

GEOLOGICAL SURVEY ANNUAL REVIEW 2020–21



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

Geological Survey of
Western Australia



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Based on consultation with the Western Desert Lands Aboriginal Corporation (WDLAC) on the cultural significance of the name, Waukarlycarly, it has been agreed to change the name of the well to Barnicarndy 1 and the tectonic subdivision to Barnicarndy Graben. This and all future publications will now refer to the Barnicarndy 1 stratigraphic drillhole (previously Waukarlycarly 1) and the Barnicarndy Graben (previously Waukarlycarly Embayment).

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Cover image: On the way to Kermit's Pool, Karijini National Park, Western Australia (photo by L Brisbout, DMIRS)

Page iv image: Limestone pillars known as The Pinnacles in the Nambung National Park near Cervantes, Western Australia (photo by B Striewski, DMIRS)

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Year in review

2020–21



As I look back on 2020–21, I see the resilience, innovation and ‘can do’ attitude of the dedicated staff at the Geological Survey of Western Australia (GSWA). Faced with extraordinary circumstances and the vision we made last year on making data available sooner, GSWA developed, implemented and delivered the Accelerated Geoscience Program (AGP) resulting in an eye-watering 1088 data layers in 88 datasets covering four main themes:

1. Publication of existing data into GIS layers
2. Data integration and analyses – the Yilgarn Craton
3. Statewide critical minerals prospectivity study
4. Energy systems including petroleum, geothermal, and carbon capture and storage.

GSWA has successfully steered through virtual meetings and conferences and is now generating webinars to send our message to investors both at home and overseas. In fact, this year I have done more international travelling than ever before, but virtually and in the comfort of my home or office.

The past year has seen further changes in the Leadership Team. Deavi Purnomo joined us as the Chief Geoscience Information Officer in October 2020, and Paul Duncan was appointed General Manager, Geoscience and Titles Information in the middle of the year.

GSWA has developed a 10-year strategy, which provides direction for the organization in four key areas:

- Garnering geoscientific knowledge – building our geological understanding of the State through precompetitive data acquisition and synthesis by utilizing collaborative research and strategic partnerships
- Transforming our data – transforming the way we store, analyse and deliver our data to ensure our vast repository can move fluidly with emerging technology and innovation
- Strengthening our team – ensuring we are building capacity for a high-performing workforce by attracting people with exceptional skills, developing and stretching their capabilities, ensuring they have the resources to excel, and encouraging innovation
- Providing trusted information – providing trusted geoscientific information and advice to our community, our government and our resources industry.

This Work Program strategy resulted in 35 text publications, six geological maps, 16 geoscience posters and 20 commodity flyers being released during the year in addition to the AGP work published. GSWA has also published the 2020–21 edition of the Mineral and Petroleum Statistical Digest along with the downloadable resources data files for 2020 and 2020–21, generated by the Resource Strategy team.

GSWA continued to generate exciting precompetitive geoscience data through the AGP, with the release of the Southwest Yilgarn 2021 Geological Exploration Package (GEP), the Far East Yilgarn GEP, the Critical Minerals GEP, and the Energy Systems Atlas.

Year in review

The Statutory and Resource Information branch ensured that all Western Australian Mineral Exploration index (WAMEX) reports not available in a non-optical recognition format were converted into the appropriate format. An external Amazon Web Services (AWS) website was launched. This allows for text searching of all WAMEX reports that are currently available on a hard drive which is released biannually.

This year, a series of new MINEDEX reports was developed to make it easy for users to work with resource estimate data that is compliant with industry presentation standards. The Western Australian Petroleum and Geothermal Information Management System (WAPIMS) enhancements included the addition of a new group of layers in WAPIMS map under Energy Systems Atlas, the addition of age to the Formation Tops reference table and its display on the formation top grid including links with the Explanatory Notes System (ENS), new columns in Data by Depth and the implementation of an 'Online lodgement grid' to monitor data submission registered through the Petroleum and Geothermal Register (PGR).

Commodity flyers had a makeover as did some of the Report covers and posters.

The Energy Geoscience and Carbon Strategy branch continued to develop consistent, basinwide stratigraphic, structural and energy system frameworks for Western Australia's onshore sedimentary basins. The aim is to encourage increased exploration for petroleum, helium, geothermal and emerging energy resources (such as natural hydrogen) and assess the potential for CO₂ sequestration, to secure the State's energy future.

As part of the AGP, the Energy Geoscience and Carbon Strategy branch participated in developing the Energy Systems Atlas within the WAPIMS map.

Land Use Planning has been heavily involved in the government initiatives around Plan for Our Parks, the South West Native Title Settlement and other land use planning programs.

In 2020–21, the Exploration Incentive Scheme (EIS) Co-funded Exploration Drilling Program gained a \$5 million boost which enabled an increase in funding for Rounds 22 and 23 of the Co-funded Drilling Program and the introduction of the Energy Analysis Program.

Rounds 20 (2020) and 21 (2020–21) of the Co-funded Drilling Program had completion rates of 61% and 69%, respectively, compared to the historical average of 58%. The first round of the Energy Analysis Program allocated a total pool of \$250 000. Significant outputs in precompetitive data were also achieved including geophysical, geochemical and geochronology projects. Notably, the acquisition of second-generation gravity for the Pilbara completed the State coverage.

Western Australia and its resources sector continued to navigate the global COVID-19 pandemic successfully to deliver mineral and petroleum sales valued at a record \$210 billion in 2020–21.

The result was driven almost entirely by the iron ore industry, which recorded sales valued at a massive \$155 billion. It was achieved via all-time high iron ore prices which exceeded US\$200 per tonne for the first time on the back of ongoing tight supply and stronger demand in China's steel industry.

To put this into perspective, iron ore industry sales in 2020–21 were valued at more than all mineral and petroleum sales from Western Australia just two years ago.

Gold sales were valued at \$16.6 billion (with nearly 6.7 million ounces of gold sold), caused by prices hitting record levels in US dollar terms amid ongoing economic uncertainty created by the COVID-19 pandemic and trade and geopolitical tensions.

Year in review

This astounding result was countered by a downturn in the petroleum industry with the value of liquefied natural gas (LNG) (down \$11 billion or 41% on 2019–20), condensate (down \$1 billion or 21%), and crude oil (down \$965 million or 36%) sales all decreasing.

The falling sales of LNG and condensate were due to a combination of the aftermath of oil prices falling to their lowest level in 20 years, and lower sales quantities amid operational issues and maintenance shutdowns.

As a result, the mining of minerals increased its position as the dominant activity in the State's resources sector with \$186 billion in sales, accounting for 89% of all mineral and petroleum sales. Conversely, the petroleum sector's share of total sales dropped to 11% in 2020–21, its lowest level since prior to the development of the North West Shelf project in the late 1980s.

A similar pattern was observed in the exploration sector.

Mineral exploration activity in Western Australia continued to strengthen in 2020–21 and expenditure was at its highest level since 2012. The State's share of national mineral exploration expenditure also increased to 65%, highlighting the fact that overall growth in exploration expenditure for the country as a whole was overwhelmingly due to Western Australia's success.

Petroleum exploration did not fare as well and was at its lowest level since 1996–97, reflecting cuts to exploration budgets amid ongoing overall weak oil prices.

In conclusion, 2019–20 has been a year of consolidation and realignment for the division. Upon entering 2020–21, the focus is on further refining our direction, strategies and products.



EXECUTIVE DIRECTOR

Note: all currencies are Australian dollars unless otherwise indicated.

Overview of exploration and development trends

Western Australia has a globally significant, diversified, resources sector. It is currently the world's largest supplier of iron ore and lithium, the second largest exporter of alumina, diamonds and garnet, and was among the top five jurisdictions for the production of cobalt, gold, LNG, nickel, rare earth elements (REE), salt and zircon. The State was also in the top 10 for manganese, ilmenite and rutile output.

The minerals and petroleum industries are leading contributors to the Western Australian economy, delivering wealth, jobs, investment and revenue to the State and its people.

Nickel sales were valued at a seven-year high of \$3.5 billion on higher volumes and an increase in prices to a level last sustained eight years ago at a time of parity between the US and Australian dollar.

These positive results were countered by a downturn in the petroleum industry due to a combination of lower sales quantities and overall weak prices. The value of LNG (down \$11 billion or 41% on 2019–20), condensate (down \$1 billion or 21%), and crude oil (down \$965 million or 36%) all dropped.

Investment

Western Australia has a strong pipeline of investment projects across a diverse range of commodities that will help to sustain such results and secure the State's position as a globally significant minerals and petroleum producer.

Of particular significance, BHP's South Flank iron ore project, Mineral Resources' Wonmunna iron ore project, and Capricorn Metals' Karlawinda gold project, among others, all entered production during the year, and will contribute to the State's minerals output in the coming years.

As of September 2021, Western Australia had resources projects in the development pipeline valued at an estimated \$127 billion.

Over the past year, several significant new projects were announced including:

- Northern Star Resources' Fimiston South cutback at the Super Pit
- BHP's Western Ridge iron ore project
- Newcrest Mining's Telfer West Dome Stage 5 gold project
- King River Resources Limited's Kwinana high-purity alumina plant
- Talison Lithium's Greenbushes tailings retreatment plant.

There was also a significant number of projects that progressed to a final investment decision or construction including:

- APA Group's Northern Goldfields Interconnector pipeline
- Bellevue Gold's namesake gold project
- Chevron's Jansz-lo compression project
- Covalent Lithium's Mount Holland lithium project
- Galena Mining's Abra lead project
- Mitsui and Co's Waitsia Stage 2 gas expansion

Overview

- Newcrest Mining's early works program at Havieron
- Nickel West's expansion plans at Mt Keith and Northern Goldfields solar project
- Northern Star Resource's Thunderbox mill expansion
- Red 5's King of the Hills expansion
- Strandline Resources' Coburn mineral sands project
- Wiluna Mining's Stage 1 growth project at Wiluna
- Woodside's Pluto – North West Shelf Interconnector and Greater Western Flank Phase-3 projects.

Exploration

Ongoing exploration and new discoveries expand the pipeline of investment projects, ensuring the sustainability of the resources sector.

Mineral exploration expenditure in Western Australia was \$2.1 billion in 2020–21, an increase of 21% from \$1.7 billion in 2019–20 and its highest level since 2012.

Growth in mineral exploration expenditure was mainly due to increased spending on gold (up \$286 million), supported by record high prices. The other notable increases in spending were for iron ore (up \$106 million) and nickel–cobalt (up \$36 million), again reflecting higher prices for these commodities.

These commodities also represented the main targets of mineral exploration in Western Australia: gold (52%), iron ore (22%) and nickel–cobalt (9%). Spending on gold exploration in Western Australia surpassed \$1 billion for the first time in history, while iron ore exploration (\$455 million) was at its highest level since 2013–14 and nickel–cobalt exploration (\$185 million) recorded a nine-year high.

The COVID-19 pandemic appears to have had a temporary impact on overall exploration activity and spending in the State. This was isolated to the heights of restrictions including limits on regional travel during the June quarter 2020. The September quarter 2020 represented a return to growth that continued throughout the rest of 2020–21.

The pandemic has perhaps had a more pronounced and lasting impact on the location of exploration after concerns over access to some remote parts of the State led to the cancellation and scaling back of exploration programs in greenfields areas. While exploration targeting new deposits still increased marginally (by 5%) during the year, spending on existing deposits increased markedly (31%). The end result was that the share of expenditure in greenfields areas compared to brownfields areas was 33% in 2020–21, down from 38% the previous year.

Petroleum exploration expenditure in Western Australia was down to \$442 million, its lowest level since 1996–97, reflecting cuts to exploration budgets amid ongoing overall weak oil prices.

Lower petroleum exploration spending in Western Australia, combined with increased expenditure in Queensland, resulted in Western Australia's share of the national spend declining to a new single-year average low of 44%.

Exploration activities during the year targeted a range of geological areas and prospects across the State.

Overview

The Goldfields and Mid West regions remain a hotspot of exploration activity with significant discoveries, upgraded resources, and drilling activities announced during the year:

- **Mid West**

- Cobalt mineralization was discovered at the Mt Labouchere prospect, an area traditionally prospective for manganese, with results from shallow drilling including 5 m at 0.24% copper, 0.20% cobalt and 0.12% nickel
- High-grade gold intersections were found at the Trident prospect within the Marymia project including 9 m at 26.2 g per tonne gold from 137 m
- Drilling results were announced for Eelya South that included 3 m at 3.78% copper, 6.68 g per tonne gold and 81 g per tonne silver
- The Bellevue mineral resource estimate increased to 3.0 million ounces gold following inclusion of the Marceline and Deacon North lodes
- High-grade drilling was announced for the White Heat prospect at the Break of Day deposit with results of 3.4 m at 107.6 g per tonne gold from 74.6 m, including 1.2 m at 303.2 g per tonne gold from 74.6 m
- The mineral resource estimate for the Menari and Menari North deposits (part of the Lucky Bay project) increased significantly to 438.8 million tonnes at 4.3% heavy minerals and 86.2% garnet for 18.8 million tonnes of heavy minerals and 16.2 million tonnes of garnet
- Drilling at the Lockyer Deep-1 well to a depth of 4000 m identified a significant gas discovery in the Kingia sandstone.

- **Goldfields**

- A new zone of gold mineralization was discovered at the Ida Valley project
- A new zone of gold mineralization was discovered at the Mulgabbie North project, with drilling results including 4 m at 5.02 g per tonne gold and 10 m at 2.8 g per tonne gold (including 1 m at 21.6 g per tonne gold) from 17 m
- A new nickel zone referred to as Gamma 50C has been announced at Beta Hunt. This hole was drilled under the EIS and encountered significant nickel intersections of 4.6 m at 11.6% nickel from 135.1 m including 2.2 m at 18.4% nickel, 0.3 m at 1.2% nickel from 193.6 m, and 1.8 m at 2.4% nickel from 161.95 m. This followed another significant nickel discovery called 30C Nickel Trough with results that include 1.2 m at 7.2% nickel and 2.2 m at 4.1% nickel
- High-grade gold mineralization was discovered at the Scotia prospect in the Central Norseman project, representing the first drilling program into the Noganyer Formation
- A single shallow infill hole drilled for advanced metallurgical and research and development studies returned the highest ever recorded gold intercept at Kat Gap of 10 m at 40.5 g per tonne gold from 26.5 m including 0.5 m at 592.0 g per tonne from 28.5 m

Overview

- Drilling results at the Dusty prospect confirmed 4.5 m of cumulative massive nickel sulfides were intersected with an average grade of 3.91% nickel, 0.34% copper, 0.13% cobalt and 0.45 g per tonne platinum and palladium
- Bonanza grades were intersected at the Cox's Find main lode with results including 5.65 m at 80.0 g per tonne gold (as well as 1.1 m at 404 g per tonne gold)
- Drilling results from the Investigators prospect within the Mt Alexander project, confirmed a thick interval of high-grade nickel–copper sulfides with results of 11.07 m at 1.58% nickel, 0.71% copper, 1.23 g per tonne total platinum group elements from 333.5 m including 3.9 m at 3.98% nickel, 1.8% copper, 3.1 g per tonne total platinum group elements
- A maiden underground inferred mineral resource of 18.47 million tonnes at 1.47 g per tonne gold for 0.87 million ounces of gold was announced for Gruyere.

Increased interest and activity across the remainder of the State have also led to several other significant exploration announcements in the past year:

- **Wheatbelt**

- Further high-grade drilling results from the Julimar Gonneville intrusion eastern footwall contact included 14 m at 4.2 g per tonne palladium, 1.1 g per tonne platinum, 0.2 g per tonne gold, 0.5% nickel, 0.8% copper and 0.03% cobalt from 85 m
- A maiden inferred mineral resource estimate was announced for the Cloud Nine Halloysite–Kaolin deposit following the completion of a maiden drilling program in 2020.

- **Albany–Fraser**

- Drilling continued at the Mawson prospect, part of the Rockford Project with recent results reported of 14.45 m at 2.63% nickel, 2.09% copper, and 0.14% cobalt from 162.05 m
- Nickel–copper mineralization was intersected at the Lantern South prospect, with 41 m at 0.19% nickel and 0.14% copper from 55 m.

- **Pilbara**

- Several zones of massive nickel–copper sulfides were intersected at Andover, including the VC-07 East target with drilling results of 7.15 m at 2.28% nickel and 0.57% copper from 135.4 m including 4.25 m at 3.59% nickel and 0.78% copper from 137.1 m
- A maiden indicated and inferred mineral resource estimate of 192 million tonnes at 1.1 g per tonne gold for 6.8 million ounces of gold was announced for Hemi
- A new lithium–tantalum discovery in spodumene-hosted pegmatite dykes was announced for the Marble Bar project, followed by a maiden inferred resource estimate of 10.5 million tonnes at 1.0% lithium oxide and 44 parts per million tantalum pentoxide.

Recurrent budget

Since the Machinery of Government changes, the Geological Survey work program and the Annual Review have primarily followed the role of reporting against projects which were historically managed in the previous incarnation of GSWA within the Department of Mines and Petroleum. As time has progressed, it has become more evident that the entire division is responsible for the outcomes of GSWA assisting multiple areas across the Department of Mines, Industry Regulation and Safety (DMIRS) and, externally, enhancing the exploration potential of the State. With this in mind, the budget summary reflects the entire divisional budget. However, Table 1 itemizes the Geological Survey and Resource Strategy Division (GSRSD) directorates to permit a comparison with previous years.

For the 2020–21 financial year, the GSRSD had some internal organizational changes associated with the introduction of a new directorate, Geoscience Data Management. With the recruitment of a new Chief Geoscience Information Officer, the responsibilities for data delivery and services were moved from the Geoscience Titles and Information branch into the Geoscience Data Management directorate. Along with this organizational change, salaries and a small proportion of operational funds were also moved. The financial change will not be fully reflected until 2021–22, and any incremental changes for the 2020–21 financial year are shown in Table 1.

The total budget for GSRSD was \$36 million (excluding departmentally funded projects). This can be separated into \$15 million towards the EIS and the remaining \$21 million for GSRSD overall. The total expenditure against this was \$36.265 million overall (salary and non-salary inclusive).

Figure 1 illustrates GSRSD directorates' salary and non-salary budgets vs actual expenses in 2020–21. All reference to the EIS budget and expenses are discussed in a later section (see Exploration Incentive Scheme – overview and major achievements).

Staffing

The total number of public sector staff employed by GSRSD at the end of the financial year was 174 people (equivalent to 171.6 full-time equivalents [FTE]) with a revised recurrent salary budget allocation of \$17.36 million. The full FTE breakdown per directorate can be seen in Table 1. With the inclusion of the eight EIS-funded positions (seven occupied in 2020–21), the total salary budget was \$18.24 million.

GSRSD was within the overall budget allocation with a reduction in salary expenses and within the acceptable variance for non-salary expenses. This does not include the four Mining Rehabilitation Funded (MRF) positions, funded through the MRF program.

