.6
345	GS55 Geophysics and Remote Sensing	272	81	353	2.0
102	GS56 North Australian Craton	103	0	103	1.0
0	GS57 West Musgrave	0	0	0	0.0
604	GS58 Youanmi Terrane	510	45	555	4.0
335	GS61 Albany–Fraser Orogen and Eucla basement	261	65	326	2.0
347	GS62 3D Geoscience	364	0	364	3.0
224	GS63 Tectonic evolution of the Fortescue and Hamersley Groups	132	21	153	0.9
4407	Subtotal cost centre 3103	3511	804	4315	29.5
	3104 - Logistics and Field Support				
1364	GS70 Field Support	316	1,221	1537	4.0
1364	Subtotal cost centre 3104	316	1221	1537	4.0
	3105 - Geoscientific Editing and Publishing				
1056	GS80 Publications	751	219	970	7.0
757	GS81 Series Mapping	685	67	752	8.0

256	GS82	Publication Drafting (CADD)	313	0	313	3.0
631	GS83	GIS Services	640	51	691	6.0
98	GS78	Geoscience Information and Resource Centre	0	150	150	0
1045	GS84	Business Systems Support	566	895	1461	5.0
405	GS85	Promotion and Exhibitions	238	49	287	3.0
4248	Subtotal cost centre 3105		3193	1431	4624	32.0
3106 - Geoscientific and Exploration Information						
751	GS91	Mineral Exploration Information Management	564	160	724	6.5
849	GS92	Petroleum Exploration Information Management	739	109	848	9.0
847	GS94	Core Library Perth	386	260	646	6.0
376	GS95	Virtual Core Library	119	237	356	1.0
419	GS96	Core Library Kalgoorlie	159	135	294	2.0
3242	Subtotal cost centre 3106		1967	901	2868	24.5
18571	GEOLOGICAL SURVEY BUDGET		13,175	5,092	18,267	127.5

13169.0 5089

allocated budget is but includes south west settlement
\$150K

SWS
115000.0
12000.0
127000.0

9. GSWA's 2017–18 recurrent budget, with support budgets distributed pro rata to geoscience activities

GEOLOGICAL SURVEY 2017–18 RECURRENT BUDGET DISTRIBUTION

With support budgets distributed on a pro rata basis (FTE) to geoscience activities

Cost centres	2016–17	2017–18 Fully attributed budget			Div
	TOTAL	Salary	Non-salary	TOTAL	Plan
	\$,000	\$,000	\$,000	\$,000	FTE
Projects and support activities					

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	345.2	271.8	99.5	371.3	2.1
GS45	Pilbara Craton	321.2	272.8	65.8	338.6	2.1
GS47	Gascoyne Province	603.4	373.6	156.5	530.2	4.3
GS49	Edmund and Collier Basins	310.2	120.8	65.8	186.6	2.1
GS52	East Yilgarn (Kalgoorlie Office)	770.4	452.6	348.5	801.2	4.3
GS55	Geophysics and Remote Sensing	685.4	513.6	212.5	726.2	4.3
GS56	North Australian Craton	272.2	223.8	65.8	289.6	2.1
GS57	West Musgrave	0.0	0.0	0.0	0.0	0.0
GS58	Youanmi Terrane	1284.8	993.3	308.1	1301.3	8.6
GS61	Albany–Fraser Orogen and Eucla basement	675.4	502.6	196.5	699.2	4.3
GS62	3D Geoscience	857.6	726.4	197.3	923.7	6.4
GS63	Tectonic evolution of the Fortescue and Hamersley Groups	377.2	240.7	80.2	320.9	1.9
Sub-Total		6503.0	4692.2	1796.4	6488.7	42.7

Petroleum System Studies and Exploration Information

GS10	Petroleum Geology	3613.2	2695.4	965.3	3660.7	24.7
GS92	Petroleum Exploration Information Management	2026.7	1312.7	581.7	1894.4	15.7
Sub-Total		5639.9	4008.1	1547.0	5555.1	40.4

Mineral Resource Services and Exploration Information

GS12	Land Use Geoscience*	1528.7	1271.5	234.1	1505.6	11.0
GS14	Commodity & Industry Analysis**	1369.8	807.8	463.4	1271.1	7.9
GS20	Mineral Systems Studies	1700.2	1324.9	461.5	1786.4	12.9
GS91	Mineral Exploration Information Management	1829.6	1070.6	589.2	1659.7	12.6
Sub-Total		6428.3	4474.7	1748.2	6222.9	44.3