Table 1. Comparison of allocated recurrent budget and expenditure for GSRSD including the breakdown for directorates and branches

Directorates and business areas	Budget		Actual expenses		FTE	No. of staff
	Salaries	Non-salaries	Salaries	Non-salaries		
Executive and Administration Support	\$1 154 279	\$140 000	\$1 298 581	\$82 794	6.0	6
Minerals and Petroleum Resources Studies	\$5 416 019	\$888 308	\$5 376 416	\$847 646	51.5	52
Regional Geoscience Mapping Projects	\$3 870 201	\$343 861	\$3 776 107	\$332 256	33.3	34
Core Libraries and Field Support	\$1 202 474	\$897 375	\$1 193 966	\$844 329	17.0	17
Geoscience Editing and Publishing, incl. Titles Information	\$3 921 246	\$1 337 182	\$3 802 481	\$1 401 564	44.2	45
Geoscience Data Management	\$604 250	\$20 000	\$461 520	\$30	1.0	1
Resources Strategy	\$1 191 141	\$110 000	\$1 367 030	\$47 075	12.0	12
EIS	\$882 838	\$14 027 004	\$746 553	\$13 494 380	6.6	7
Totals	\$18 242 447	\$17 763 730	\$18 022 653	\$18 242 447	171.6	174.0

All budget calculations exclude hydraulic fracturing, MRF, Tjiwarl and State Batteries

Recurrent budget

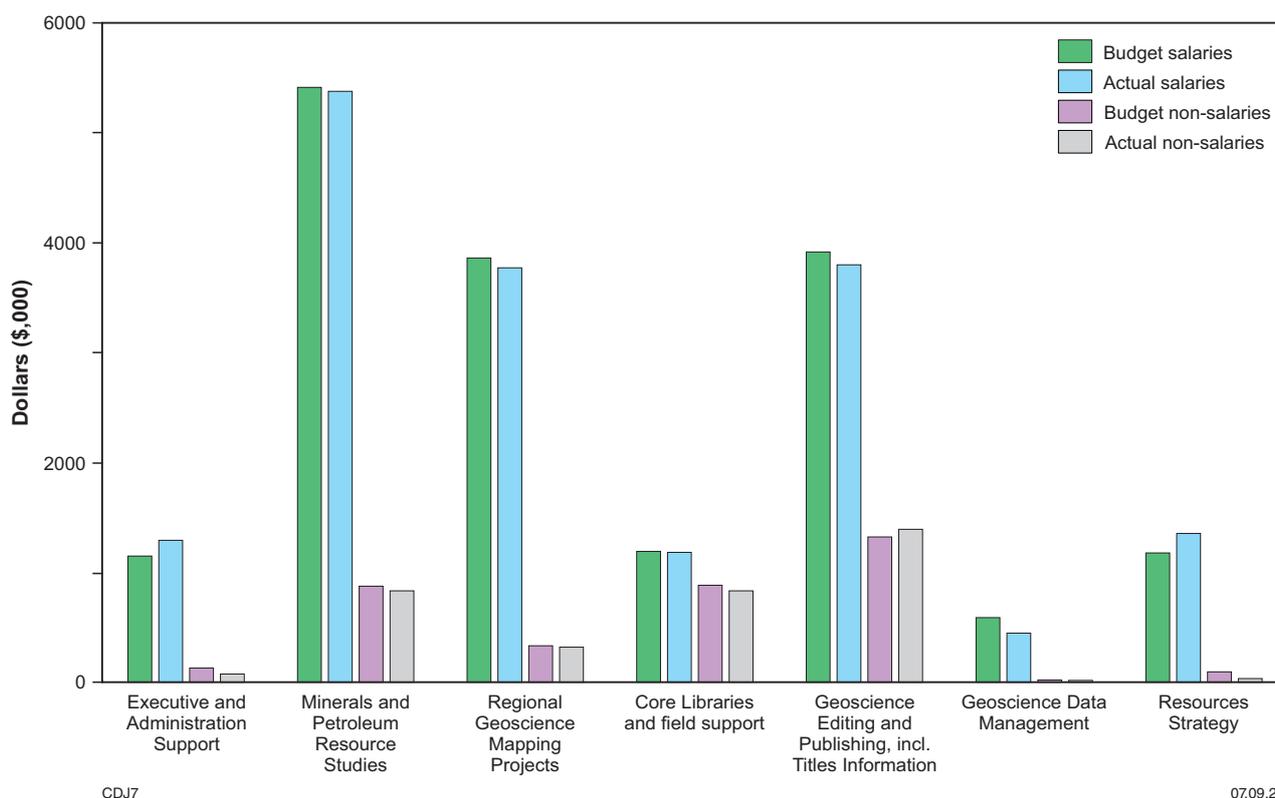


Figure 1. Comparison of budget for GSRSD and actual expenditure for 2020–21 financial year

At the end of the financial year, GSRSD employed seven fee-for-service (FFS) contractors for short-term and finite projects.

Collaborative projects

Thirty-eight collaborative projects were commenced or ongoing in 2020–21 with a total of nine completed in the financial year. Further details are provided in Appendix 1.

Publications

As reported in the Geological Survey work program 2020–21, GSWA forecast the publication of four maps, 28 text publications (not including posters) and seven data packages. The final count for these categories on 30 June 2020 was five maps, 32 text publications and 17 data packages. Since 2019–20 there has been a move away from Geological Series maps to digital seamless layers delivered via data packages. This is reflected in the reduced number of maps released, and the addition of the new measure to count digital layers as shown in the Appendices. GSWA published a total of 70 posters (compared to 82 in the previous financial year) which were presented at conferences, GSWA Open Day and other events throughout the year. Given the reduced physical attendance at interstate and international conferences due to COVID-19 border closures, this number of posters is indicative of GSWA’s commitment to promoting the State’s resource potential to interested stakeholders.

GSWA provides a diverse array of data and services funded through appropriated and EIS funding. The Appendices highlight a range of GSWA’s published data, products, advice and services for 2020–21.

Program review

Accelerated Geoscience Program

The Geological Survey of Western Australia (GSWA) reprioritized its 2020–21 work program due to the impact of travel and operational restrictions imposed by the COVID-19 pandemic. By using its extensive, geoscience datasets and outstanding rock and paleontology collections, GSWA's Accelerated Geoscience Program (AGP) aimed to aid economic recovery and stimulate the exploration industry. GSWA delivered new interpretive datasets across all areas of geoscience in key regions of the State, accelerating understanding of the geology and mineral prospectivity of the regions.

AGP main projects

Dedicated geoscientists from across GSWA concentrated their efforts on four main projects:

1. Publication of existing data into GIS layers
2. Data integration and analyses – the Yilgarn Craton
3. Statewide critical minerals prospectivity study
4. Energy systems including petroleum, geothermal, and carbon capture and storage.

The AGP delivered 100 new interpreted datasets across the four projects, consisting of 1088 interpreted data layers that comprised original work by GSWA and repurposed or reprocessed data originating from other organizations. Many of the layers were published online, and are available through the Data and Software Centre, GeoVIEW.WA and the Petroleum and Geothermal Information Management System (WAPIMS). However, most of the data are available within three standalone Geological Exploration Packages:

- Southwest Yilgarn, 2021
- Far East Yilgarn, 2021
- Critical minerals, 2021.

These standalone packages facilitate use for all levels of technical competency and software, from prospectors to Tier 1 companies. As these datasets formed part of the State's economic recovery from COVID-19, the three Geological Exploration Packages are available at no cost from the First Floor counter in Mineral House and at other events attended by GSWA.

Publication of existing data into GIS layers

This project delivered previously non-digital datasets as new spatial datasets. The majority of the 13 new datasets (160 layers) were delivered at the State scale and provide a significantly improved understanding of the prospectivity of Western Australia. These new results feed into other projects in the AGP.

Data integration and analyses – the Yilgarn Craton

The Yilgarn Craton is one of Western Australia's most prospective regions and contains significant deposits of gold, nickel, lithium, copper–zinc, iron ore, tantalum, aluminium and uranium. Recent high-grade gold and nickel discoveries in the craton's far eastern (Gruyere, Tropicana, Neale) and southwestern margins (Julimar), have shown that these two poorly exposed and geologically not well-understood regions are likely to be as prospective as the craton's interior (i.e. Eastern Goldfields). Despite both regions being covered by a thick blanket of regolith, GSWA holds a vast amount of geoscientific data relating to the bedrock as well as the regolith geology. This data has the potential to facilitate the discovery of significant new mineral deposits under cover.

Program review

The minerals industry is increasingly aware that the new era of Tier 1 deposits is likely to be under deep cover. Working to the UNCOVER plan, the AGP delivered 55 new integrated geoscience datasets (500 layers) for the southwestern and far eastern Yilgarn Craton margins. The program also incorporated the results of ongoing work in the Eastern Goldfields, and performed new analyses on archived samples.

Statewide critical minerals prospectivity study

Both the State and Federal Governments outlined a list of minerals that are deemed critical for emerging high-tech applications and are considered essential for economic and industrial development over the next decade. Western Australia is well placed to capitalize on increasing demand for critical minerals as we transition globally to low-carbon technologies. Knowledge of the geological settings where these deposits are likely to be located not only reveals emerging exploration plays but allows the government the foresight to manage land for strategic industrial purposes such as downstream processing.

The aim of this project was to catalogue the known critical mineral resources of the State to better understand the mineral systems in which they occur and the associated alteration systems. The program delivered 20 new datasets consisting of 251 new layers that can help to define new exploration targets and to stimulate and increase investment in the critical minerals sector by releasing new parts of the State to exploration.

Energy systems including petroleum, geothermal, and carbon capture and storage

This project created 12 new datasets consisting of 129 data layers that critically define elements of petroleum and geothermal systems to enhance regional understanding of the prospectivity of the State's potential energy resources, including low-carbon technology.

The petroleum industry was one of the most affected by COVID-19, having a simultaneous supply and demand shock caused by an oil price war that coincided with the start of the pandemic. The goals of this project were to produce a graphic summary of the State's well data, in addition to other GIS layers, that directly benefit petroleum industry exploration.

Detailed results are presented in [Record 2021/4 Accelerated Geoscience Program extended abstracts, 2021](#).

The business improvement aspects of the economic recovery are integrated in individual projects.

Program review

GS10 Energy Geoscience and Carbon Strategy

Manager: Deidre Brooks

Objectives

The primary goal of the Energy Geoscience and Carbon Strategy branch is to develop consistent, basinwide stratigraphic, structural and energy system frameworks for Western Australia's onshore sedimentary basins. The aim is to encourage increased exploration for petroleum, helium, coal, geothermal and emerging energy resources (such as natural hydrogen) and assess the potential for CO₂ sequestration, to secure the State's energy future.

Currently, the branch's main focus is the Canning, Carnarvon and Perth Basins. These basins have proven petroleum systems and are underexplored, particularly in the case of the vast Canning and Officer Basins. The branch is also contributing to geological mapping and new reviews of the Western Australian portion of the Centralian Superbasin, including the Amadeus and Officer Basins, and interpreting results to better understand the energy potential of these older basins.

As part of the AGP, the Energy Geoscience and Carbon Strategy branch participated in developing the Energy Systems Atlas within the WAPIMS map.

Highlights and activities

- Compilation of petroleum geochemistry data was completed and incorporated into a Report and data package on the petroleum source rocks of Western Australia. The Report underwent extensive review leading to substantial modifications during 2020–21. The report therefore will not be released until 2021–22
- Geophysical interpretation and mapping of the southern Canning Basin continued. Interpretation of the AEM data commenced and results will be incorporated into the seismic interpretation of the Kidson Sub-basin, Ryan Shelf and Crossland Platform, which will be the final area covered by this project. The latest interpretation utilizes the results from the Barnicarndy 1 stratigraphic well drilled in 2019, the EIS and Geoscience Australia's (GA) Exploring for the Future (EFTF) co-funded Kidson Sub-basin seismic survey and the reprocessed vintage 2D seismic lines which were both completed in the 2018–19 financial year
- Building 3D depth models of significant geological surfaces in the southern Perth Basin and western Canning Basin were completed and released in September 2020
- A publication on the stratigraphy and biostratigraphy of the Grant and Reeves Formations of the Canning Basin was completed in the 2019–20 financial year and was released in December 2020
- In collaboration with Curtin University, work progressed on the Western Australia unearthed book on the Mesozoic of Western Australia
- The Sally May 2 Digital Core Atlas was released through WAPIMS in June 2021
- GS10 projects placed on hold or delayed due to the post-well analysis and interpretation of Barnicarndy 1 include:
 - compilation of Digital Core Atlas for Nicolay 1
 - a review of the Cobb Embayment of the Canning Basin
 - geological studies on the Ordovician, Canning Basin
 - a Report on the structure and stratigraphy of the western Amadeus Basin
 - a Record on the bitumen recovered in Goonderoo 1 and 1A, Moora Basin.

Program review

Products released

- Report 207 Mid-Carboniferous – Lower Permian palynology and stratigraphy, Canning Basin, Western Australia
- 3D digital product – 3D depth model of the southern Perth Basin
- 3D digital product – 3D depth model of the western Canning Basin
- Sally May 2, Canning Basin: Digital Core Atlas (interactive flipbook)
- New precompetitive sample analyses released in 2020–21 (not including Barnicarndy 1 listed under ES47) is listed below:
 - Samples from the Carnarvon Basin were analysed for organic petrography, geochemistry and palynology and results released through WAPIMS
 - Bitumen analyses
 - » A recently discovered bitumen occurrence in legacy mineral exploration drillcore N1-1 (lower Neoproterozoic, Officer Basin) was confirmed by Gas Chromatography Mass Spectrometry (GCMS) analysis. The data and accompanying petrography will be released through WAMEX
 - Petrography
 - » Outcrop thin sections of carbonates from the Western Australian Amadeus Basin and clastics from the Lucas Outlier (Canning Basin) were prepared by Core Labs as a part of ongoing investigations in those areas
- External publication – see Appendix 5

Program review

GS12 Land Use Planning

Manager: Samantha Carter/Kevin Ridge

Objectives

Land Use Planning 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.

Highlights and activities

- 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, recommendations, advice and where necessary, approvals made accordingly
- Work continued in collaboration with other government agencies on implementing the Plan for Our Parks program, which was announced by the Premier on 20 February 2019. This program involves the creation of 5 million hectares (ha) of conservation estate over five years. As a risk management strategy, 1.2 million ha of additional areas were proposed early in 2020. The branch has played a key role in consultation with the resources industry, prospectivity assessment and input into this whole-of-government project
- A significant volume of assessments, recommendations and approvals were carried out to support the land component for the South West Native Title Settlement (SWNTS) project. The assessment and approvals for the land component will be ongoing over the next few years. After significant legal delays, the six Indigenous Land Use Agreements (ILUAs) were conclusively registered as part of the SWNTS, which formally commenced on 25 February 2021. Additional external funding continued for a geologist to facilitate the branch's role in this project.

Product released

- Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia – 2021 (map)

Program review

GS14 Statutory and Resource Information

Manager: Nicole Wyche

Objectives

The Statutory and Resource Information (SRI) branch tracks mineral exploration and mining activities in Western Australia. The branch collates data on mineralized sites, exploration and mining projects, mineral resources and production. This data allows DMIRS to provide specialist technical advice on commodities to internal and external stakeholders via the Mines and Mineral Deposits business system (MINEDEX), and to produce industry-focused publications. The MINEDEX application also provides data services critical to the function of other DMIRS business systems including the Environmental Assessment and Regulatory System (EARS), Safety Regulation System (SRS) and Royalties Management System (RMS). The SRI branch also has a regulatory role, performing compliance assessments relating to the *Mining Act 1978* and related legislation.

Highlights and activities

- Each month, MINEDEX is visited by around 1200 individual users. Usage is spread over 3000 sessions and 65 000 individual page views. Over 50% of users are new users
- MINEDEX downloads account for three of the top 10 products downloaded from GSWA annually (Table 2)
- This year, a series of new MINEDEX reports have been developed to make it easy for users to work with resource estimate data that is compliant with industry presentation standards. Extracts have also been developed to provide spatial layers of resource estimate data that update daily; for example, with regard to current resource estimates for all gold projects (Fig. 2)
- Delivery from MINEDEX to internal and external customers was changed to centralized portals. For example, all MINEDEX extracts are now provided via the DMIRS Data and Software Centre
- New security roles were created for MINEDEX to allow other work areas to capture data in MINEDEX without compromising data accuracy and integrity. For example, from the 2021–22 financial year, data from Annual Mineral Exploration Reports will be captured in MINEDEX as part of the report assessment process.

Table 2. Rank and number of downloads of MINEDEX products in annual download statistics for all GSWA products

<i>Rank</i>	<i>Product</i>	<i>Downloads</i>
2	Mines and Mineral Deposits (MINEDEX)	6351
6	Mines – operating and under development, WA	2339
9	Major resource projects, WA	1883

Program review

Products released

MINEDEX products received rebranding this year to modernize and standardize their appearance. Products released include:

- Mines – operating and under development, Western Australia – 2021 (map)
- Major resource projects, Western Australia 2021 (map)
- Atlas of mineral deposits and major petroleum projects 2021 (A0 version)
- Atlas of mineral deposits and major petroleum projects 2021 (book)
- Exploration and mining highlights (Hotspots) July 2020 (poster)
- Exploration and mining highlights (Hotspots) February 2021 (poster)
- Lithium (poster)
- Battery metals (poster)
- Flyers in the Investment Promotion series (which provide a summary of resource amounts and distribution, and project development highlights): iron, gold, titanium–zircon, alumina, nickel–cobalt, lithium, vanadium, manganese, rare earth elements, graphite, copper, zinc, lead, potash, antimony, tungsten, chromium, phosphate, diamond, garnet

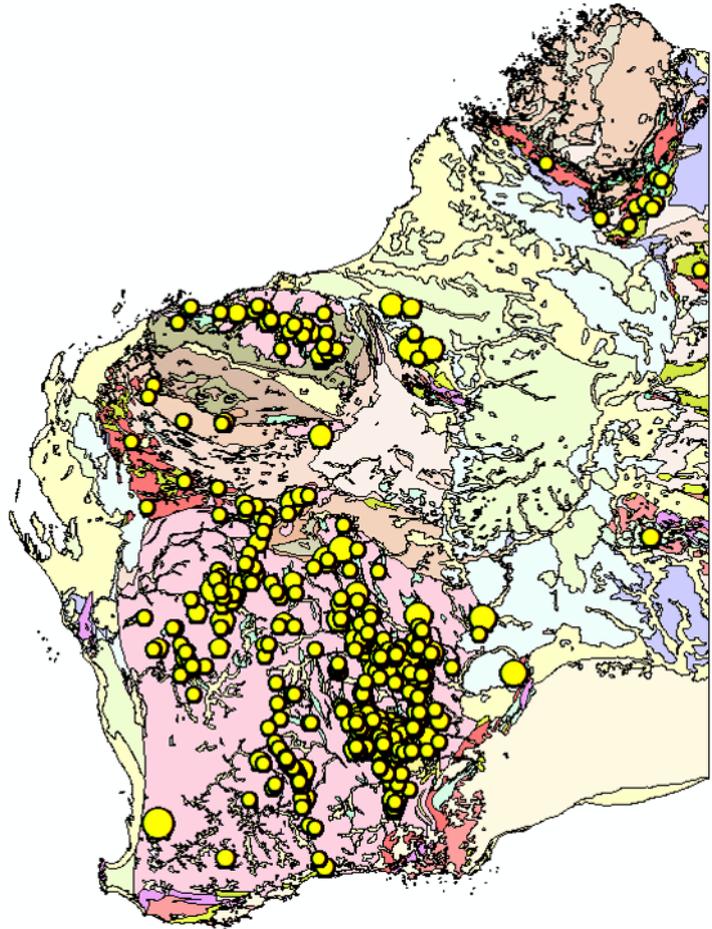


Figure 2. Western Australian gold projects with resource estimates. Project location point is scaled relative to the size of the estimate (base map: generalized regional geology)

Performance metrics

This section is responsible for one Resource and Environmental Regulation performance metric. This metric requires that 80% of all applications for mining leases by Mineralization Report or Resource Report be processed within 21 business days. For the 2020–21 financial year, 98% of applications were reviewed on time.

Program review

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore (transferring to Warren Ormsby)

Objectives

The Minerals Geoscience branch focuses on mineral systems in Western Australia, with the objectives of building metallogenic models and improving our understanding of the geodynamic environment of ore formation, thereby assisting with making exploration targeting in greenfields areas more predictive. Such work typically involves both fieldwork (mapping, core logging, sampling) and laboratory studies (petrology, geochronology, isotope chemistry), and is supported by, and supplements, existing databases. The branch makes extensive use of the HyLogger (GS95) to assist with detailed studies of alteration assemblages in diamond drillcore and other specimens from mineral deposits. The work in this area has been complemented by projects funded by the EIS (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 geographical information system (GIS) packages, and internal and external publications.

Highlights and activities

Much of the 'regular' Mineral Systems program was placed on hold during 2020–21, while the branch contributed to the AGP initiative, a program of rapid data delivery to support recovery of the resources industry during and beyond the COVID-19 pandemic. The Minerals Systems branch lead Project C – Critical Minerals prospectivity – delivering a GIS-based package of geological, mineralogical, geochemical and other data relevant to discovering REE, Li, Ta, potash and other critical minerals. Branch staff were also involved in Mineral Systems-oriented themes in three other AGP projects (Statewide Geoscience, Southwest Yilgarn, Far East Yilgarn).

The branch progressed several strands of its well-established regular program of mineral systems and deposit studies.