TOTAL GSWA BUDGET

18,571.2 | 13,175.0 5,091.6 18,266.6 | 127.5

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 & Field Support	Distributed pro rata to all mapping and petroleum geology projects
GS80	Publication Editing and Information	Distributed pro rata to all mapping and resource projects
GS81	Series Mapping	Distributed pro rata to all mapping and resource projects
GS82	Publication Drafting and Design	Distributed pro rata to all mapping and resource projects
GS83	GIS Services	Distributed pro rata to all mapping and resource projects
GS84	Business Systems Support	Distributed pro rata to all projects
GS85	Promotion & Exhibitions	Distributed pro rata to all projects
GS94	Core Library Perth	Distributed pro rata to exploration information projects
GS95	Virtual Core Library	Distributed pro rata to exploration Information projects
GS96	Core Library Kalgoorlie	Distributed pro rata to exploration Information projects
GS77	Mining Act Section 16(3) Referrals*	Distributed pro rata to Land Use Geoscience (GS12)
GS78	Geoscience Info & Resource Centre - ISD	Distributed as per Business Systems Support (GS84)
GS79	MINEDEX / Royalties**	Distributed pro rata to Commodity & Industry Analysis (GS14)

10. Distribution of GSWA staff (excluding EIS-, CO2- and KSCS-funded staff) among specialist groups funded by the Consolidated Revenue fund in 2017–18

Specialist group	Actual FTEs 2013–14		Actual FTEs 2014–15		Actual FTEs 2015–16		Actual FTEs 2016–17		Planned FTEs 2017–18	
	FTEs	%	FTEs	%	FTEs	%	FTEs	%	FTEs	%
Geoscientists	72.1	54.9	73.1	56.6	73.1	57.7	70.6	58.7	67.0	55.7
Cartographers and GIS specialists	26.0	19.8	26.0	20.1	26.0	19.9	23.0	19.1	23.0	19.1
Other (technical and field support, data entry administrative support)	33.3	25.3	31.3	23.3	31.3	22.5	26.7	22.2	26.7	22.2
Total	131.4	100	130.4	100	124.9	100	120.3	100	116.7	100

11. Distribution of recurrent budget to high-level strategic objectives in 2017–18

Monitoring Inputs Needed To Achieve Strategic Objectives

GSWA DISTRIBUTION RATIOS				SERVICE 2: GEOSCIENCE INFORMATION AND ADVICE																			TOTAL				
				A Geological Framework of the State and Its Resources and An Archive of Geoscientific and Resource Exploration Data																							
				3162				3165														3166					
				Petrolium Geology		Mineral Resources		Regional Geoscience Mapping														Exploration Information and Core Libraries					
Projects		GS10	GS12	GS14	GS20	GS43	GS45	GS47	GS49	GS52	GS55	GS56	GS57	GS58	GS61	GS62	GS63	GS91	GS92								
STRATEGIC OBJECTIVES	Enhancement and Promotion of State Prospectivity	Prospective pathways of data and use of information	13.72	Minerals	12.23	Established and Producing Areas	3.81	Precious metals	0.01	0.01	0.15	0.02	0.08	0.04		0.10	0.10	0.05	0.05	0.20	0.20	0.40	0.02	1.12			
								Base metals	0.01	0.01	0.10	0.02	0.09	0.03	0.10	0.05	0.05	0.05	0.05	0.17					0.10		
								Ferro-alloys	0.01	0.01	0.10	0.02	0.09	0.02		0.05	0.10			0.20	0.10				0.70		
								Non-Metals	0.01	0.01	0.05			0.01			0.05			0.02							
				Green Fields	8.42	Precious metals	0.01	0.01	0.10	0.25	0.20	0.30	0.25	0.30	0.30	0.40	0.30	0.10	0.30	0.20	0.10	0.25	0.08	3.42			
						Base metals	0.05	0.01	0.01	0.10	0.25	0.20	0.35	0.45	0.10	0.10	0.30	0.40	0.10	0.30	0.20				0.10		
						Ferro-alloys	0.01	0.01	0.10	0.25	0.20	0.10	0.10	0.10	0.15	0.10	0.10	0.10	0.10	0.10	0.10						
						Non-Metals	0.01	0.01	0.05		0.05	0.05			0.05			0.01									
				Petrolium and Coal	1.49	Producing Areas	0.28	0.10	0.01	0.01												0.01	0.15	0.28			
								Frontier Areas	1.21	0.70	0.01	0.01												0.04	0.45	1.21	
PROSPECTIVITY ENHANCEMENT				SUB TOTALS		0.85	0.10	0.10	0.75	0.81	0.91	0.90	0.90	0.70	0.90	0.90	0.90	0.90	0.90	0.90	0.70	0.70	13.72				
Assisting in Development of the State	Responsive management, custodianship and provision of policy advice and information	4.28	Information on resource potential	2.37	0.04	0.45	0.55	0.10	0.00	0.07	0.07	0.08	0.20	0.00	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	2.37				
					Policy advice on resource issues	0.08	0.45	0.35	0.10																0.07	0.07	1.12
					Information for R&D and the general public	0.76			0.05	0.10	0.02	0.03	0.02	0.10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.15	0.15	0.79
INFORMATION SERVICES				SUB TOTALS		0.15	0.90	0.90	0.25	0.19	0.09	0.10	0.10	0.30	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.30	0.30	4.28		
TOTALS						1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.00			

KEY

1. The budget of each project has been attributed in proportion to its perceived contribution to various strategic objectives.
 2. The vertical total column to the right represents the aggregated weighted contribution of all Output 4 projects to various strategic objectives.

Project Titles

GS10 Petrolium Geology
 GS12 Land Use Geoscience
 GS14 Commodity & Industry Analysis
 GS20 Mineralization Mapping
 GS43 Geochemistry
 GS45 Pilbara Craton Field Mapping
 GS47 Geoscience Complex Field Mapping
 GS49 Edmund & Collier Basins Field Mapping

GS46 Edmund & Collier Basins Field Mapping
 GS52 East Yilgarn Field Mapping (Kalgoorlie Office)
 GS55 Geophysics & Remote Sensing
 GS56 North Australian Craton Field Mapping
 GS57 West Musgrave Field Mapping
 GS58 Macintyre Field Mapping
 GS61 Albany Fraser Orogen
 GS62 3D Geology
 GS63 Hamersley Field Mapping

GS90 Inventory of Abandoned Mine Sites
 GS91 Mineral Exploration Information Management
 GS92 Petrolium Exploration Information Management

12. Planned achievements for release in 2017–18

	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18 Planned
Books (Reports, Records, non-series books, etc.)	26	36	52	35	39	39	39	40	38	40
External publications	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	38.	54	52	55
1:100 000 and 1:250 000 series maps	14	13	12	12	10	10	8	10	5	4
Maps — other (includes Plates and geophysical maps)	17	11	8	14	17	20	19	18	9	18
Digital information packages	19	21	17	18	11	20	20	16	15	
1000 line-km of airborne geophysical data (EIS) ^(a)	398	908	720	768	1157	588	0	110	38.4	120
Weighted Total Published Product	118	170	188	174	173	187	124	140	N.A. ^(b)	N.A. ^(b)
Days of effort to produce all GSWA product	N.A.	26 613 ^(b)	N.A.							

(a) Plus release of 28 690 gravity points and 287 km of deep crustal seismic in 2015–16
Geophysical surveys in 2016–17 and 2017–18 are airborne gravity

(b) Note that for 2016–17 the methodology for calculating the KPI-style 'Weighed Total Published Product' was discontinued and replaced by a measure of the total days of effort to produce all GSWA products — hence is fundamentally different and is not by itself a KPI measure. As such, it now also includes the effort to produce additional products not included this table.

13. Fraser Institute's Policy Potential Index — relative ranking of Australian States only

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	WA
2	Qld	Tas	NT	NT	WA	SA	SA	SA	SA	SA	SA
3	Tas	NT	WA	WA	NSW	NSW	NT	NT	Tas	NT	NT
4	Vic	WA	NSW	NSW	NT	Tas	Vic	Qld	NT	Qld	Tas
5											Qld
6											Vic
7	WA										NSW