Significant upgrades were made to the content of the Mineral Systems Atlas and associated Guide. Systematic analyses completed in the 2019–20 financial year for rare-metal pegmatite and orthomagmatic vanadium systems were translated into 45 new mappable geological proxies for critical metallogenic processes, and published in April 2021.

The study of nickel prospectivity of the northeastern Yilgarn Craton was wrapped up with completion of a study of the fertility for nickel sulfide mineralization of komatiites in the Collurabbie region. The associated GSWA Report is pending.

The results from the study of the Mount Clement syngenetic gold deposit in the Capricorn Orogen were published (Report 209), as were those for the 'fingerprinting' study of detrital gold from the Kurnalpi region (Report 212). The EIS-funded investigation of the provenance and prospectivity of gold in the Pilbara Craton also continued, using 'gold fingerprinting' techniques developed in the pilot study of the Kurnalpi region. The John de Laeter Centre for Isotope Research at Curtin University also commenced a six-month, EIS-funded study to determine whether the timing and the source(s) of Western Australian gold mineralization can be constrained using Pb–Pb and Re–Os radiogenic isotope systematics and other trace element compositions (see ES43 for further details of these EIS-funded projects).

Program review

The study of fluid inclusions from the John Galt hydrothermal vein- and-breccia-hosted REE deposit was near completion and is expected to place constraints on the physical and chemical conditions of mineralization. A Report is pending.

The branch continued its support for several EIS-funded projects (ES36 Participation in MinEx CRC and ES38 Proterozoic Margins), by documenting the geological setting and characteristics of the Obelisk Cu–Au mineralization in the Paterson Orogen, using drillcore stored at the Perth Core Library and sourced from resource companies working in the region. A Report on a study of the prospect is pending.

The Mineral Systems branch underwent some staffing changes during the year, with one member taking extended leave, another exchanging positions with a member from the Land Use Planning branch, and branch management transferring to Warren Ormsby in the 2021–22 financial year, to free the incumbent to develop a new branch (New Energy Systems).

Products released

- Statewide Critical Mineral prospectivity data package (AGP) – published to USB and the Data and Software Centre
- Additions to the Mineral Systems Atlas and Guide – Rare-metal pegmatites (36 layers); Orthomagmatic vanadium (seven layers); tectonic units (two layers)
- Report 209 Syngenetic gold mineralization at Mount Clement – an underexplored mineralization style in the northern Capricorn Orogen
- Report 212 Provenance fingerprinting of gold from the Kurnalpi Goldfield
- External publications – see Appendix 5

Program review

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Jyotindra Sapkota

Objectives

The Eastern Goldfields Superterrane (EGST) occupies the eastern third of the Archean Yilgarn Craton and is widely considered a typical upper crustal granite–greenstone terrane. This highly mineralized region contains world-class gold and nickel deposits, and significant deposits of other commodities including base metals, REE, uranium, gemstones and industrial minerals. The present terrane configuration of the EGST is traditionally interpreted to reflect accretion of a number of pre-existing ‘continents’ in a series of collisional events between c. 2800 and 2650 Ma. However, local abundance of komatiites and associated thick basaltic successions, and the identification of a basement succession broadly similar in age to regions of the western Yilgarn Craton suggests that subsequent closure following the c. 2.7 Ga mantle plume-fed rifting of an autochthonous basement may represent an alternative geodynamic model. 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.

Highlights and activities

- Geological reinterpretation of the volume imaged by the 2019 Ora Banda – Kambalda high-resolution seismic survey
- Field traverses and geochemical, geochronological and isotopic sampling of the granite–greenstone belt across the Kalgoorlie Terrane. More than 200 outcrop samples for geochemistry and three samples for geochronology have been submitted
- Geochemical sampling of diamond drillholes (GSWA and company core libraries) from well-established stratigraphies in support of the Greenstone Stratigraphic Geochemical Barcoding project. About 450 samples for geochemistry and 10 samples for geochronology collected from diamond drillcore in the Norseman region
- Petrophysical analysis of about 2000 samples from diamond drillcore intersecting key Kalgoorlie, Kambalda, Kundana and Yamarna stratigraphies. The samples were analysed for Induced Polarization Galvanic Resistivity, Inductive Conductivity, Magnetic Susceptibility, Remnant Magnetization, Dry Bulk Density, Apparent Porosity and P-wave Sonic Velocity. Terra Petrophysics Pty Ltd has submitted the petrophysical data and report to GSWA
- Explanatory notes drafted for 37 stratigraphic units covering the Broad Arrow and Veters Subgroups of the Kalgoorlie Group.

Products released

- East Yilgarn, 2020 GIS data package

Program review

GS53 State Geoscience

Managers: Simon Johnson, Klaus Gessner, David Martin

Objectives

The State Geoscience branch is responsible for maintaining and communicating a coherent geoscience framework for Western Australia via GSWA databases, the GSWA website and social media, statewide layers on GeoVIEW.WA, published Reports, and the State geological map. The branch (formerly GS53 Chief Geoscientist and Terrane Custodians) was reorganized as part of a restructure of the Geoscience Directorate in May 2021. This included moving the Chief Geoscientist role and responsibilities to the Leadership Team and restructuring to incorporate four sections:

- ENS and State Maps
- Paleontology and Geoheritage
- Geophysics Acquisition and Processing (formerly GS55)
- Earth Imaging and Observation (formerly GS62 3D Geoscience).

Highlights and activities

- ENS Search Tools reinstated in GeoVIEW.WA. These tools allow textual and spatial searching of current lithostratigraphic units, tectonic units, and events from the Explanatory Notes database, including units that are not represented on State maps
- Updated GSWA Code Builder with most recent stratigraphic and tectonic codes
- Completion of development of WAGIMS, the **W**estern **A**ustralia **G**eochronology, **I**sotope, **M**etamorphic history and mineral chemistry **S**ystem. WAGIMS centralizes storage of all data files related to these subjects and offers the ability to interrogate data at a granular level
- Development started on an ENS module for the digital compilation and online delivery of geochronology records
- Assistance provided with developing formats and layout for metamorphic history records, as well as with release of geochronology records
- Contributed to a review of issues related to search options and functionality in eBookshop and Geodocs (the internal system that underpins delivery of GSWA products on the eBookshop platform)
- Release of several new web pages on the DMIRS website
- Development of a WAROX Search Tool to facilitate internal interrogation of GSWA's field observations database
- Participation in the **Global Eco Conference** (Margaret River, December 2020), aimed at advertising GSWA's role and products in the field of Geotourism and Geoheritage
- Preliminary biostratigraphic studies completed on Barnicarndy 1, resulting in two Paleontology Reports summarizing all results to date
- Contribution to the Biostratigraphy portion of the Energy Systems Atlas (part of the AGP), including advising on data format and presentation. Work to update the current WAPIMS biostratigraphic data, and extend data in the Perth and Officer Basins, is ongoing
- Extensive Geoheritage and Geotourism advocacy, including provision of advice and assessments of mining proposals

Program review

- Extensive public outreach, including two GSWA webinars (on Western Australian microbialites and Western Australian Geoheritage), public talks to natural history interest groups, and various presentations at tourism and paleontology conferences. Education outreach has included a number of curriculum-linked primary and high school talks and co-leading a field trip for Year 11 Atar Earth and Environment students. An ongoing series of monthly 'Fossil Friday' social media posts for Facebook was also established
- Input into a monitoring plan for the Lake Clifton thrombolites
- Continued cross-border correlations working with the Northern Territory Geological Survey in the Centralian Superbasin
- Work continued on improving Geoheritage processes and reviewing sites on the State Geoheritage Register, including updating the public digital layer available through GeoVIEW.WA. A GSWA Record detailing the nomination process for new Geoheritage sites will be released early next financial year
- Compilation of Australian microbialite forms for the Atlas of Living Australia, published by Australasian Palaeontologists
- Continued assistance with enquiries (both internal and external).

Products released

- 1:2 500 000 major crustal boundaries of Western Australia (AGP product) and associated 3D geological model (see Fig. 3) (for more detail, see GS62)
- Report 214 Dating Proterozoic fault movement using K–Ar geochronology of illite separated from lithified fault gouge
- Paleontology Report 2021/1 Preliminary paleontological summary of Barnicarndy 1 stratigraphic well, Canning Basin
- Paleontology Report 2021/2 Preliminary conodont studies of Barnicarndy 1 stratigraphic well, Canning Basin
- Paleontology Report 2021/3 Paleontological assessment of a purported 'fossil forest' on the northern edge of Wangine Lake
- Revised stratigraphy for Northern Territory Geological Survey (NTGS) stratigraphic drillholes LA05DD01 and BR05DD01, western Amadeus Basin, Northern Territory, NTGS, Record 2020-007
- Three consultant Paleontology Reports (Paleontology Report 2020/47–49)
- A traveller's guide to Geoheritage in Western Australia – general public flyer
- External publications – see Appendix 5

Program review

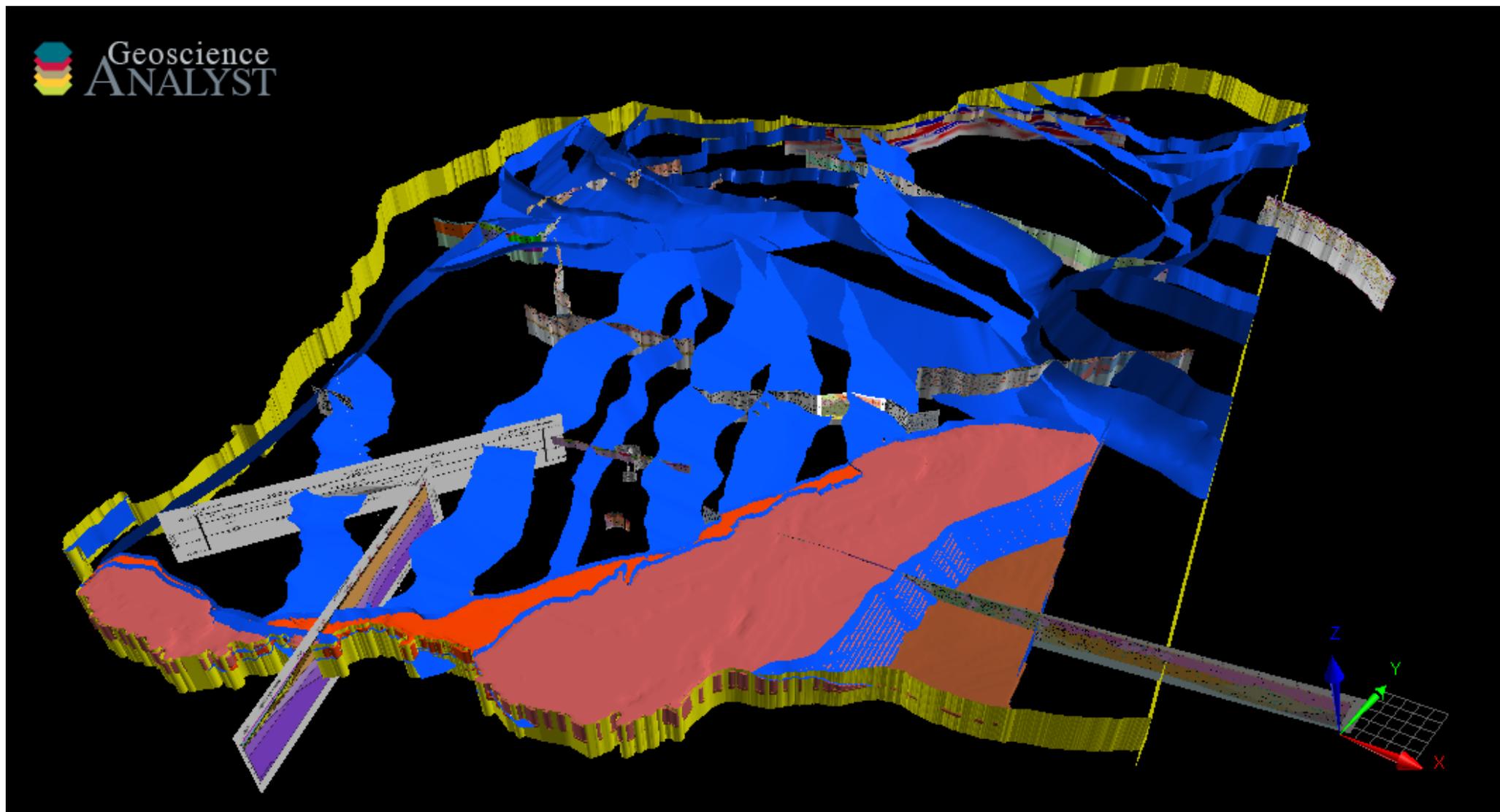


Figure 3. Screenshot from the Geoscience Analyst Viewer of the major crustal boundaries, seismic lines and Albany-Fraser volumes of the Western Australia State 3D model

Program review

GS54 Geochronology and Geochemistry

Manager: Michael Wingate

Objectives

Geochronology, isotope geology and geochemistry are fundamental components of GSWA's geoscience programs and mineralization studies, and contribute to enhancing the prospectivity of the State.

Precise and accurate geochronology of minerals and rocks is essential to determine the timing of geological events and to understanding the geological history of Western Australia (Fig. 4).

Geochronological techniques provide temporal constraints on magmatism, metamorphism, deformation and mineralization, and involve a range of isotope systems (mainly U–Pb, Ar/Ar and Re–Os) and a variety of minerals (zircon, baddeleyite, monazite, xenotime, titanite, hornblende, feldspars, micas and sulfide minerals). Geochemical studies of rocks and regolith are important for understanding the sources and petrogenesis of igneous suites, the relationships within and between igneous suites, and the provenance and compositional characters of sedimentary rocks and regolith.

The Sensitive High-Resolution Ion Microprobe (SHRIMP) facilities in the John de Laeter Centre at Curtin University are used extensively for U–Pb geochronology. GSWA uses laser ablation inductively coupled mass spectrometry (LA-ICP-MS) instruments in the John de Laeter Centre and in the Centre for Microscopy, Characterization and Analysis (CMCA) at The University of Western Australia (UWA) to date detrital zircons, analyse metamorphic phosphate minerals such as monazite and xenotime in thin sections, and to measure the trace element compositions of zircons. Geochronology of minerals in thin sections includes extensive imaging and elemental microanalysis using a TESCAN Integrated Mineral Analyser (TIMA) and scanning electron microscopes (SEM) at the John de Laeter Centre, and electron probe microanalysers (EPMA) at CMCA. The varied aspects of the geochronology and geochemistry programs are supported by world-class sample preparation services provided by the GSWA laboratory.

Project work for GS54 is funded through ES46 (Enhanced Geochronology and Isotopic Mapping). Details are discussed under ES46.

Program review

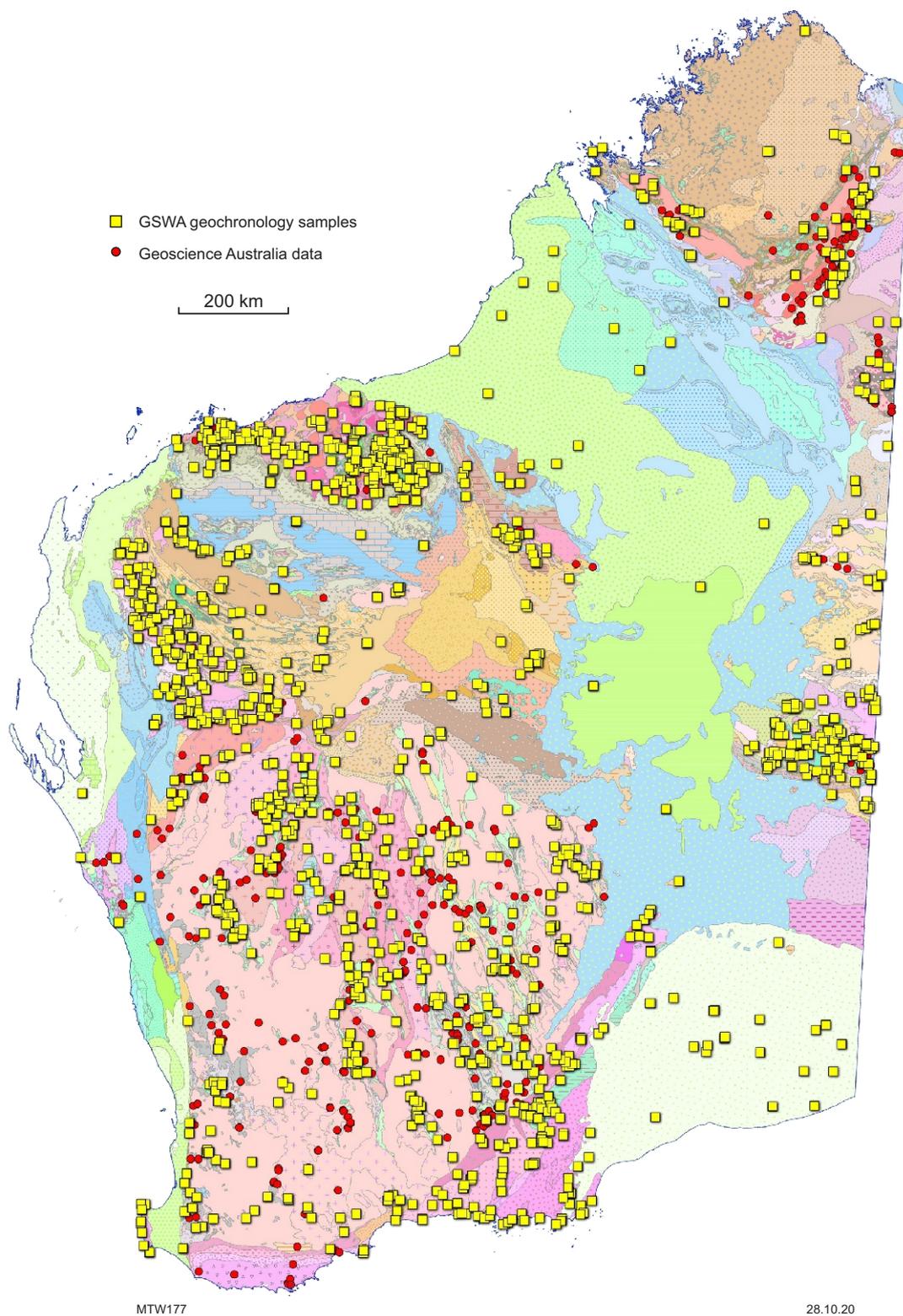


Figure 4. Locations of geochronology samples analysed by GSWA from 1994 to 2020, and those compiled by GA, superimposed on a geological map of Western Australia (1:500 000 Interpreted Bedrock Geology, 2016)

Program review

GS55 Geophysics Acquisition and Processing

Manager: David Howard

Objectives

The acquisition, processing, synthesis and interpretation of geophysical and remotely sensed spectral information are integral parts of GSWA's regional geoscience activities. The role of the Geophysics Acquisition and Processing 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 and interpretation services and advice as required.

Highlights and activities

- Regional survey data acquisition activities are reported under the EIS programs ES30 Airborne and Ground Geophysical Surveys
- A new online platform was published for direct survey registration and data submission by external users into the **MAGIX** geophysical data repository
- 71 new company airborne survey datasets containing about 400 000 line-km of data were received for inclusion in the repository. At 30 June 2021, the repository contained some 12.5 million line-km of company data from 2772 surveys. Open-file datasets are available for download via the department's GeoVIEW.WA online system
- Maintenance, updates and enhancements to the statewide radiometric, magnetic, and gravity grid compilations, and the development and release of new compilation products: multiscale edges ('worms') from the 400 m gravity and the 80 m magnetic grids; and a point gravity integration of ground and subsampled airborne survey data.

Product released

- Magnetic anomaly grids (20 m, 40 m and 80 m) of Western Australia (2020 – version 1) and associated products

Program review

GS58 West Yilgarn

Manager: Raphael Quentin de Gromard

Objectives

The western part of the Archean Yilgarn Craton has a long and complex geological history. The area contains significant deposits of gold, iron ore, nickel, copper, lead, zinc, tungsten, molybdenum, bismuth, vanadium, titanium, beryllium, lithium, tin, tantalum and uranium, and has the potential for more discoveries of these commodities. 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.