14. EIS budget allocation by project and by year

Programs 2014-2017		Programs 2017 onwards		FTEs	2014-15 (\$000)	2015-16 (\$000)	2016-17 (\$000)	2017-18 (\$000)	2018-19 (\$000)	Total (\$000)
Exploration Facilitation		3301			350	300	80	0	0	730
ES01 Exploration and Environmental Coordination					350	300	80	0	0	730
		3302								
Innovative Drilling Promotion		Innovative Drilling Promotion			5800	5800	5800	5150	5150	27700
ES20 Government-Industry co-funded exploration drilling		ES20 Government-Industry co-funded exploration drilling		1	5675	5675	5675	5000	5000	27025
ES21 Mineral and Exploration Promotion		ES21 Targeted international exploration promotion			125	125	125	150	150	675
		3303								
Geophysical and Geochemical surveys		Encouraging exploration through cover			300	600	1340	2250	2250	6740
		ES30 Airborne and ground geophysical surveys			0	0	0	1000	1000	2000
ES31 Deep seismic survey program		ES31 Deep crustal seismic and MT surveys			300	300	0	800	800	2200
ES32 Regional Gravity Surveys					0	300	880	0	0	1180
ES33 Yilgarn Margin Geochemistry		ES33 Regolith geochemical and resistate mineral surveys			0	0	460	150	150	760
		ES34 Regolith and 3D paleosurface mapping		2	0	0	0	250	250	500
		ES35 Big data: Exploration data analysis			0	0	0	50	50	100
		3304								
		3D Prospectivity Mapping			3070	2950	2430	2250	2250	12950
ES40 WA Geology Online		ES40 WA Geology Online		1	150	100	200	550	550	1550
ES42 3D Geoscience		ES42 3D lithosphere visualisation			300	300	300	150	150	1200
ES43 Mineral Systems Atlas		ES43 Mineral systems			890	850	200	100	100	2140
ES45 Geological Mapping and Interpretation		ES45 Mapping geodynamic setting		3	520	500	530	450	450	2450
ES46 Enhanced Geochronology and Isotopic Fingerprinting		ES46 Enhanced geochronology and isotopic mapping			310	300	300	300	300	1510
ES47 Petroleum, Coal and CO2 Geosequestration Program		ES47 Petroleum systems		1	900	900	900	700	700	4100
		3305								
		Promoting Strategic Research with Industry			480	350	350	350	350	1880
ES50 Strategic Industry Research Program		ES50 MRIWA support			480	350	350	350	350	1880
		Total		8	10000	10000	10000	10000	10000	50000

15. List of successful applicants for Round 14 of the Co-funded Drilling program

Co-funded Drilling Round 14, 2017



Map ID	Applicant Name	Drilling Project Title	Target Commodities
1	ACH Nickel Pty Ltd	Kenilworth Magnetic Anomaly	Au, Ni
2	Agnew Gold Mining Company	Agnew Strategic Stratigraphic	Au
3	Anglo Australian Resources NL	Feysville	Au
4	Antipa Minerals	Citadel Project	Cu, Au
5	Antipa Minerals	Minyari Dome IP	Au, Cu
6	Aphrodite Gold Ltd	Phi North Deep	Au
7	Apollo Phoenix Resources Pty Ltd	Carr Boyd	Ni, Cu, PGE
8	Austral Pacific Pty Ltd	Paris Gold Project	Au, Ag, Cu
9	Australian Mines Ltd	North Dovers Stratigraphic	Cu, Au
10	Black Raven Mining	Erayinia King North	Au, Cu, Zn
11	Chalice Gold Mines Ltd	West Musgraves La Serena, Harvarti & Manyas	Ni-Cu-PGE
12	Chalice Gold Mines Ltd	West Musgraves Pepperjack & Rokpol	Ni-Cu-PGE
13	Encounter Resources Ltd	Telfer West Project	Au, Cu
14	Encounter Resources Ltd	Fishhook	Cu, Co
15	Fortescue Metals Group	Separation East	Cu, Au
16	Fortescue Metals Group	Separation Graben	Cu, Au
17	Fortescue Metals Group	Rudall West	Cu, Au
18	Gold Road Resources	Hann Structural Corridor	Au
19	Impact Minerals Ltd	Mulga Tank Pan Handle	Ni, Cu, Au, PGE
20	IronRinger (Tarraji) Pty Ltd	Tarraji	Cu, Zn, Au
21	Kairos Minerals Ltd	Roe Hills Project	Ni, Cu
22	Key Petroleum (Aust) Pty Ltd	Wye Knot-1	Petroleum
23	Lodestar Minerals Ltd	Contessa Gold Prospect	Au
24	MB Exploration Pty Ltd	Lakes Edge Project	K
25	Meridian (Lennard Shelf) Pty Ltd	Mt Talbot North	Pb, Zn
26	Middle Island Resources Ltd	Two Mile Hill BIF Deeps	Au
27	Minjar Gold	Curara Well	Au
28	Mt Magnet Gold Pty Ltd	Morning Star Deeps	Au
29	Poseidon Nickel Ltd	Abi Rose Genesis	Ni
30	Quadrio Resources Pty Ltd	Calingiri	Cu
31	Rio Tinto Exploration	Budjidown	Cu, Au
32	Rox Resources Ltd	Camelwoop deeps	Ni
33	Sipa Exploration NL	Paterson North	Au, Co