This section (formerly GS58 Youanmi Terrane) was reorganized as part of a restructure of the Geoscience Directorate in May 2021. This was primarily as a result of work and interpretations that emerged from the 2020–21 southwest Yilgarn AGP. Hence, the Youanmi Terrane project has again been expanded to include the South West Terrane and the Narryer Terrane, under the new title, GS58 West Yilgarn (Fig. 5).

Highlights and activities

- Substantial data collation and new data collection, interpretation and compilation in the southwest Yilgarn as a result of the southwest Yilgarn AGP
- Digital Interpreted Bedrock Geology (IBG) map of the Sandstone greenstone belt released on the Youanmi GIS 2020 USB product: includes updated stratigraphy, suites and structures at 1:100 000 scale
- Continued mapping and sampling in the Ravensthorpe, Weld Range and Murgoo areas
- Ongoing, targeted geochemical sampling of stratigraphic intervals through greenstones across the west Yilgarn has established that the rationale of the Eastern Goldfields Geochemical Barcoding Project can be applied here
- Sampling for geochronology and geochemistry of greenstone belts in the western Youanmi Terrane is investigating the extent and nature of exposed c. 2950 Ma crust
- Cooperative projects continued, involving geochemistry, metamorphic and structural studies in the northern Youanmi Terrane, and structural and isotope studies in the Narryer Terrane
- Work continued on the volcanic geochemistry of the northern Murchison Domain project; however, the associated GSWA Report has been delayed until 2022 due to the extension of the supporting PhD project.

Products released

- Southwest Yilgarn 2021 Geological Exploration Package (GEP) data package including the pre-Mesozoic interpreted bedrock geology of the southwest Yilgarn
- Youanmi 2020 GIS data package
- Record 2020/13 Stratigraphy, petrography and structure of Archaean rocks in the Rothsay mining area, western Yilgarn Craton
- Murchison Supergroup and granitic suites update in ENS

Program review

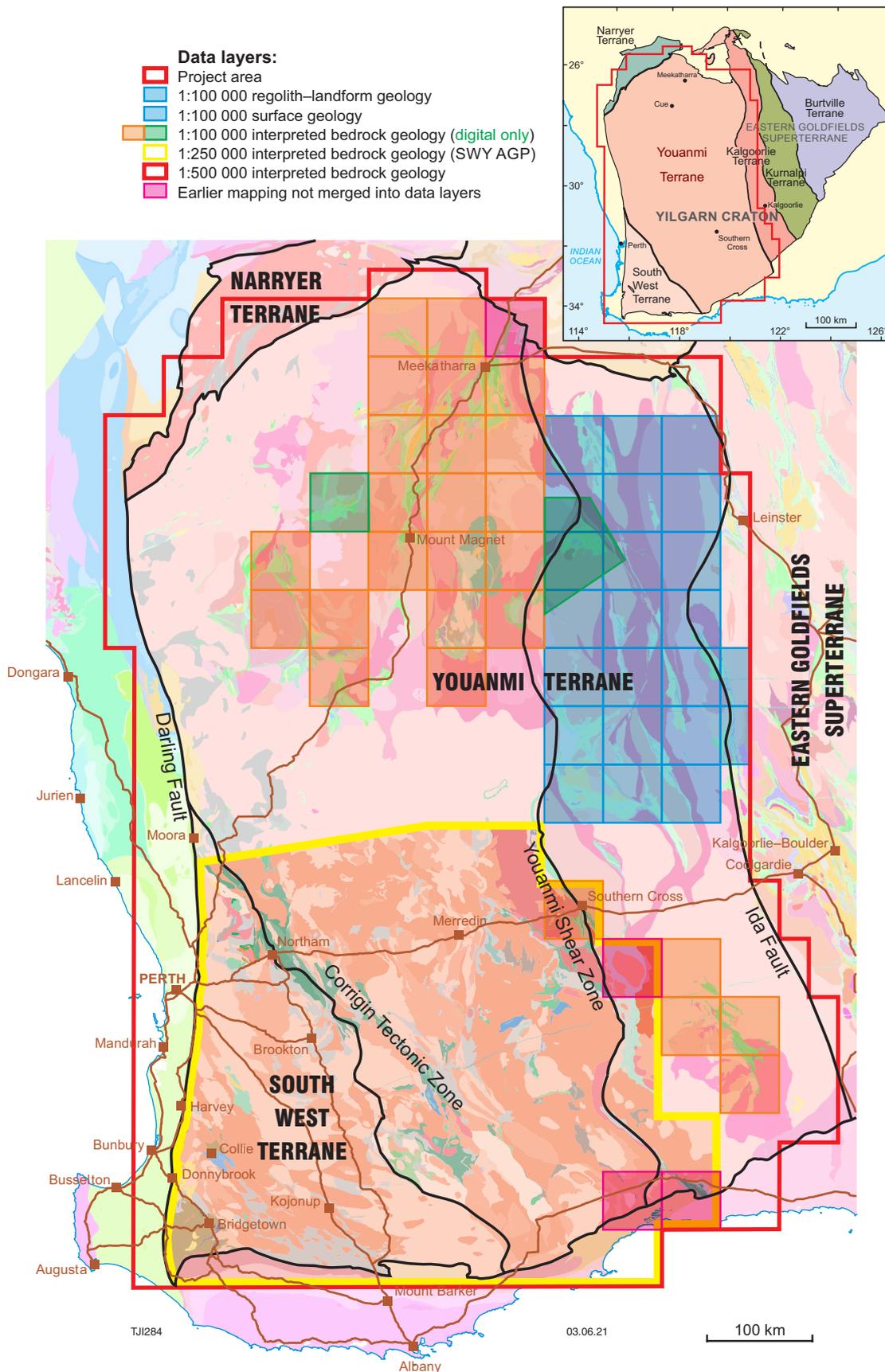


Figure 5. Simplified interpreted bedrock geology map highlighting the extent and mapping progress of the GS58 West Yilgarn project area

Program review

GS62 3D Geoscience

Manager: Ruth Murdie

Objectives

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. A large part of the section's activities involve EIS-funded collaborative projects with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling.

Highlights and activities

- This year concentrated on providing products for the AGP, in particular a compilation of 3D data for the southwest Yilgarn and a whole of State 3D model
- Three legacy 3D products were added to the 3D Geomodel Series
- Australian Research Council (ARC) Linkage grant for a passive seismic network in the southwest Yilgarn with the Australian National University (ANU), GA and the Department of Fire and Emergency Services (LP170100890) was started with the installation of 27 seismometers and the collection of the first eight months of data.

Product released

- Record 2020/11 Imaging a magmatic underplate with 3D gravity modelling: east Albany–Fraser Orogen margin
- Record 2021/7 Applying geophysics for 3D paleochannel imaging in the Gascoyne Province, Western Australia
- West Musgrave Province 3D model 2013
- Yilgarn Craton – Officer Basin – Musgrave Province 3D model 2013
- Eastern Yilgarn Craton 3D data compilation 2019
- Southwest Yilgarn 3D data compilation
- WA State 3D model

Program review

GS63 Pilbara and Hamersley

Manager: Heather Howard

Objectives

The 2775–2630 Ma volcanosedimentary 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 main objective of the Pilbara and Hamersley project is to increase understanding of the Fortescue and Hamersley Groups in terms of their context within the wider Mount Bruce Supergroup, and more recent work in the Capricorn Orogen. The project seeks to use significant stratigraphic and structural data to review the relationships between the volcanic and sedimentary units, integrating this with petrogenetic constraints on magmatism to better understand the tectonic evolution of the Mount Bruce Supergroup.

Highlights and activities

- Acquisition of new geochemical data from drillcore sampling in the Fortescue Group
- Approximately 150 ENS lithostratigraphic unit reports completed for the Pilbara Craton and a further 15 ENS events drafted
- 1:100 000-scale IBG compiled for YULE, SATIRIST and HOOLEY map sheets for release on GeoVIEW. WA in 2021–22.

Products released

- Report 143 East Pilbara Craton: a record of one billion years in the growth of Archean continental crust
- Northwest Pilbara, 2020 GIS
- External publications – see Appendix 5

Program review

GS64 Geoscience Mapping Through Cover

Manager: Richard Chopping

Objectives

Geoscience Mapping Through Cover incorporates the regolith and cover component of GS43 Geochemistry and Regolith, which concluded in 2017–18. GS64 is linked to ES36, which is the EIS project area for the Mineral Exploration Cooperative Research Centre (MinEx CRC).

The mapping of the distribution of different regolith types is integral to geoscience studies and exploration. Regolith mapping includes the use of orthophotos, satellite imagery (e.g. ASTER), and geophysical data that images near-surface cover (e.g. airborne electromagnetic, passive seismic) linked to field-based studies and analysis of drillcores. A scale-independent regolith–landform classification scheme has been developed and is applied regardless of the geological terrain, and a new module for regolith units has been developed within ENS. The compiled maps and documentation provide context for landscape evolution studies and dating of regolith materials, with an aim to produce 3D and 4D models of the regolith in case study areas.

The primary focus for GS64 for 2020–21 was the production of material for the AGP, especially with the production of new regolith mapping products and the release of the Far East Yilgarn GEP.

Highlights and activities

- Publication of the Far East Yilgarn GEP under the AGP
- New regolith mapping products to support the AGP, including utilizing samples from the Department of Primary Industries and Regional Development (DPIRD) to map the depth to transported regolith within the southwest Yilgarn
- Conclusion of the Yangibana paleochannel study
- Continuing research in preparation for drilling campaigns under the MinEx CRC National Drilling Initiative (NDI) (see ES36)

Products released

- Record 2021/17 Applying geophysics for 3D paleochannel imaging in the Gascoyne Province, Western Australia
- AGP layer: 1:100 000 regolith geology regimes
- AGP layer: Mapping transported regolith in the southwest Yilgarn utilizing the HyLogger

Program review

GS65 Proterozoic Margins

Manager: Fawna Korhonen

Objectives

Proterozoic Margins amalgamates the activities of two previous sections – GS56 North Australian Craton and GS61 Albany–Fraser Orogen and the Eucla basement project – and currently resides within the Geoscience Mapping Through Cover branch. The primary objective is to investigate and map the geology of the remote greenfields regions on the margins of the Officer and Canning Basins, to which the basement is informally known as ‘The Gap’, and provide essential data and knowledge towards GSWA’s commitment to the NDI of the MinEx CRC (see GS64 and ES36). The project work is primarily funded through ES38, and activities for 2020–21 are reported under that section.

Mapping regions of sparse outcrop incorporates interpretations of geophysical data with knowledge gained from field mapping and drillcore analysis, with particular emphasis on using EIS co-funded drillcores housed at the Perth Core Library. Unfortunately, due to access restrictions followed by the COVID-19 pandemic, no fieldwork was conducted this financial year.

The project builds on the successful approach developed in the Albany–Fraser Orogen and Eucla basement projects, applying new or emerging techniques where available. One of the aims of the Proterozoic Margins section is to open up new frontiers in mineral exploration by understanding the magmatic, sedimentary and tectonic environments. This provides fundamental information to enable exploration teams to evaluate prospectivity and potential targets.

Highlights and activities

- Supporting the AGP through interpretation of the basement geology and robust metamorphic analysis of selected samples for the southwest and Far East Yilgarn GEP
- Detailed structural and metamorphic analysis of Mesoproterozoic events in the east Albany–Fraser Orogen, with emphasis on their links to mineralization and the kinematic and magmatic history of crustal-scale shear zones
- Analysis of the age, character and correlations of Paleoproterozoic–Neoproterozoic sedimentary basin outliers in the Kimberley region
- Continued research into the West Arunta orogen through the MinEx CRC embedded researcher placed at GSWA
- Submission and acceptance of two National Argon Map (NAM) project proposals. Data processing and interpretation is currently underway for the first of these projects, and samples for the second have been sent for irradiation from ANU
- Completion of a pilot study for novel in situ Rb–Sr dating of biotite from 11 samples across the State
- Supporting petrophysical data acquisition in the Paterson, Eucla and West Arunta regions
- Sample selection and the completion of a preliminary dataset for heavy mineral concentrates from regolith in the West Arunta; these data will be incorporated into the Heavy Mineral Map of Australia, in collaboration with Curtin University and GA.

Program review

Products released

- Far East Yilgarn IBG and abstract, under the Far East Yilgarn GEP
- Metamorphic History digital layer and abstract, under the southwest Yilgarn GEP
- Metamorphic History State layer on GeoVIEW.WA
- Metamorphic History Records 1–10, available on GeoVIEW.WA
- External publications – see Appendix 5

Program review

GS83 Data Services
GS84 Data Delivery
GS86 Data Governance

Manager: Deavi Purnomo (from October 2020)

Objectives

A new Data Management branch was formed in October 2020. The branch is managed by the newly created position of Chief Geoscience Information Officer. The position of Chief Geoscience Information Officer and the Geoscience Data Management branch have been created to ensure accountability for data action, and for the efficient management, availability and accessibility of geoscience data. These outcomes form part of the **Geoscience Data Transformation Strategy's** direct actions.

The branch consists of experienced well-qualified staff who are critical to the quality and delivery of geoscience data and systems. These staff members include geoscience database managers, geospatial officers, web mapping specialists, data analysts, business analysts, application developers and GIS specialists.

The branch incorporates three sections:

- Geoscience Data Services (formerly GIS Services)
- Geoscience Data Delivery (formerly Spatial Systems)
- Geoscience Data Governance (formerly Spatial Systems)

Highlights and activities

There was continued focus on the management and delivery of geoscience data and systems.

The following online Geoscience Information Systems were released:

- MINEDEX user interface
- New digital data layers downloadable from the Data and Software Centre and through GeoVIEW.WA
- Upgrade of the Data and Software Centre to support GDA2020

The team has:

- Delivered geoscientific digital datasets and data layers (including the AGP)
- Provided online applications and database training
- Maintained geoscience data delivery platforms.

Products released

- 3 AGP data packages
- 3 data layers
- 9 online products (including 3D geomodels)

Program review

GS80 Editing and Publishing

GS81 Mapping and Events

GS82 Graphics

GS90 Native Title

GS97 Discover Geology

Manager: Stephen Bandy (transferring to Paul Duncan)

Objectives

High-quality map, graphic and information products are critical to support the effective delivery of geoscience and titles information. The Geoscience and Titles Information branch delivers this capability with qualified and experienced geoscience editors, cartographers, graphics officers, product designers, project managers, desktop publishers, online coordinators and geospatial professionals.

Highlights and activities

There was continued focus on the management and delivery of geoscience and titles information.

The following Geoscience and Titles Information initiatives were finalized:

- Implementation of ESRI ArcGIS Pro solution to replace legacy TENGRAPH modules, for internal tenement and petroleum information maintenance
- Deployment of eLodgement of Survey Documents and Survey Data within Mineral Titles Online Lodgement framework
- Delivery of native title claim related tenement data
- Exploration of innovative engagement channels with the online Rottnest StoryMap.

The team has:

- produced geoscientific maps, manuscripts and promotional materials
- delivered 44 native title claims data packages and 331 maps
- involvement in production of Geotourism products
- reduced the survey lease backlog to business-as-usual manageable levels.

Products released

- 35 text publications
- 6 geological maps, plates
- 16 geoscience posters
- 20 commodity flyers

Program review

GS85 Resources Investment Information

Manager: Warren Ormsby

Objectives

Our ongoing objective is to facilitate the provision of resource-related information to industry, researchers, and the wider public. This contributes to the stimulation of mineral and petroleum investment in Western Australia, the acceleration of exploration, and the development of new resources. This facilitation occurs by provision of geoscientific, policy, and regulatory information to assist with attracting new resource investment. A major element of this in 2020–21 has been the promotion of the AGP.

Highlights and activities

Proactive engagement is undertaken directly by GSWA, and in collaboration with 'Australia Minerals' (the collective name given to joint activities overseas with other geological surveys across Australia). Engagement examples include:

- Establishing a booth presence with high-impact information displays at major investment conferences and seminars
- Conducting investment workshops, seminars, and updates for small groups
- Publishing high-quality maps, posters and flyers in hardcopy and online
- Responding to investor requests for information and advice relating to geoscience, policies, and regulations
- Providing a steady stream of relevant information via social media on LinkedIn and Facebook
- Producing the GSWA Webinar Series
- Publishing the 'This is GSWA' short film that showcases GSWA as never before.

Industry engagement

Due to travel restrictions as a consequence of the COVID-19 pandemic, GSWA was represented virtually at these international events:

- Prospectors & Developers Association of Canada Annual Convention (PDAC)
- North American Prospect Expo (NAPE) Summit
- Australia Japan Mineral Resources Investment Seminar
- Australian American Chamber of Commerce Texas (AACC) Petroleum Seminar
- AAPG Prospect and Property Expo (APPEX) Global
- MINREX – Middle East Mining & Resources Expo & Summit

Program review

GSWA was represented in person at these intrastate events:

- Diggers & Dealers Mining Forum
- RIU Explorers Conference
- Paydirt's Battery Minerals Conference
- Asian Engagement Summit with AIMWA – Invest and Trade WA (in collaboration with the Department of Jobs, Tourism, Science and Innovation)
- Australian Petroleum Production and Exploration Association (APPEA) Conference
- RIU Good Oil & Gas Conference
- Perth Gem and Mineral Show – as sponsors for this inaugural event.

Program review

GS91 Statutory Mineral Exploration Information

Manager: Julia Thom

Objectives

The Mineral Exploration Information section manages the DMIRS statutory obligation to collect, store and release company exploration reports containing geoscience information on mining tenements in Western Australia. The archive of statutory exploration information is a valuable resource, providing a means for companies to assess the potential of an area and develop exploration strategies using previously obtained data. This minimizes duplication of exploration effort enabling more efficient exploration.

Highlights and activities

- Data received and reviewed:
 - 3348 mineral exploration reports and data were reviewed
 - 3364 reports were released to open file
 - Over 93% of reports are received via the online submission wizard
 - 1290 drill collar files and related data files uploaded into the drillholes database comprising 220 791 individual drillholes and associated downhole data
 - 1646 surface geochemistry files uploaded into the drillholes database comprising 805 101 individual samples and associated geochemistry data
- All WAMEX reports that were not available in a non-optical recognition format have now been converted. An external Amazon Web Services (AWS) website has been launched. This allows for text searching of all WAMEX reports that are currently available on the biannually released hard drive
- An AWS external website facility has been launched to search for and download harmonized open-file surface and downhole geochemistry data from exploration company datasets in the Mineral Drillholes database. Data in the 'geochemistry tables' in the database have been harmonized by standardizing company analyte names and units. The facility allows searching and downloading the harmonized open-file surface and downhole geochemistry data. In addition, the complete database and all of Western Australian harmonized and pivoted assays can be downloaded as .bak files.
- Data requests:
 - 147 core library (mineral core) viewing and sampling requests were approved
 - 695 Combined Reporting Groups were granted or amended
 - Under the provisions of Regulation 96(4) of the Mining Act, commonly known as the 'sunset clause', 1210 reports were received in 2015. A total of 1081 of the 2015 reports did not receive objections and were released
 - In addition, a list of 564 reports submitted between 2002 and 2010 (the lapsed objections) were advertised on the website for release. A total of 99 reports were released without objection and 465 received renewed objections. These are currently under review.

Program review

Performance measures

This section of the Statutory and Resource Information branch is responsible for three Resource and Environmental Regulation performance metrics. These metrics require that 85% of statutory mineral exploration reports be reviewed within 90 calendar days of receipt; all data requests receive a response within five calendar days of receipt; all mineral core viewing and/or sampling requests receive a response within five calendar days of the request.

- Mineral exploration reports received and reviewed – currently 99% of data are received and reviewed within 90 calendar days of receipt
- Data requests – currently 100% of data requests are responded to within five calendar days
- Core sampling requests – currently 100% of sampling requests are responded to within five calendar days.

Program review

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

Objectives

The Statutory Petroleum Exploration Information section is involved with the monitoring, administration and release of petroleum and geothermal data submitted under the *Petroleum and Geothermal Energy Resources Act 1967 (WA)* and the *Petroleum (Submerged Lands) Act 1982 (WA)*, covering onshore and territorial sea.

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. As part of the AGP, the WAPIMS team is working on the Energy Systems Atlas in collaboration with the Energy Geoscience branch.

Highlights and activities

- WAPIMS main enhancements
 - Added new group of layers in WAPIMS map under Energy System Atlas as part of the AGP
 - Added age to Formation Tops reference table and displayed it on the formation top grid – links with ENS
 - Added new columns in Data by Depth (Rock-eval, geochem, core images, well logs display, HyLogger images)
 - Implemented 'Online lodgement grid' – to monitor data submission registered through PGR
 - Released documents grid enhancements includes all assets, increased search functionality (by type, date, author, S number, etc.)
 - Redesigned seismic reprocessing projects workflow
 - Functionality enhancements: batch edited for some grids; bulk loaded for 2D shape files; ability to search columns that take multiple values from dropdown list
- Data remastering – transcribed petroleum data to a modern stable media for industry and government
 - 944 tapes transcribed to a new media and data loaded in WAPIMS
 - 488 seismic sections vectorized to SEGY
 - 300 well logs scanned
- WAPIMS data management
 - 58 689 new records created
 - 40 756 records updated

Program review

- Data received and reviewed
 - 379 reports, 36 logs, 97 survey data, 19 071 slides and residues
 - 470 reports reviewed and information captured (new and legacy)
 - Other WAPIMS entries: monthly production (11 542), underground storage daily data (3432), underground storage monthly data (134), CO₂ injection by well (2736), water injection by well (608), water production by well (1215)
- Data released – reports, well logs, survey data published in WAPIMS: 263 documents, 10 041 slides and residues
- Sampling approval requests processed: 76 from 257 wells
- Statistics and metrics 2020–21
 - 62 174 documents downloaded from WAPIMS
 - 9953 users accessed WAPIMS
 - 86% of reports received accessioned within 14 days
 - 90.7% of the sampling approvals processed within five days, from 233 wells
 - 90% of the slides and residues received accessioned and archived within 14 days
- Achievements
 - Prepared WAPIMS data and designed new grids in WAPIMS for the Energy System Atlas.

Program review

GS94 and GS96 Core Library Services

Managers: Paul Stephenson (Perth), Debbie Caple (Kalgoorlie)

Objectives

The Perth Core Library (Carlisle) and JH (Joe) Lord Core Library (Kalgoorlie) house an important collection of mineral core samples representative of the geology and mineral endowment of Western Australia.

These collections have been sourced over many decades from Government stratigraphic drilling, mineral industry donations and the EIS co-funded drilling program, petroleum industry onshore and offshore drilling (Perth only), geothermal drilling, water bores and geotechnical drilling. Kalgoorlie also has a large collection of paleochannel core drilled by GSWA during the mid-1980s.

This constitutes a significant source of precompetitive geoscience information that promotes the mineral and energy prospectively of the State, and encourages innovative resources exploration.

Highlights and activities

- 2020 Yilgarn Conference (rescheduled) held in May 2021, Kalgoorlie
- September 2020 groundworks started for the Joe Lord Core Library (Kalgoorlie) expansion (on track for completion in October 2021)
- WAPIMS and CIMS updated weekly.

Program review

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Objectives

The 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), short-wave 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 processed and 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 available upon request.

Highlights and activities

- From July 2020 to June 2021, over 42 000 m of core and about 2000 m of chips from 200 drillholes were scanned. These comprised 83 EIS co-funded holes (Rounds 18–20), 97 historical and donated mineral holes, and 20 petroleum wells. AuScope, as part of an NCRIS grant scheme, funded delivery and data processing of up to 4000 m of core from 15 mineral historical drillholes from the Joe Lord Core Library in Kalgoorlie. Rock chips from DPIRD's 58 water bore holes were scanned and a data package released as part of the GSWA AGP southwest Yilgarn study, Regolith Evolution project
- Overall, high-resolution core images and hyperspectral data for 328 000 m of drillcore from 1114 drillholes were delivered to the AuScope national portal and GeoVIEW.WA using the HyLogger database, which includes 63 datasets processed to level 1 or level 2 in the year
- HyLogger staff were actively involved in several GSWA, UWA and CSIRO research projects, including the AGP and Business Improvement Program by compiling and releasing standardized HyLogger data for the southwest Yilgarn; studies of carbonate and salt in Perth and Canning Basins; stratigraphy analyses of the Southern Carnarvon Basin; lithostratigraphic 'barcoding' and petrophysics projects at the Eastern Goldfield, and Jimberlana Dyke at the Youanmi Terrane. HyLogger staff also contributed to the EIS drilling program delivering hyperspectral data and high-resolution images of 83 drillholes from 27 exploration companies
- The HyLogger team is actively collaborating with GSRSD Data Systems and DMIRS Business Innovation Directorate to promote HyLogger data to the Cloud
- The HyLogger team provided seven educational tours for State delegations visiting the Perth Core Library, presented four TSG trainings/consultancies for industry and students, and manually delivered 242 datasets, excluding external portals
- The HyLogger workshop, in collaboration with CSIRO, was delivered in May to academic and industry to promote the use of the hyperspectral technology
- HyLogger staff initiated and commenced the systematic collection of geochemical data from scanned drillcore using portable XRF (pXRF) technology. Protocol of data acquisition was developed and evaluated on 39 drillholes. The utility of pXRF geochemical data will be provided in a GSWA Record

Program review

- A new service was organized in the Perth Core Library for geochemical and mineralogical characterization of requested drillcore using GSWA's pXRF and pXRD. The service is available for all visitors to the Perth Core Library.

Products released

- AGP Abstract and USB package HyLogger spectral mineralogy of regolith from the central southwest Yilgarn
- AGP Abstract and USB package HyLogger spectral mineralogy of diamond drillcore from the southwest Yilgarn
- Report 213 Reservoir quality of Permian sandstones of the onshore northern Perth Basin – an assessment using HyLogger spectral data and petrography

Program review

GS97 Discover Geology

Manager: Stephen White (from January 2021)

Objectives

The Discover Geology section was established midway through the 2020–21 year to focus on delivering geoscience products for the public. The main objectives are to:

- Publish innovative, interactive products pitched to levels suitable for a general audience, using content from previous GSWA products
- Increase recognition among the public and the Geotourism industry of GSWA as the authoritative source of geoscience information about Western Australia
- Support Geotourism initiatives within DMIRS and in collaboration with outside organizations.

Highlights and activities

In its first six months of work, the team completed a pilot project in the ArcGIS Online StoryMaps platform. This was released in May 2021 and StoryMaps was endorsed as one of the primary formats to deliver products for the public.

Other activities:

- Established a draft program out to 2023 and set schedules for delivery of two online products and one book; the latter will be printed for distribution via tourism and information centres
- Completed an online course Practical Geocommunications provided by Geologize.org
- Joined Working Group 1 of the National Geotourism Strategy administered by the Australian Geoscience Council.

Product released

- Wadjemup / Rottnest Island StoryMap

EIS overview

Exploration Incentive Scheme – overview and major achievements

Overview

The Western Australian Government's EIS began in 2009, funded from the Royalties for Regions program. The objective is to promote exploration in Western Australia to increase the discovery rate of economic deposits, emphasizing greenfields areas underexplored for mineral deposits and frontier petroleum basins.

At the end of the 2020–21 financial year, the EIS had received \$175.54 million (Fig. 6a–d) from variable funding sources (Table 3).

In late 2017, a review was initiated to determine a suitable future funding source for EIS 4 (from 1 July 2019) at \$10 million per annum. A proposal to the State Government resulted in an agreement to increase mining tenement rentals (MTR) above the Consumer Price Index (CPI). It was proposed that MTR would be increased by 6% to raise \$5 million in 2019–20 and the same again the following year to raise \$10 million. All tenement rents would increase with the exception of exploration licences (for years 1–3) which are linked to payable shire rates. This change was brought forward by one year and introduced in the second half of the 2018–19 financial year. In 2020–21, the budget appropriation was \$10 million sourced from MTR.

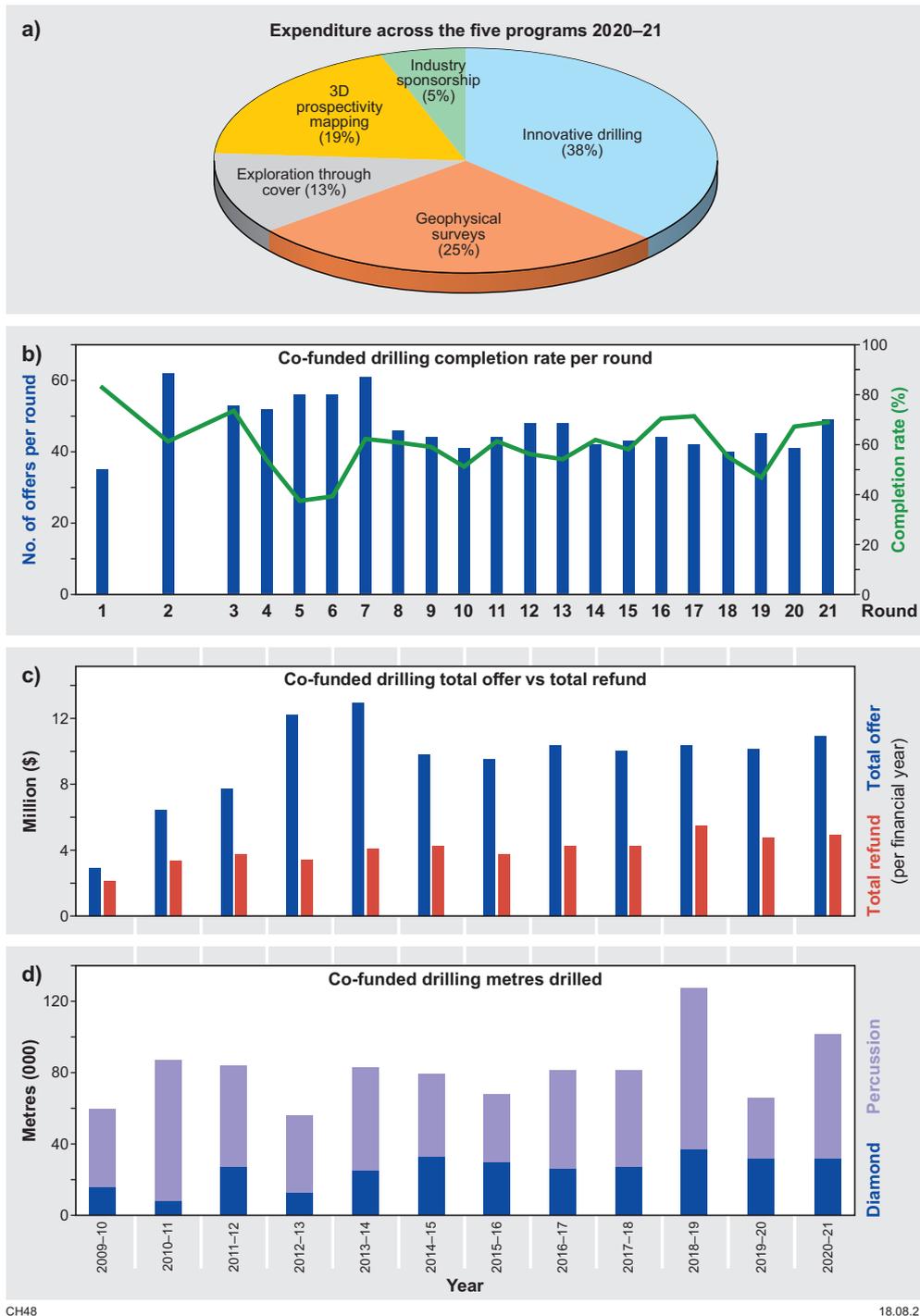
A one-off, additional \$5 million was allocated to the EIS for the 2020–21 financial year as part of the State Government's COVID-19 recovery plan. With the additional funds, \$2.55 million was assigned to the in-progress AusAEM20-WA acquisition across the southern half of Western Australia. The other \$2.45 million was used to increase the number of successful applicants in Rounds 22 and 23 of the Co-funded Drilling Program.

In February 2021, a new co-funded program called the Energy Analysis Program (EAP) was introduced. Designed to encourage exploration of petroleum and geothermal resources in Western Australia, the program makes funding available for analysis of existing State resources (e.g. core, cuttings, and oil, condensate, water, and gas samples) and to allow reanalysis or reprocessing of existing digital data.

Table 3. Funding sources for the EIS since 2009

<i>EIS phase</i>	<i>Year</i>	<i>Royalties for regions</i>	<i>Consolidated revenue</i>	<i>Mining tenement rent (MTR)</i>
EIS 1	2008–09 to 2012–13	\$76 340 000		
EIS 1A	2013–14	\$24 200 000		
EIS 2	2013–14 to 2016–17		\$30 000 000	
EIS 3	2017–18 to 2018–19	\$15 000 000		\$5 000 000
EIS 4	2019–21			\$25 000 000

EIS overview



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Figure 6. Dashboard view of the EIS: a) pie chart showing the expenditure across the five EIS programs for 2020–21; b) percentage of applicants offered a grant that completed a proposed drilling program for each round. From Round 3 onwards, there have been two application periods six months apart. Even-numbered rounds must start and finish drilling within a 12-month calendar period, and odd-numbered rounds within a 12-month financial-year period; c) money offered to successful applicants in a financial year vs the amount refunded. Factors affecting the refund include the number of applicants that withdraw, fewer holes drilled than estimated, and actual direct drilling costs being less than estimated; d) total number of metres drilled by diamond and percussion (e.g. RC, rotary air blast, aircore, auger)

EIS overview

Major programs

Five overarching comprehensive programs provide the framework to stimulate an increase in private sector resource exploration, to bring about new mineral and energy discoveries and maintain Western Australia's ranking as one of the most attractive minerals investment destinations. Although field-based activities by GSWA staff were impacted by COVID-19 restrictions and the focus was placed on the AGP, many projects such as the Geochemical Barcoding Project, continued to operate and release new data. The five programs were:

1. Government–Industry co-funding

- 1.1 Co-funded Government–Industry drilling
- 1.2 Co-funded Government–Industry Energy Analysis

2. Geophysical surveys

- 2.1 Airborne gravity surveys
- 2.2 Deep crustal seismic, magnetotelluric and passive seismic

3. Encouraging exploration through cover

- 3.1 Depth of Cover and its interfaces
- 3.2 Basement geology and evolution
- 3.3 Proterozoic margins
- 3.4 Petrophysics
- 3.5 MinEx CRC participation

4. 3D prospectivity mapping

- 4.1 Mineral systems
- 4.2 Petroleum systems
- 4.3 3D lithospheric visualization
- 4.4 Geochemical Barcoding
- 4.5 Yilgarn Granite project
- 4.6 Mapping geodynamic setting

5. Promoting strategic research with industry

- 5.1 MRIWA support

EIS overview

Dashboard view of the EIS

Major highlights and activities

- An extra \$5 million was allocated to the EIS, bringing the total budget for 2020–21 to \$15 million
- ES20 Co-funded Exploration Drilling – Rounds 20 (2020) and 21 (2020–21) had completion rates of 61% and 69%, respectively
- Round 21 of the co-funded drilling had a high completion rate of 69%, compared with one year ago when Round 19 only had a 47% completion rate. The historical average is 58%
- ES20 Co-funded Exploration Drilling – Rounds 22 and 23 opened for applications in 2020–21 (Table 4)
- ES20 Co-funded Exploration Drilling – 101.8 km of drilling by 56 projects completed in the 2020–21 financial year (Table 5)
- ES30 Airborne and Ground Geophysical Surveys – under a National Collaborative Agreement with GA, an airborne electromagnetic (AEM) project was started to capture the southern half of Western Australia at 20 km line spacing. Surveys across Southwest and Goldfields covered 31 000 km and were released by the end of March 2021
- ES31 Deep crustal seismic – Reprocessed data from 1991 BMR Eastern Goldfields deep crustal survey project L132 (MAGIX number R71610) released
- ES46 Enhanced Geochronology and Isotopic Mapping GSWA's first statewide samarium–neodymium (Sm–Nd) and lutetium–hafnium (Lu–Hf) isotope maps were released under the AGP
- ES49 Greenstone Stratigraphic Geochemical Barcoding Project released 1889 whole-rock major and trace element geochemical data to open file. GSWA Record 2021/15 was published to accompany the data release.

Table 4. Application statistics for EIS Co-funded Exploration Drilling Rounds 22 and 23

Round	Number of applications	Number of successful applications
22	96	57 (49 general, 8 prospectors)
23	84	52 (46 general, 6 prospectors)

Table 5. EIS Co-funded Exploration Drilling statistics for the 2020–21 financial year

Diamond drilling (m)	Percussion drilling (m)	Total (m)	Co-funded offers	Projects completed
36 686	65 192	101 878	86	56

EIS program review

ES20 Government–Industry Co-funded Exploration Drilling

Manager: Charlotte Hall

Objectives

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

Highlights and activities

- Round 20 – 12-month drilling period ended 31 December 2020 with a 61% completion rate
- Round 21 – 12-month drilling period ended 30 June 2021 with a 69% completion rate
- Cost of mobilization and demobilization was made allowable in the calculation of direct drilling costs from Round 22 onwards, where previously this was not permitted. The maximum amount refundable is zone dependent, with values capped based on remoteness of the drilling program
- A refund of diamond core tray costs was introduced, provided a minimum of half core is present. The refund is on top of the drilling refund
- Rumble Resources, Round 20 EIS co-funded drilling at Bakers Prospect, Braeside Project discovered high-grade galena mineralization
- Salt Lake Mining (Karora Mining) – Round 21 co-funded drilling intersects a new significant nickel zone (called 50C) at the Beta Hunt Extension, Kambalda
- Musgrave Minerals (Round 21) – 4 of 6 co-funded holes intersected significant gold grades associated with the newly defined White Light Lode
- Great Southern Mining – co-funded drilling at Cox's Find project discovered new mineralization at depth below operations that closed for production in 1942
- De Grey Mining – new style of gold mineralization was proven below 100 m to a depth of at least 720 m at their Toweranna prospect (Round 19).

Products released

- The total number of EIS Co-funded Exploration Drilling reports released to open file was 34, including eight with battery elements listed in target commodity (nickel, cobalt, lithium, manganese, aluminum, REE and graphite). The number of released reports is significantly lower than in 2019–20 (68) due to COVID-19 restrictions affecting drilling completion rates in the previous 6 to 12 months

EIS program review

ES23 Government–Industry Co-funded Energy Analysis Program

Manager: Charlotte Hall

Objectives

The Energy Analysis Program (EAP) makes funding available to petroleum and geothermal companies, holding titles in Western Australia, to undertake analysis of existing State resources (core, sidewall core, cuttings, and oil, condensate, water, and gas samples) and to allow reanalysis or reprocessing of existing digital data. Analysis of material and data is limited to that acquired within regions that are under Western Australian legislation, excluding Commonwealth regions (offshore) which are likely to require additional approvals.

The inaugural EAP co-funding, referred to as a 'Series' was introduced in February 2021 to coincide with the application period of the co-funded drilling. The grant process is competitive, with marks assigned according to an applicant's responses to technical criteria. Individual project refunds are up to 50% of the analysis costs to a maximum of \$50 000 (ex GST) for completion of a project within 12 months. Successful applicants are required to submit results in a final report that will go to open file on the DMIRS WAPIMS database 15 months after a series starts.

Highlights and activities

Table 6 outlines the highlights for the year.

Table 6. Applicant statistics of Series 1, Energy Analysis Program

<i>Series/Year</i>	<i>Number of applicants</i>	<i>Number of grants</i>	<i>Petroleum grants</i>	<i>Geothermal grants</i>	<i>Date for reports to open file</i>
Series 1 / 2021–22	12	8	6	2	1 Sep 2022

EIS program review

ES30 Airborne and Ground Geophysical Surveys

Manager: David Howard

Objectives

The Airborne and Ground Geophysical Surveys component of the EIS encompasses the acquisition and processing of aeromagnetic, radiometric, gravity and airborne electromagnetic data on a regional scale for statewide coverage at increasing levels of resolution. All these regional surveys are run in collaboration with GA under National Collaborative Framework (NCF) agreements.

Highlights and activities

- The AusAEM20-WA program to extend the AusAEM 20 km line spacing survey program across the remainder of Western Australia commenced in August 2020 with TEMPEST surveys over the central southern part of the State. Data acquisition was completed in January 2021 and all data from the 31 000 km of survey were released by the end of March 2021. TEMPEST survey flying in the southwest commenced in November 2020 and was completed in late April. Data are being processed for release early in the 2021–22 financial year. SkyTEM coverage over the Murchison survey block is scheduled to commence in August 2021 (see Fig. 7).