34	Traka Resources	West Musgraves Munster & Cambozola	Ni-Cu-PGE
35	Ventnor Resources Pty Ltd	Silver Dragon Copper Nickel Project	Cu, Ni
36	Baracus Pty Ltd	Mt Dockerell	Au
37	Christopher Potts	Mc Auley	Au
38	David Pascoe	New Waverley	Au
39	Mendelyarri Pty Ltd	Proprietary Project	Au
40	Moving Rock & Resources Pty Ltd	Braemore Project	Au
41	Peter Kerley	Never Can Tell	Au
42	Zebina Minerals Pty Ltd	Mizina / Coralie Prospect	Au

16. List of successful applicants for Round 15 of the Co-funded Drilling program

Co-funded Drilling Round 15, 2017/18



Map ID	Applicant Name	Drilling Project Title	Target Commodities
1	Antipa Minerals	Greater Rimfire	Au-Cu-W
2	Antipa Resources Pty Ltd	Minyari	Au; Cu
3	Ausgold Exploration P/L	Katanning Gold Project Regional Drilling	Au
4	Ausinox Pty Ltd	Chromite Reef	Cr, Cu, Ni, PGE
5	Buxton Resources Ltd	Double Magic	Ni; Cu; Co
6	Canning Potash Pty Ltd	West McLarty	Potash
7	Cassini Resources Ltd	West Arunta Project	Zn Pb
8	Chalices Gold Mines Ltd	Ashburton Gold Project	Au
9	Comet Resources Ltd	Springdale Graphite	Graphite
10	Cygnus Gold Ltd	Stanley	Au
11	Dacian Gold Limited	Westralia Deep Stratigraphic Drilling	Au
12	De Grey Mining Limited	King Col Pegmatite	Li, Ta
13	Draig Resources Ltd	Bellevue Gold Project	Au
14	Empire Oil Company (WA) Limited	North Erregulla Deep-1	Oil
15	Encounter Resources Ltd	BM2	Zn
16	FQM Exploration (Australia) Pty Ltd	Rhea Copper Project	Cu
17	Geocrystal Limited	Webb Diamonds	Diamonds
18	Great Boulder Resources	Yamarna JV	Cu, Ni
19	Greenmount Resources Pty. Ltd.	Karlawinda Strat/Fault	Au
20	MacPhersons Resources Ltd	Boorara	Au
21	Maria Resources Pty Ltd	Lennis	Ni, Cu Pb Zn PGE Co
22	Metals X Limited	Finch Prospect	Cu, Pb, Zn
23	Northern Star Resources Ltd	Back Flag Group	Au
24	Pioneer Resources Limited	Pioneer Dome	Li, Cs
25	Red Metal Limited	Forrest Project	Cu; Au
26	Red Metal Limited	Sharon Dam	Cu Au
27	Redstone Resources Ltd	Tollu	Cu, Ni, Co
28	Reed Exploration Pty Ltd	QVR Nickel Project	Massive nickel sulphides
29	RNI NL	Wodger VMS Target	Au-Cu
30	Silver Lake Resources	Stratigraphic characteristics Daisy Milano	Au
31	Sipa Exploration NL	Paterson North Dome	Au, Cu, Pb, Zn
32	St. Ives Gold Mining Company (Pty) Limited	Invincible South	Au
33	Syndicated Metals Ltd	Old Copper	Au
34	Traka Resources Limited	Mt Morphett Project	Ni-Cr-Cu-PGE
35	Venture Minerals Ltd	Caesar Project	Cu; Ni; Co
36	Venturex Resources Ltd	Mons Cupri South VHMS	Zn-Cu-Pb-Ag-Au
37	Australian Live-stock Suppliers Pty Ltd	Derrys Own Extensions	Au
38	Charles Chitty –Yayhoo Mining Pty Ltd	Lehmans Well Project	Au & Base Metals
39	Christopher Potts	Lakewood	Gold
40	Cranston Edwards	Mayday Prospect	Au
41	Matthew Eggelston	Bardoc	Au
42	Phillip Winton Warren & Arne Olavi Eriksson	Gum Creek East	Au
43	Steven Kean	Binduli North	Au

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