Products released

- TEMPEST survey areas datasets and inversions (MAGIX numbers 71586, 71635, 71636)

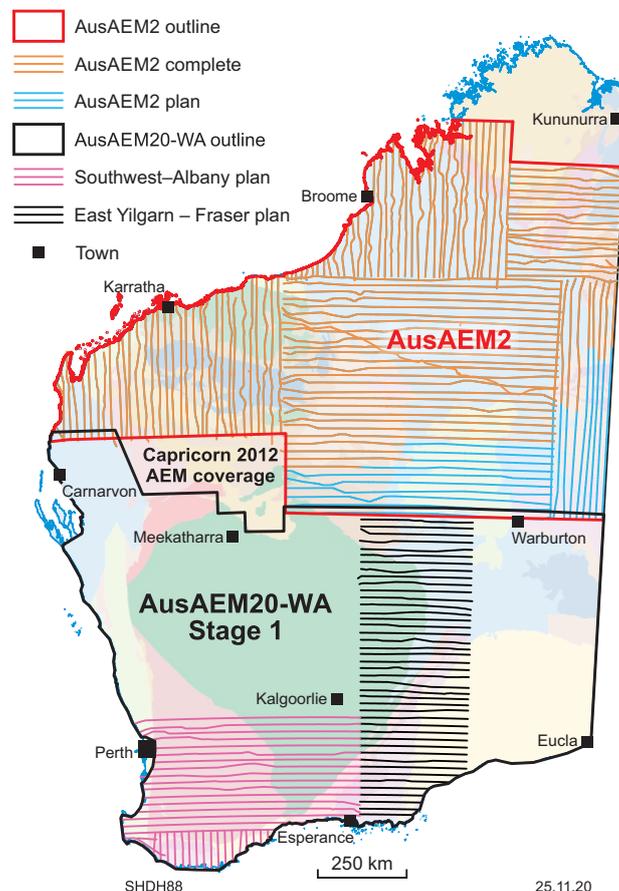


Figure 7. Location of AusAEM20-WA Stage 1 survey areas

EIS program review

ES31 Deep Seismic Survey Program

Manager: Klaus Gessner

Objectives

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, are critical for understanding the geological evolution of the Australian lithosphere over some four billion years of the Earth's history. These transects also provide an understanding of the localization of mineral systems within the upper crust. In addition to collaborating with GA on the active source seismic acquisition, GSWA is collaborating with Macquarie University and UWA on passive source and magnetotelluric (MT) surveys.

Highlights and activities

- Reprocessing of 1991 BMR Eastern Goldfields deep crustal survey project L132 to improve data quality, imaging reflective structural features in the region, and to complement the high-resolution seismic data acquired by GSWA in 2019 (2019–20 project ES37)
- Reprocessing of a seismic survey NN92 near New Norcia to improve data quality and imaging of shallow structural features
- Contributions to the interpretation of the Kidson Sub-Basin 2D seismic survey 18GA–KB1 as published in the GA 'Exploring for the Future' extended abstract volume.

Products released

- Reprocessed data from 1991 BMR Eastern Goldfields deep crustal survey project L132 (MAGIX number R71610)
- Reprocessed data from NN92 (WAPIMS Archive ID S10115 A2)
- External publication – see Appendix 5

EIS program review

ES36 Participation in MinEx CRC

Manager: Richard Chopping

Objectives

Project area ES36, which commenced in 2018, and is linked to GS64 Geoscience Mapping Through Cover, manages GSWA's involvement in the MinEx Cooperative Research Centre (CRC). The MinEx CRC was granted by the Commonwealth Government in March 2018 and brings together industry, government and research organizations. MinEx CRC comprises three programs that commenced in early 2019. GSWA is a participant in Program 3 the NDI, and Project 6 Automated 3D Modelling. This participation includes placement in GSWA of an embedded researcher from the University of South Australia.

The GSWA embedded researcher position is placed from the University of South Australia for three years from January 2020 to December 2022, although staff movements here required backfilling the position. The research focus of this position is to understand the mineralizing fluids within key regions of Western Australia to allow for predictive studies of likely mineralization within these greenfields areas.

Within Western Australia, 'The Gap' continues to be the focus region, with priority work on understanding legacy drillcores and planning future geoscience studies in three areas: the Paterson, the West Arunta and the eastern Yilgarn including its undercover margins. Work programs in these areas will include drilling under the NDI, although not all focus areas will be drilled under the NDI.

Highlights and activities

- Continued research through a postdoctoral researcher engaged through University of South Australia and placed within GSWA
- Continuing focus on NDI work in Western Australia within 'The Gap'
- Supervision of students
- Supporting the acquisition of petrophysical data (see ES39) in the Paterson and West Arunta regions, co-located with geochemical or geochronology samples from available drilling
- Supporting the sampling for geochronology and geochemistry in the Paterson and West Arunta regions (reported in GS65).

EIS program review

ES38 Proterozoic Margins

Manager: Fawna Korhonen

Objectives

The Proterozoic Margins section operates predominantly under ES38, but with links to GS65. The primary objective is to investigate and map the geology of the remote greenfields regions on the margins of the Officer and Canning Basins, where the basement is informally known as 'The Gap', much of which resides under regolith and younger basin cover (Fig. 8). The work provides essential data and knowledge towards GSWA's commitment to the NDI of the MinEx CRC (see GS64 and ES36).

Mapping regions of sparse outcrop incorporates interpretations of geophysical data with knowledge gained from field mapping and drillcore analysis, with particular emphasis on using EIS co-funded drillcores housed at the core library. Unfortunately, due to access restrictions followed by the COVID-19 pandemic, no fieldwork was conducted this financial year.

The project builds on the successful approach developed in the Albany–Fraser Orogen and Eucla basement projects, applying new or emerging techniques where available. One of the aims of the Proterozoic Margins section is to open up new frontiers in mineral exploration by understanding the magmatic, sedimentary and tectonic environments. This provides fundamental information to enable exploration teams to evaluate prospectivity and potential targets.

Highlights and activities

- Supporting the AGP through multiple interpretative geoscience layers
- Establishment of a new MRIWA follow-up project on the Albany–Fraser Orogen, M470a
- Sampling of drillcore from the Yeneena Basin (Paterson Orogen) for geochronology, as part of MRIWA project M521 and MinEx CRC
- Collaborative work on the Paterson Orogen, as part of the MRIWA M521 project

Products released

- See GS65

EIS program review

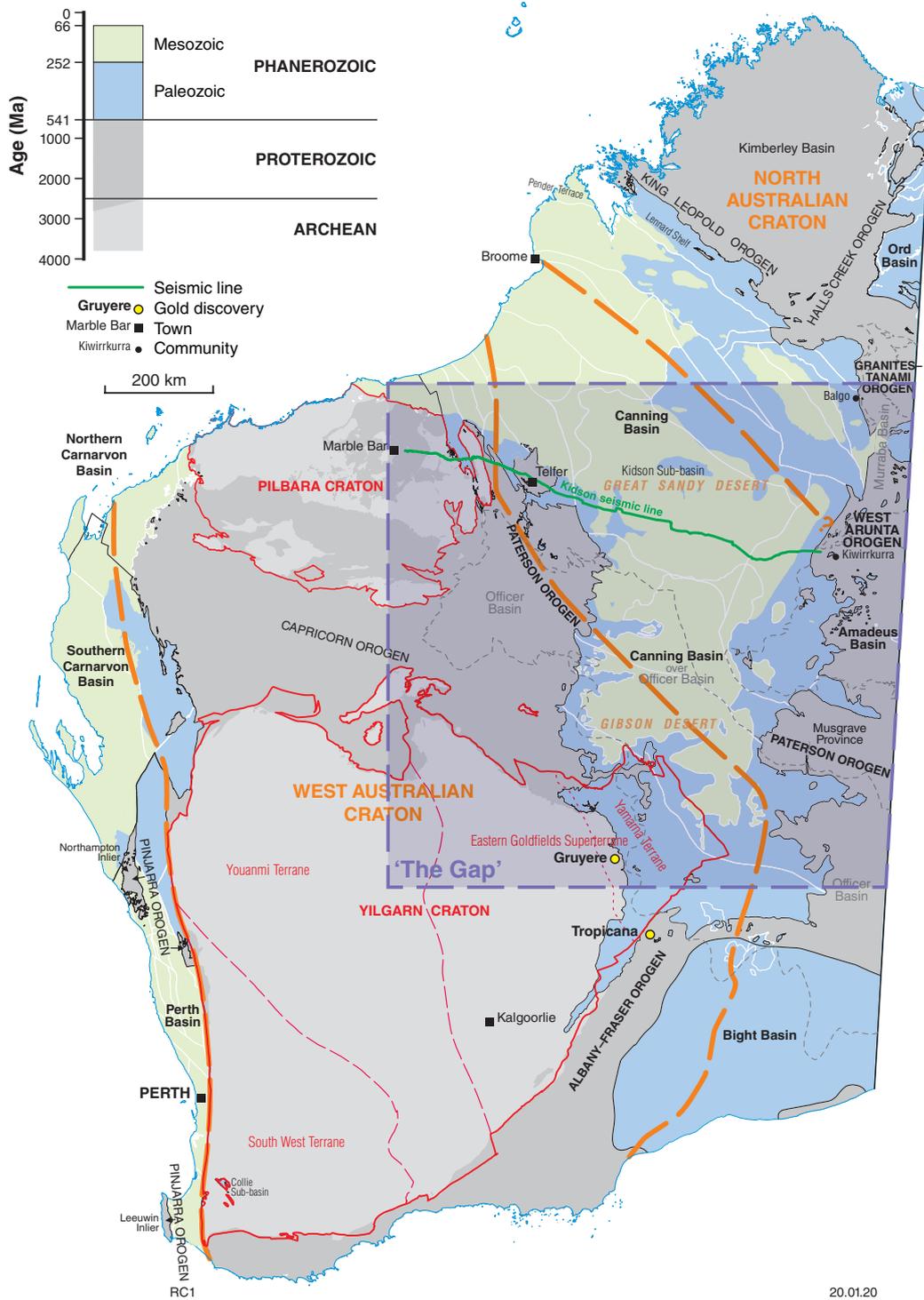


Figure 8. Tectonic units of the State showing the project areas covered by ES38 within dashed outline. The region is informally defined as 'The Gap', reflecting the basement regions between the North, West and South Australian Cratons

EIS program review

ES39 Petrophysics

Managers: David Howard (Stage 1), Charlotte Hall (Stage 2)

Objectives

During 2020–21, GSWA undertook a pilot project to gauge the ‘value proposition’ for acquiring petrophysical data as a complement to regional geophysical survey data, and as an input for constraining interpretation models from those data. The pilot project was carried out in two stages as a collaborative (cost-sharing) exercise with the Perth-based company, Terra Petrophysics Pty Ltd. Samples were sourced from drillholes in the Eucla, Paterson and West Arunta regions (Stage 1 with 1342 samples) and in the Eastern Goldfields (Stage 2 with 1997 samples, nearing completion in June 2021). The results and reports are available from GSWA’s MAGIX geophysical data repository.

Products released

- Eucla basin – Paterson Orogen – West Arunta Petrophysics 2020–21
- MAGIX database, Registration Number 72014, data download link:
<https://geodownloads.dmp.wa.gov.au/downloads/geophysics/72014.zip>

EIS program review

ES42 3D Lithosphere Visualization

Manager: Klaus Gessner

Objectives

The aim of the 3D Lithosphere Visualization project is to visualize and model relevant portions of the solid Earth in Western Australia. The objective is to extend knowledge from exposed and well-understood areas of the Earth's crust and lithosphere to inaccessible or data-poor parts using 3D structural analysis, modelling and numerical simulation techniques. These techniques also test the validity of conceptual models and interpretations. An important aspect of ES42 is the cooperation with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling. In addition to collaborating with GA, GSWA also engages with Macquarie University, the Institute of Geology and Geophysics at the Chinese Academy of Sciences (IGG-CAS), Monash University and UWA on passive source seismology, MT surveys and next-generation 3D modelling techniques. The ES42 activities closely relate to the 3D Geoscience section (GS62).

Highlights and activities

- Australian Research Council (ARC) project LP170100890 'Enhanced 3-D seismic structure of Southwest Australia' – a collaboration with the ANU, GA and the Department of Fire and Emergency Services – commenced with the installation of 27 seismometers, which have since collected around eight months of data
- ARC Linkage Project LP170100985 'Enabling 3D stochastic geological modelling' (3DLOOP) delivered training workshops and released open-source software products
- Seismic monitoring equipment for the planned Canning Basin seismic monitoring project was procured and funding was obtained through the Gas Industry Social and Environmental Research Alliance (GISERA) to develop software that will enable data from the deployment to be processed at GSWA.

Products released

- Record 208 A passive seismic experiment in the Perth Basin, Western Australia
- External publication – see Appendix 5

EIS program review

ES43 Mineral Systems Atlas

Manager: Trevor Beardsmore (transferring to Warren Ormsby)

Objectives

GSWA is collaborating with other government, university and/or industry partners in several projects evaluating specific aspects of Western Australian mineral systems, with EIS funding, in-house participation managed by the Minerals Geoscience branch. These projects are:

- Pilbara gold fingerprinting (\$25 000 per annum over two years)
- Isotopic fingerprinting of native gold from Western Australia (\$31 500 for a six-month pilot study)
- MRIWA M532 – Geology, mineralogy and metallurgy of eMaterial resources in Western Australia (\$50 000 per annum over two years)
- Rare earth resource potential of northern Australia (\$20 000 per annum over three years)
- Critical Metals (Li, Ta, Nb, W, REE) in the western Yilgarn Craton (\$100 000 for one year).

Highlights and activities

The Pilbara gold 'fingerprinting' project continued in 2020–21, characterizing the provenance and metallogenesis of gold mineralization across the Pilbara Craton. All gold-bearing specimens provided by industry partners have been visually inspected, mounted in resin, cut and polished, and analysed quantitatively for a suite of trace elements using energy dispersive X-ray spectroscopy (SEM-EDX). About half of the samples have also been analysed using LA-ICP-MS, with the assistance of John Watling (TSW Analytical), and subjected to acid etching and crystallographic examination. The outstanding geochemical and crystallographic analyses have been delayed by difficulties in accessing third party polishing and analytical services. GSWA has subsequently established an in-house gold sample polishing facility to remove dependence on third party providers, but is still awaiting the commissioning of a new commercial LA-ICPMS instrument. Available data have been evaluated and compiled into a series of Mineralogical Records. All Records will be published upon completion in the 2021–22 financial year.

In April 2021, GSWA commissioned the John de Laeter Centre for Isotope Research at Curtin University to undertake a six-month pilot study to determine whether the timing and the source(s) of gold mineralization can be constrained using Pb–Pb and Re–Os radiogenic isotope systematics and other trace element compositions. GSWA provided a selection of native gold specimens from Western Australia that represent a range of geological settings, ages and types of gold deposits, and for which mineralogy and trace element chemistry have already been determined. All analyses have been completed, and John de Laeter Centre researchers are now evaluating the data. A final report will be released in the 2021–22 financial year.

EIS program review

MRIWA project M532 aims to provide an understanding of the geology and mineralogy of Western Australian spodumene-bearing lithium–cesium–tantalum (LCT) pegmatite-hosted lithium deposits, in order to develop practical geometallurgical models to optimize the sustainable development of these deposits, and verify the suitability of field portable analytical devices for determining lithium abundance and distribution during exploration. The researchers at the John de Laeter Centre at Curtin University completed all analytical aspects of the project in the 2020–21 financial year. This included development of a petrological and geochemical classification for LCT pegmatites, characterizing the mineralogy and deportment of economic and deleterious elements, and testing the effects of calcination on spodumene concentrates. The final MRIWA report is expected in the 2021–22 financial year.

The ‘Rare earth resources of northern Australia’ project commenced in 2020–21 after being awarded an ARC Linkage grant. Principal investigators at Adelaide University (originally James Cook University) and ANU have been working with sponsors GSWA, GA, the Geological Surveys of New South Wales and Queensland, and REE-focused resource companies to develop a detailed research program that will yield metallogenic models and exploration tools. Case studies of relevance to Western Australia will include the Browns Range and John Galt REE deposits in the East Kimberley – West Tanami region of northern Western Australia, but as yet no visits by researchers to these deposits have been possible, and there has been no progress on this component of the overall project.

CSIRO reanalysed approximately 3200 laterite samples from the western Yilgarn Craton using modern analytical techniques, to determine Li and several other critical metals (i.e. Sn, W, REE) that could not be reliably measured in previous analytical campaigns using older technologies. The study combined conventional geochemical analysis with the UltraFine+ methodology, indicator mineral chemistry, and studies of regolith characteristics and deportment of critical metals in primary critical mineral deposits (including the Greenbushes pegmatite-hosted Li–Ta deposit). The aim is to understand the formation of critical metal anomalies in the regolith, and their significance as indicators of the size and quality of potential underlying mineralization, hence assess critical metal potential value in the region, and provide a tool that might be applied to critical metals exploration at the regional scale. Delivery of the final report and all data was expected in late 2020, but GSWA identified issues with the quality of geochemical analyses, and the (commercial) laboratory was directed to reanalyse a significant portion of the sample suite. This has delayed completion of this project until 2021–22.

EIS program review

ES46 Enhanced Geochronology and Isotopic Mapping

Manager: Michael Wingate

Objectives

Project ES46 includes operational geochronology and geochemistry activities previously conducted as part of GS54 Geochronology and Geochemistry. In addition to the activities described above under GS54, ES46 enhances GSWA's core geochronology program with a range of studies conducted in collaboration with university research groups, including Lu–Hf and oxygen isotope and trace element analysis of zircons, and Sm–Nd isotope analysis of whole-rock samples. These analyses underpin construction of a range of isotope maps, which are powerful for imaging lithospheric and crustal architecture, identifying metallogenic terranes and geodynamic environments favourable for mineralization, and constraining the 4D evolution of the lithosphere. Other isotope techniques include Re–Os geochronology, whole-rock Lu–Hf and Pb isotopes, and in situ laser Rb–Sr geochronology. Whole-rock geochemistry is critically important to GSWA's geoscience programs, and a large proportion of geochemistry analyses is related to samples submitted under ES49 Greenstone Geochemical Barcoding Project and ES51 Yilgarn Granite Project.

Highlights and activities

- GSWA's first statewide samarium–neodymium (Sm–Nd) and lutetium–hafnium (Lu–Hf) isotope maps were released under the AGP. The maps depict two-stage depleted mantle model ages (T_{DM^2}), which are proxies for the ages of the crustal sources of igneous rocks, and crustal residence times (TCR), which show the difference between model ages and corresponding crystallization ages, and indicate how long the sources resided in the crust. Significant gradients in model ages are typically associated with major crustal structures that are potentially important for localizing mineral systems. For example, maps of the Yilgarn Craton highlight the Cue and Kalgoorlie–Kurnalpi 'rifts', which exhibit younger model ages than surrounding areas, and contain the majority of gold deposits in Western Australia
- GSWA's first statewide zircon oxygen isotope map was released under the AGP. Zircon oxygen isotope ($\delta^{18}O$) values identify reworking and recycling of supracrustal rocks that have interacted with Earth's hydrosphere, and can be related to geodynamic processes. The map shows that the Pilbara and Yilgarn Cratons are dominated by mantle-like $\delta^{18}O$ values (4.7 – 5.9‰), suggesting that Archean granitic rocks were mainly formed through reworking of igneous material that had not been exposed at the surface. In contrast, Proterozoic rocks in the Capricorn, Paterson and Albany–Fraser Orogens and the Madura and Coompana Provinces indicate mainly elevated $\delta^{18}O$ values (6.6 – 10.4‰), suggesting significant reworking of upper crustal material subjected to weathering or low-temperature hydrothermal alteration. These new zircon oxygen isotope data have shed new light on how the Earth's first continental crust was formed, and have been showcased in the journal *Nature*
- SHRIMP and LA-ICP-MS U–Pb geochronology of 105 zircon, monazite and baddeleyite samples, mainly from the South West and Youanmi Terranes and the Eastern Goldfields Superterrane of the Yilgarn Craton, the Capricorn, Albany–Fraser, Arunta, and Wunaamin Miliwundi Orogens, and the Murraba, Yeneena, and Canning Basins. Zircon and monazite samples from the South West Terrane were given priority under the AGP
- Using LA-ICP-MS U–Pb geochronology of monazite in thin section, high-grade metamorphic and tectonic events (see also GS53) were identified at c. 2665 and 2655–2635 Ma in the Corrigin Tectonic Zone, which marks the redefined boundary between the South West and Youanmi Terranes

EIS program review

- New geochronology data from the recently discovered Julimar PGE–Ni–Cu–Co deposit in the South West Terrane define a new age of c. 2670 Ma for ultramafic magmatism and orthomagmatic mineralization in the Yilgarn Craton. A pegmatitic metagabbro from the ore-hosting Gonneville intrusion at Julimar yielded an igneous crystallization age of 2668 ± 4 Ma. A granodiorite that crosscuts the Gonneville intrusion crystallized at 2663 ± 8 Ma. Pendlantite in a sulfide ore sample produced a range of Re–Os model ages suggesting that Proterozoic alteration or recrystallization of Archean sulfide ore was younger than c. 2356 Ma. The Julimar metagabbro is similar in age to the Coates Siding gabbro (2664 ± 6 Ma) associated with the Morangup greenstone belt farther east. Together with a peak of granitic magmatism at c. 2670 Ma, these results may signify that c. 2670 Ma mafic–ultramafic and felsic magmatic rocks are widespread in the South West Terrane and potentially prospective for mineralization
- SHRIMP U–Pb zircon geochronology of detrital zircons has been completed for samples from Barnicarndy 1, the deep stratigraphic well drilled in late 2019 to intersect the Canning sedimentary succession and basement rocks in the Barnicarndy Embayment (see ES47). Results for the basal Canning Basin succession and unconformably underlying Yeneena Basin are available as Geochronology Records in GeoVIEW.WA and summarized in GSWA and external publications. Also completed is a collaborative project with the John de Laeter Centre that employed (U–Th)/He thermochronology studies of zircon and apatite crystals from Barnicarndy 1 geochronology samples to understand the uplift and cooling history of strata in the Barnicarndy Graben
- SHRIMP U–Pb zircon geochronology of drillcore samples from western Arunta Orogen rocks beneath the eastern margin of the Canning Basin (see GS65) has continued. Results for granitic gneisses indicate protolith crystallization ages of c. 1875 Ma, and detrital zircons in paragneiss samples are dominated by c. 1870 Ma age components and yield maximum depositional ages of 1870–1850 Ma. Zircon rims in all samples indicate high-grade metamorphism at 1620–1610 Ma
- Isotope studies of late Neoproterozoic (650–500 Ma) granitic basement rocks beneath the northwestern Canning Basin indicate Lu–Hf compositions similar to those for the Musgrave, Madura and Coompana Provinces, but different to those from the North and West Australian Cratons. This suggests the existence of a subsurface Proterozoic terrane beneath the Canning Basin, possibly related to the Mirning Ocean
- The ARC Linkage project ‘New tools for old rocks: first cycle provenance information’, in which GSWA is a participant, together with Curtin University and Northern Star Resources Ltd, is continuing. The project is aimed at applying novel provenance fingerprinting tools in K-feldspar (lead isotopes) and apatite (U–Pb, strontium isotopes and mineral chemistry). Highly variable Pb isotope compositions of 52 Pilbara Craton granitic rocks indicate that the oldest felsic rocks in the Pilbara Craton formed by the reworking of a long-lived mafic precursor that existed for up to 700 million years. More than 90 Yilgarn Craton granitic samples were used to construct novel Pb evolution models that suggest the Youanmi Terrane and Eastern Goldfields Superterrane (EGST) shared a common basement and underwent rifting and re-accretion rather than successive accretion of exotic EGST terranes to a Youanmi proto-continent. Variation in Pb isotope signatures is also found to be greater in Pb-rich ores related to gold deposits compared with those in volcanogenic massive sulfide ores and komatiite-hosted Ni–sulfide ores, leading to potential applications in exploration for metal deposits
- GSWA and Curtin University completed a collaborative pilot study to demonstrate the utility of a novel in situ Rb–Sr analytical technique that uses laser ablation collision–reaction cell inductively coupled plasma mass spectrometry (LA-CRC-ICP-MS) to eliminate isobaric interference between parent ^{87}Rb and radiogenic ^{87}Sr . The technique was applied successfully to date biotite and apatite from 11 metasedimentary and meta-igneous rocks from various locations in Western Australia. This new analytical tool is complementary to other techniques and will allow dating of a wider range of rocks and geological events. The new instrument was acquired via a 2020 ARC Linkage Infrastructure, Equipment and Facilities (LIEF) grant awarded to Curtin University and sponsored by GSWA, UWA and CSIRO

EIS program review

- GSWA provided in-kind support, together with seven Australian universities, to another successful ARC LIEF grant, for next-generation, multicollector mass spectrometers and ultraclean gas line systems, capable of revolutionizing noble-gas ($^{40}\text{Ar}/^{39}\text{Ar}$) dating. The installation at Curtin University will be optimized to analyse ultrasmall and potassium-poor samples, such as tiny inclusions in ore minerals and feldspars and pyroxenes in mafic igneous rocks, which cannot be dated by other methods
- The McNaughton Legacy SHRIMP Mount Collection data layer was released under the AGP, and represents a collection of geochronology samples and associated digital information donated to GSWA by Professor Neal McNaughton of the John de Laeter Centre at Curtin University. These materials were compiled as part of the university's Preservation of Legacy Collections Project, jointly funded by GSWA, AuScope and Curtin University. The data layer can be accessed in GeoVIEW.WA and the Data and Software Centre (DASC), and enables SHRIMP mounts curated by GSWA to be borrowed for additional analytical studies by GSWA and external researchers
- Following much development and testing, the WAGIMS database is essentially complete and is ready to be populated with all metadata, files and data related to geochronology, isotope and mineral chemistry. The new database will enable complex, statewide data queries and form the basis of a new system for publishing reports that provides access to additional sample-related materials and consistently incorporates the most up-to-date geological and analytical information
- Contributions to GSWA publications and data packages:
 - Report 143 East Pilbara Craton: a record of one billion years in the growth of Archean continental crust
 - Record 2020/12 Proterozoic dolerite dykes in the western Capricorn Orogen, Western Australia
 - Record 2020/14 The utility of the metamorphic rock record: constraining the pressure–temperature–time conditions of metamorphism
 - Record 2021/4 Accelerated Geoscience Program extended abstracts, 2021
 - Southwest Yilgarn Geological Exploration Package
 - Geological Information Series: Northwest Pilbara 2020, East Yilgarn 2020, East Albany–Fraser Orogen 2020, Youanmi 2020
 - Barnicarndy 1 deep stratigraphic drillhole (poster)
 - GSWA Fieldnotes and social media pages

EIS program review

Products released

- 86 new Geochronology Records and U–Pb datasets released to online applications, published maps and digital products (GeoVIEW.WA, DASC and eBookshop)
- 2678 new whole-rock geochemistry analyses released via GeoChem Extract and GEOVIEW.WA
- New digital data layers released or updated in GeoVIEW.WA, DASC and/or digital data packages:
 - GSWA Geochronology, featuring 1796 Geochronology Records, together with corresponding digital isotope datasets
 - Whole-rock Sm–Nd isotope maps and extended abstract, including 1994 samples in total (new data for 114 samples)
 - Zircon Lu–Hf isotope maps and extended abstract, including 12 902 spot analyses from 729 samples (new data from 132 samples)
 - Zircon oxygen isotope map and extended abstract, including 3029 spot analyses from 182 samples (new data from 67 samples)
 - McNaughton Legacy SHRIMP Mount Collection and extended abstract
 - New geochemical and geochronological constraints on the magmatic evolution of Boddington, southwest Yilgarn
 - Variations in granite geochemistry in the southwest Yilgarn
- Record 2021/5 Eastern Goldfields Greenstone Geochemical Barcoding Project – notes to accompany 2021 data release
- Record 2021/6 Yilgarn Granite Project – notes to accompany 2021 data release

EIS program review

ES47 Petroleum Systems

Manager: Deidre Brooks

Objectives

The objective of this program area is to collect precompetitive data to assist in determining the State's potential for energy sources such as petroleum, geothermal, carbon capture and storage, helium and natural hydrogen that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms some of which were completed during the 2020–21 financial year.

Highlights and activities

- An EIS-funded study of the parameters influencing the reservoir quality of Permian sandstones in the northern Perth Basin was completed in 2019–20. The Report was released in June 2021
- The Barnicarndy 1 stratigraphic well (formerly known as Waukarlycarly 1) was drilled during 2019–20. The drilling was funded by the Commonwealth Government EFTF program, administered by GA. The post-well analysis performed by GSWA is funded by the EIS. Analysis completed during 2020–21 will be incorporated into the Interpretive Well Completion Report (to be released in 2021–22). A summary of the new analyses is listed in the products released section below
- A Report interpreting the Canning Basin portion of the Kidson Sub-basin Seismic Survey was completed and released in June 2021. Acquisition of this seismic survey was co-funded by EIS and GA's EFTF program
- In 2015–16 the EIS-funded Canning Basin collaborative core analysis project included interpretation of the core acquired through the Nambheet Formation in Olympic 1. The results of this work were published in May 2021 in Report 211.

Products released

- Report 211 Reference section, revised stratigraphy and facies analysis of the Ordovician Nambheet Formation, Canning Basin, Western Australia
- Report 213 Reservoir quality of Permian sandstones of the onshore northern Perth Basin – an assessment using HyLogger spectral data and petrography
- Report 216 Kidson Sub-basin Seismic Survey – a panorama of the southern Canning Basin
- Barnicarndy 1 post-well analysis:
 - Palynological analysis of Waukarlycarly 1, Canning Basin, Western Australia (released through eBookshop and WAPIMS)
 - Waukarlycarly 1: palynology of seven samples (released through eBookshop and WAPIMS)
 - Waukarlycarly 1 Petrographic Report (released through WAPIMS)
 - Waukarlycarly 1 Routine Core Analysis and Spectral Core Gamma Report (released through WAPIMS)
 - Waukarlycarly 1 TOC and Rock-Eval Pyrolysis Report by GA (released through WAPIMS) – not EIS funded, included for completeness
 - Waukarlycarly 1 Organic Petrology Report by GA (released through WAPIMS) – not EIS funded, included for completeness

EIS program review

ES49 Greenstone Geochemical Barcoding Project

Manager: Hugh Smithies

Objectives

The Greenstone Geochemical Barcoding Project aims to geochemically characterize greenstone stratigraphy throughout the EGST. This project will substantially increase the amount of high-quality, multi-element, geochemical data for greenstones, targeting available diamond drillcores that sample the most geologically well-constrained, or best-understood, parts of various greenstone belts. Through detailed geochemical sampling of diamond drillcore we hope to establish a geochemical 'barcode' of the stratigraphy (including local variations) in these better known sections of greenstone belts. A new, data-rich, high-quality geochemical dataset regionally representative of all magmatic rock types will additionally help further develop our understanding of petrogenetic processes in greenstone evolution and associated mineralization.

Highlights and activities

- 1889 new samples were submitted for whole-rock major and trace element geochemistry
- New sampling included collection of outcrop and drillcore samples from the southern Kalgoorlie Terrane to support chemostratigraphic interpretations in that area, a drillcore sampling campaign (~400 samples) in the Norseman region, and sampling in support of regional chemostratigraphic interpretations in the northern Kalgoorlie Terrane through the Yilgarn 2020 Project conducted through the Centre for Exploration Targeting (CET) and UWA.

Products released

- Greenstone Geochemical Barcoding Project – 2021 data release (Record 2021/5 Eastern Goldfields Geochemical Barcoding dataset Appendix 1)
- Record 2021/5 Eastern Goldfields greenstone geochemical barcoding project – notes to accompany 2021 data release

EIS program review

ES51 Yilgarn Granite Project

Manager: Hugh Smithies

Objectives

The Yilgarn Granite Project aims to provide complete and detailed coverage of the Yilgarn Craton in terms of modern, high-quality, major and trace element data (including Li) on felsic intrusive rocks, and at the same time, expand the coverage of whole-rock Sm–Nd isotope data. These data should help in identifying potential proxies for crustal source composition, melting conditions and for fertility in terms of producing precious and strategic mineral deposits. As data is accumulated, the project will provide interpretation (digital data, GIS layers, Reports) that attempts to place these data within the context of crustal-scale structure, source regions and economic mineral fertility. A significant portion of data generated during this project will come from reanalysing archived materials from GSWA and from GA's Yilgarn Craton granite collection (now housed with GSWA), but supplemented with new samples.

Highlights and activities

- 1033 samples from the GA Yilgarn Craton granite archive collection were submitted for whole-rock major and trace element geochemistry
- About 2000 samples from the GA Yilgarn Craton granite archive collection were prepared for submission.

Products released

- Yilgarn Granite Project – 2021 data release (Record 2021/6 Yilgarn Granite Project dataset Appendix 1)
- Record 2021/6 Yilgarn Granite Project – notes to accompany 2021 data release

Appendix 1

GSWA collaborative research projects

Completed projects 2020–21



Ar/Ar dating of pyroxene

Project manager: Michael Wingate

Partner researchers/institutions: John de Laeter Centre, Curtin University

GSWA contact: Michael Wingate

Duration of project: 2017–20

Project description

To test whether Ar/Ar analysis of pyroxene can be used to date mafic and ultramafic rocks that cannot be dated by other methods.

Outputs – actual

- Posters displayed at 2018 and 2020 GSWA Open Days.
- Ware, B, Wells, M, Aylmore, M, Jourdan, F, Wingate, MTD and McInnes, BIA 2021, Spodumene $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology for a cleaner future: Goldschmidt 2021, Lyon, France, July, abstract 5529.
- Ware, B, Wingate, MTD, Jourdan, F and McInnes, BIA 2019, Expanding the understanding of the $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of pyroxene: Thermochronology and Noble Gas Geochronology and Geochemistry Organisation (TANG30) Conference, Hobart, November.



Crustal evolution of Western Australia

Project manager: Chris Kirkland

Partner researchers/institutions: Curtin University

GSWA contact: Michael Wingate

Duration of project: 2015–20

Project description

The project aims were to:

- Produce contoured, time-dynamic hafnium isotope maps from selected regions of Western Australia
- Implement secondary ion mass spectroscopy oxygen analyses of GSWA mounts and contribute to isotope data.

Outputs – actual

- Gardiner, N, Lu, Y, Hickman, AH, Kirkland, CL and Wingate, MTD 2017, New Hf Isotopic Insights into the Paleoproterozoic Magmatic Evolution of the Mount Edgar Dome, Pilbara Craton: Implications for Early Earth and Crust Formation Processes: Geological Survey of Western Australia, Report 181, 47p.
- Gardiner, NJ, Hickman, AH, Kirkland, CL, Lu, Y, Johnson, T and Zhao, J-X 2017, Processes of crust formation in the early Earth imaged through Hf isotopes from the East Pilbara Terrane: Precambrian Research, v. 297, p. 56–76.

Appendix 1

- Gardiner, NJ, Johnson, T, Kirkland, CL and Smithies, RH 2018, Melting controls on the lutetium–hafnium evolution of Archaean crust: *Precambrian Research*, v. 305, p. 479–488.
- Gardiner, NJ, Maidment, DW, Kirkland, CL, Bodorkos, S, Smithies, RH and Jeon, H 2018, Isotopic insight into the Proterozoic crustal evolution of the Rudall Province, Western Australia: *Precambrian Research*, v. 313, p. 31–50.
- Johnson, SP, Kirkland, CL, Evans, NJ, McDonald, BJ and Cutten, HN 2018, The complexity of sediment recycling as revealed by common Pb isotopes in K-feldspar: *Geoscience Frontiers*, v. 9, p. 1515–1527.
- Kirkland, CL, Gardiner, N, Smithies, RH, Spaggiari, CV, Wingate, MTD, Quentin De Gromard, R, Clark, C and Belousova, EA 2017, Proterozoic crustal evolution of the Eucla basement, Australia: Implications for destruction of oceanic crust during emergence of Nuna: *Lithos*, v. 278–281, p. 427–444.
- Kirkland, CL, Spaggiari, CV, Johnson, TE, Smithies, RH, Danišík, M, Evans, N, Wingate, MTD, Clark, C, Spencer, C, Mikucki, E and McDonald, BJ 2016, Grain size matters: Implications for element and isotopic mobility in titanite: *Precambrian Research*, v. 278, p. 283–302.
- Spaggiari, CV, Smithies, RH, Kirkland, CL, Wingate, MTD and England, RN 2020, Stratigraphic and co-funded drilling of the Eucla basement – the Proterozoic geology beneath the Nullarbor Plain: *Geological Survey of Western Australia, Report 204*, 155p.



Earth composition and evolution – preservation of legacy collections project

Project manager: Michael Wingate

Partner researchers/institutions: John de Laeter Centre and Curtin Library, Curtin University

GSWA contact: Michael Wingate

Duration of project: 2018–20

Project description

The project aimed to compile a collection of geochronology samples and associated digital information donated to GSWA by Professor Neal McNaughton of the John de Laeter Centre at Curtin University, provided as part of the Curtin University Preservation of Legacy Collections Project, and jointly funded by AuScope, GSWA and Curtin University. Western Australian mineral samples in the form of SHRIMP mounts were curated by GSWA, and made available to researchers for additional measurements.

Outputs – actual

- Blereau, E, Bellenger, A, McNaughton, NJ, McInnes, BIA and Wingate, MTD 2020, McNaughton Legacy SHRIMP Mount Collection, Curtin University Preservation of Legacy Collections Project: *Geological Survey of Western Australia, digital data layer and abstract*.

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MRIWA project M446 – 4D evolution of Western Australian ore systems: Re–Os sulfide geochronology

Project manager: Neal McNaughton (John de Laeter Centre, Curtin University)

Partner researchers/institutions: Neal McNaughton, Svetlana Tessalina, Fred Jourdan, Vitor Barrote (PhD candidate; John de Laeter Centre, Curtin University), Thermo Fisher Scientific

GSWA contact: Michael Wingate

Duration of project: 2016–19 (extended to 2020)

Project description

The aims were to provide benchmark geochronology for metals exploration in Western Australia to complement the extensive 2D and 3D geological mapping and data of GSWA and industry. This sulfide geochronology project provided a new opportunity to introduce direct dating of ore sulfides along with fingerprinting metal sources. The project filled a major gap in 4D analysis of mineralized terrains, a topic recognized as a national deficiency. The specific aims were for two deposit types, volcanogenic massive sulfides and orogenic gold.

Outputs – actual

- Barrote, V, McNaughton, NJ, Tessalina, S, Evans, NJ, Talavera, C, Zi, J-W and McDonald, BJ 2020, The 4D evolution of the Teutonic Bore Camp VHMS deposits, Yilgarn Craton, Western Australia: Ore Geology Review, v. 120, 103448, doi:10.1016/j.oregeorev.2020.103448.
- Barrote, V, Tessalina, S and McNaughton, NJ 2017, Trace elements and Re-Os composition of black shales and pyrite nodules from the Nimbus Deposit, eastern Yilgarn craton, Western Australia: Timescales of Geological Processes, 2017 TIGeR Conference, Curtin University, p. 36.
- Barrote, V, Tessalina, S, McNaughton, NJ, Evans, NJ, Hollis, SP and McDonald, BJ 2021, Surge of ore metals in seawater and increased bio-activity: a tracer of VHMS mineralization in Archaean successions, Yilgarn Craton, Western Australia: Mineralium Deposita, v. 56, doi:10.1007/s00126-020-00986-6.
- Barrote, V, Tessalina, S, McNaughton, NJ, Jourdan, F, Hollis, SP, Ware, B and Zi, J-W 2020, 4D history of the Nimbus VHMS ore deposit in the Yilgarn Craton, Western Australia: Precambrian Research, v. 337, 105536, doi:10.1016/j.precamres.2019.105536.
- Barrote, VR 2020 4D Evolution of Replacement-Type VHMS Ore Systems in the Yilgarn Craton, Western Australia: PhD thesis, Curtin University, <http://hdl.handle.net/20.500.11937/81526>.
- McNaughton, NJ, Tessalina, S, McInnes, BIA Jourdan, NJ and Barrote, V 2020, 4D Evolution of WA Ore Systems: Re-Os sulphide geochronology: Minerals Research Institute of Western Australia, Report No. 446, 20p.



MRIWA project M448 – 4D evolution of Western Australian ore systems (WA4D): rutile – pathfinder to ores

Project manager: Neal McNaughton (John de Laeter Centre, Curtin University)

Partner researchers/institutions: Neal McNaughton, Noreen Evans, Fred Jourdan, Jennifer Porter (PhD candidate; John de Laeter Centre, Curtin University), Independence Group NL

GSWA contact: Michael Wingate

Duration of project: 2015–18 (extended to 2020)

Project description

This project used publicly available geochemical data on rutiles formed in different ore and unmineralized environments to build a geochemical database, and to add new geochemical data for rutiles from Western Australian ore systems and barren rocks. From this database, existing

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geochemical discriminants of mineralization were tested, and by virtue of the enhanced capabilities of the modern analytical techniques to be employed, new discriminants were developed for each ore commodity that shed light on the origin of the formation of rutile. The project targeted Western Australian ore systems for new data, and compared and contrasted against published data. The project included:

- Rapid/automated rutile identification and in situ analysis
- Verification of rutile mineralization ages by other geochronology methods (U–Pb, Ar–Ar)
- Sponsor-initiated case studies of rutile geochemical/age discriminants for gold and base metal exploration in Western Australia
- Feedback to 4D metallogenic mapping.

Outputs – actual

- Kennedy, AK, Porter, JK and Talavera, C 2018, Assessing the effect of rutile crystallographic orientation on SIMS oxygen isotopes: 9th International SHRIMP Workshop, Gyeongju, South Korea.
- McNaughton, NJ, McInnes, BIA, Evans, NJ, Jourdan, F, Talavera, C and Porter, JK 2020, 4D Evolution of WA Ore Systems: Rutile – Pathfinder to Ores: Minerals Research Institute of Western Australia, Report No. 448, 30p.
- McNaughton, NJ, Porter, JK, Evans, NJ, McDonald, B, Talavera, C and Doyle, M 2018, Detrital rutile: a new tool for gold exploration under cover: Australian Geoscience Council Convention, Adelaide, Australia, p. 120.
- McNaughton, NJ, Talavera, C, Porter, JK, Evans, NJ and McInnes, BIA 2016, Rutile U/Pb geochronology and geochemistry by SHRIMP: some observations: 8th International SHRIMP Workshop, Grenada, Spain, p. 54–56.
- Moore, J, Beinlich, A, Porter, JK, Talavera, C, Bernt, J, Piazzolo, S, Austrheim, H and Putnis, A 2020, Microstructurally controlled trace element (Zr, U–Pb) concentrations in metamorphic rutile: An example from the amphibolites of the Bergen Arcs: *Journal of Metamorphic Geology*, v. 38, p. 103–127, doi:10.1111/jmg.12514.
- Porter, JK 2019, Application of Rutile Geochemistry to Base and Precious Metal Exploration: PhD thesis, Curtin University, <<http://hdl.handle.net/20.500.11937/78505>>.
- Porter, JK, Evans, NJ, McDonald, B, Talavera, C, McNaughton, NJ, Kirkland, CL, Jourdan, F and McInnes, BIA 2017, Rutile geochemistry in ore systems – considerations for metal exploration: Goldschmidt 2017 Conference, Paris, France.
- Porter, JK, McNaughton, NJ, Evans, NJ and McDonald, BJ 2020, Rutile as a pathfinder for metals exploration: *Ore Geology Reviews*, v. 120, 103406.
- Porter, JK, McNaughton, NJ, Evans, NJ, McDonald, BJ, Talavera, C and Austrheim, H 2017, Rutile isotope and trace element geochemistry through albitite metasomatism of meta-gabbro, Bamble region, southern Norway: Timescales of Geological Processes, 2017 TIGER Conference, Curtin University, p. 66–67.
- Porter, JK, McNaughton, NJ, Evans, NJ, Talavera, C and McDonald, B 2018, Detrital rutile geochemistry in Au exploration: Resources for Future Generations (RFG) 2018, Vancouver, Canada.
- Porter, JK, Talavera, C, McNaughton, NJ, Evans, NJ, McDonald, B and McInnes, BIA 2018, Rutile geochemistry in gold exploration: International Mineralogical Association (IMA) 2018, Melbourne, Australia, p. 43.

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Feasibility of passive seismic and temperature monitoring using cemented fibre optic cable in Harvey 3 well

Project manager: Deidre Brooks

Partner researchers/institutions: Curtin University

GSWA contact: Deidre Brooks

Duration of project: January 2020 – October 2020

Project description

Distributed fibre optic sensing is an emerging technology enabling reliable long-term monitoring and surveillance of the subsurface. It can be used to monitor changes in strain, temperature, and some other physical properties at high sampling rates both spatially and temporally. Measuring dynamic strain referred to as distributed acoustic sensing (DAS) allows the conversion of a single optical fibre into an array of optical acoustic sensors with very small receiver intervals, broad frequency range and high enough sensitivity. Such receiver arrays can be used to monitor local and regional seismicity as well as detect distant seismic events. Deployment of the seismic receiver array along deep vertical wells allows seismic sensors in a quiet environment with no surface wave contamination.

The following activities were performed on the Harvey 3 well:

- Continuous passive seismic acquisition of DAS and distributed temperature setting (DTS) covering several days in mid-2020.
- Data analysis successfully demonstrated the feasibility of passive monitoring for characterization of the subsurface and analysis of performance of cemented cable
- Liaison with CSIRO and The University of Western Australia (UWA) resulted in access to their data being collected from nearby Harvey wells and passive seismic monitors.

Outputs – actual

- Raw and processed seismic data converted to generic data format (SEG-Y) received October 2020.
- Short Report summarizing findings, finalized in November 2020.
- Presentation to industry forum on results in September 2020.

Harvey 2 well water production and injection testing

Project manager: Deidre Brooks

Partner researchers/institutions: Karsten Michael (CSIRO)

GSWA contact: Deidre Brooks

Duration of project: January 2020 – June 2020 (extended to October 2020)

Project description

A multi-day water production and injection of the Harvey 2 well to establish the feasibility of future experiments at the in situ lab site.

Outputs – actual

- In February 2019, a controlled release experiment was conducted by injecting and monitoring 38 tonnes of food-grade gaseous CO₂ over four days between 336 and 342 m depth during which the gas was monitored by a wide range of downhole and surface monitoring technologies.
- Injectivity was lower than predicted from core measurements and modelling. Multiple lines of evidence suggested that a combination of wellbore damage, mud invasion and

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reservoir compartmentalization could be the cause of a lower than expected injectivity. The 2020 remediation activities aimed to improve injectivity in Harvey 2 through improving the permeability by reducing the well drilling damage.

- The research infrastructure has proven that while there is limited injectivity in the Harvey 2 well, it is possible to inject gaseous CO₂, water and compressed air (during the artificial lift testing).

CSIRO provided:

- A report in October 2020 containing an interpretation of hydraulic properties, boundary conditions and formation water quality of the perforated interval in Harvey 2.
- Logging interpretation shows that the Harvey 2 well integrity is not compromised and that the well is suitable for future injections.
- Well corrosion logging confirmed minimal corrosion of Harvey 2 well casing and tubing, and that the well completion is suitable for future fluid injection experiments. The resulting well log interpretation is included as an Appendix in the Report.



Mapping sulfur sources in selected Precambrian terranes of Western Australia to enhance predictive targeting for gold and base metal mineralization

Project manager: Marco Fiorentini (Centre for Exploration Targeting [CET], UWA)

Partner researchers/institutions: CET, UWA

GSWA contact: Trevor Beardsmore

Duration of project: 2014–17 (extended to 2020)

Project description

This work was largely done within MRIWA projects M457: Geological controls on the fractionation of sulphur isotopes in Archaean mineral systems – and M436: Distal Footprints of Giant Ore Systems, Capricorn WA. The aims of the work were to spatially constrain sulfur sources of gold and base metal mineralization in key terranes of Western Australia, notably the Archean Yilgarn and Pilbara Cratons, and intervening Capricorn Orogen.

Outputs – actual

- Baumgartner, RJ, Caruso, S, Fiorentini, ML, Van Kranendonk, MJ and Martin, L 2020, Sulfidization of 3.48 billion-year-old stromatolites of the Dresser Formation, Pilbara Craton: Constraints from in-situ sulfur isotope analysis of pyrite: *Chemical Geology*, v. 538, Paper 119488.
- Caruso, S 2018, Geological controls on the fractionation of sulfur isotopes in Archaean mineral systems; PhD Thesis (unpublished), The University of Western Australia, 195p.
- Caruso, S, Fiorentini, ML, Barnes, SJ, LaFlamme, CK and Martin, LAJ 2020, Microchemical and sulfur isotope constraints on the magmatic and hydrothermal evolution of the Black Swan Succession, Western Australia: *Mineralium Deposita*, v. 55 (3), p. 535–553.
- Caruso, S, Fiorentini, ML, Moroni, M and Martin, LAJ 2017, Evidence of magmatic degassing in Archean komatiites: insights from the Wannaway nickel-sulfide deposit, Western Australia: *Earth and Planetary Science Letters*, v. 479, p. 252–262.
- Caruso, S, Moroni, M, Fiorentini, ML, Isaac, C, Barnes, SJ, Wings, BA and Cliff, J 2014, Effects of sulphur degassing in komatiite-hosted Ni-PGE ores at Wannaway, Yilgarn Craton, Western Australia, *Proceedings SGI-SIMP Conference, Rendiconti Online della Societa Geologica Italiana*, v. 31 (suppl. 1), p. 508.
- Godefroy-Rodríguez, M, Hagemann, S, LaFlamme, C and Fiorentini, M 2018, The multiple sulfur isotope architecture of the Golden Mile and Mount Charlotte deposits, Western Australia: *Mineralium Deposita*, v. 55 (4), p. 797–822.

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- LaFlamme, C, Caruso, S, Selvaraja, V and Fiorentini, M 2020, Theme 5B: Tracing sulphur pathways through the lithosphere, *in* Final Report, MRIWA M436: Distal Footprints of Giant Ore Systems, Capricorn WA – Case Study, MRIWA Report Number 436 *edited by* T Munday, p. 185–216.
- LaFlamme, C, Fiorentini, ML, Johnson, S, Occhipinti, S, Wing, BA and Jeon, H 2015, Using Multiple Sulfur Isotope Signatures to Delineate Terrane Boundaries and Investigate Crustal Formation Mechanisms during the Paleoproterozoic: Poster Abstract, American Geophysical Union Fall Meeting, 14–18 December 2015, T11B-2882, <<https://agu.confex.com/agu/fm15/webprogram/Paper77719>>, viewed 19 May 2021.
- LaFlamme, C, Fiorentini, ML, Lindsay, MD and Bui, TH 2018, Atmospheric sulfur is recycled to the crystalline continental crust during supercontinent formation: *Nature Communications*, v. 9(1), p. 1–9.
- LaFlamme, C, Jamieson, JW, Fiorentini, ML, Thébaud, N, Caruso, S and Selvaraja, V 2018, Investigating sulfur pathways through the lithosphere by tracing mass independent fractionation of sulfur to the Lady Bountiful orogenic gold deposit, Yilgarn Craton: *Gondwana Research*, v. 58, p. 27–38.
- LaFlamme, C, Martin, L, Jeon, H, Reddy, SM, Selvaraja, V, Caruso, S, Bui, T-H, Roberts, MP, Voute, F, Hagemann, S, Wacey, D, Littman, S, Wing, B, Fiorentini, M and Kilburn, MR 2016, In situ multiple sulfur isotope analysis by SIMS of pyrite, chalcopyrite, pyrrhotite, and pentlandite to refine magmatic ore genetic models: *Chemical Geology*, v. 444, p. 1–15.
- LaFlamme, C, Sugiono, D, Thébaud, N, Caruso, S, Fiorentini, M, Selvaraja, V, Jeon, H, Voute, F and Martin, L 2018, Multiple sulfur isotopes monitor fluid evolution of an Archean orogenic gold deposit: *Geochimica et Cosmochimica Acta*, v. 222, p. 436–446.
- Selvaraja, V, Caruso, S, Fiorentini, ML, LaFlamme, CK and Bui, T-H 2017, Atmospheric sulfur in the orogenic gold deposits of the Archean Yilgarn Craton, Australia: *Geology*, v. 45 (8), p. 691–694.
- Selvaraja, V, Fiorentini, ML, Jeon, H, Savard, DD, LaFlamme, CK, Guagliardo, P, Caruso, S and Bui, T-H 2017, Evidence of local sourcing of sulfur and gold in an Archaean sediment-hosted gold deposit: *Ore Geology Reviews*, v. 89, p. 909–930.
- Selvaraja, V, Fiorentini, ML, LaFlamme, CK, Wing, BA and Bui, TH 2017, Anomalous sulfur isotopes trace volatile pathways in magmatic arcs: *Geology*, v. 45(5), p. 419–422.
- Sugiono, D, Laflamme, C, Thébaud, N, Fiorentini, M, Martin, L and Rogers, J 2019, Tracking hydrothermal fluid evolution of an Archean orogenic gold deposit through multiple sulphur isotope analysis linked to detailed structural paragenesis: Abstract, Session SY-RE01, GAC-MAC-IAH conference, Québec, 13–15 May 2019, p. 178, <https://gac.ca/wp-content/uploads/2019/09/Quebec_ABSTRACT-Final-1.pdf> viewed 19 May 2021.

Appendix 1

AusAEM20–WA Project Agreement Western Australian component of Australian 20 km airborne electromagnetic surveys, GA Ref: 004495

Falls under the NCF CMCG40003A PA4

Project manager: David Howard

Partner researchers/institutions: Geoscience Australia (GA)

GSWA contacts: David Howard, John Brett

Duration of project: 2019–21 (two 12-month extensions)

Project description

The project is a continuation of previous agreements NCF CMCG40003A PA4 and CMCG4003A 000668-1 – GA Ref 003995, described below.

The current focus of national geophysics has shifted to very widely spaced, broadscale AEM surveys, extending GA's 2017–20 EFTF AusAEM surveys, as part of a collaborative, national goal of the Commonwealth, State and territory geological survey agencies to acquire AEM data at 20 km line-spacing or less across the Australian continent.

AusAEM20–WA is the Western Australian component of this Australian 20 km Airborne Electromagnetic Survey objective (AusAEM20). AusAEM20–WA Stage 1 commenced in 2020–21 over the southwest and southeastern parts of Western Australia. The Murchison area is scheduled for completion in 2021–22.

Outputs –actual

- Survey datasets including point data, grids, images and inversion products.
- Released in 2021–22: Eastern Goldfields, East Yilgarn, Earaheedy Desert TEMPEST surveys.

Appendix 2.1

GSLC Terms of reference

DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY

GEOLOGICAL SURVEY LIAISON COMMITTEE (GSLC)

1. Purpose

To review the performance of the Geological Survey of Western Australia (GSWA) and provide feedback to the Director General, Deputy Director General, Resource and Environmental Regulation and the Executive Director, Geological Survey and Resource Strategy from industry, government geoscience organisations, and university research institutions.

2. Key responsibilities

- Review and provide feedback on the performance of GSWA in relation to its Work Program and service delivery.
- Review and provide feedback on the operations being conducted under the Exploration Incentive Scheme.
- Review, contribute and provide feedback on the future GSWA Work Program.
- Provide advice on future trends in Western Australian and national mineral and petroleum resources exploration and mining, and provide a strategic view of exploration geoscience and targeting, including emerging opportunities for cooperative research.
- Provide reports to the Director General, Deputy Director General Resource and Environmental Regulation and the Executive Director Geological Survey and Resource Strategy, advising them of the findings of the Committee
- Through the technical sub committees described below, provide technical assessments of the products, services and program as described above.

3. Relationship with other Committees

The Committee can refer and receive matters to and from the Resource Industry Consultative Committee (RICC).

4. Decision Making

- The Committee has the authority to make findings and recommendations on any matter within the scope of this Charter.
- The Committee can request that GSWA provide information, assistance and advice on any matters within its scope, so that it can perform its purpose and key responsibilities.
- Where possible, findings and recommendations will be made by consensus, otherwise by a majority of the quorum present.
- Dissenting view/s can be recorded in the minutes if so requested by the member/s

Appendix 2.1

5. Membership

5.1 Committee membership

The Committee will consist of 11 members:

- The Deputy Director General Resource and Environmental Regulation of the Department of Mines, Industry Regulation and Safety.
- The Executive Director of the Geological Survey and Resource Strategy Division (Chair).
- One member from the Association of Mining and Exploration Companies (AMEC)*;
- One member from the Chamber of Minerals and Energy Western Australia (CME);
- One member from the Australian Petroleum Production and Exploration Association (APPEA)*;
- One member representing geoscience consultancies;
- One member from Geoscience Australia (GA)
- One member from the Minerals Research Institute of Western Australia (MRIWA).
- One member each from the CSIRO, UWA and Curtin University; and
- Ex-officio members, and any other person/s the Chair authorises.

5.2 Qualifications for members

The committee will seek a gender balance (50%) in its membership.

Members and proxies will have a mix of the necessary skills and experience required to enable them to fulfil their duties and responsibilities as members of the Committee.

5.3 Appointment

- The Director General or his proxy will appoint members and proxies to the Committee on the recommendation of the institutions named above;
* These members will also be the Chairs of the technical subcommittees described below; and
- The members are appointed for a period of three years, and although they are eligible for reappointment, rotation is preferred, and the Chair will seek nominations from the represented organisations that recognise the need for gender balance, and for skills and experience relevant to the committee.

6. Technical Subcommittees

6.1 Minerals Technical Subcommittee (MTSC)

6.1.1 The MTSC will evaluate the technical aspects of the GSWA Work Program and products pertaining to minerals. The Chair of MTSC shall provide a report to the GSLC of the findings and recommendations of the MTSC.

6.1.2 Membership will consist of 8 members:

- One member from the Association of Mining and Exploration Companies (AMEC) (Chair);
- One member from the Chamber of Minerals and Energy Western Australia (CME);
- One member from the Minerals Research Institute of Western Australia (MRIWA);
- One member from the Australian Institute of Geoscientists;
- One member each from GA, CSIRO, UWA and Curtin University; and;
- Ex-officio members, and any other person/s the Chair authorises.

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6.2 Petroleum Technical Subcommittee (PTSC)

6.2.1 The PTSC will evaluate the technical aspects of the GSWA Work Program and products pertaining to petroleum. The Chair of PTSC shall provide a report to the GSLC of the findings and recommendations of the PTSC.

6.2.3 Membership will consist of 7 members:

- One member from the Australian Petroleum Production and Exploration Association (APPEA) (Chair);
- One member from the Chamber of Minerals and Energy Western Australia (CME);
- One other member from the petroleum industry;
- One member each from GA, CSIRO, UWA and Curtin University; and
- Ex-officio members, and any other person/s the Chair authorises

6.3 Qualifications of Subcommittee members

- The subcommittees will seek a gender balance (50%) in their membership.
- Members of the two technical sub committees must have qualifications such that they can make valid technical assessments on the information provided at the meeting.

7. Meetings

- The Committee shall meet as frequently as is necessary to undertake its role effectively and in any event, at least two times a year preferably in May/June (FYQ4) and November/December (FYQ2). The Q4 meeting will assess the program plan; and the Q2 meeting the Annual Review, including staffing and budget;
- The two subcommittees will meet prior to the regular twice yearly meeting of the Committee and be held to provide sufficient time for their reports to be presented to GLSC members.
- The GSLC Chair will call a meeting of the Committee if requested by any member of the Committee or the Director General;
- The Chair can nominate any other member to chair meetings if the Chair is not available;
- A quorum for the GSLC will be the Chair and any three members;
- A quorum for the two subcommittees will be the Chair and any three members;
- A notice of each meeting confirming the date, time, location, venue and agenda will be forwarded to members as soon as is practicable prior to the meeting;
- Members can attend committee meetings other than in person;
- The Chair may invite any person to attend meetings as an observer or to participate in the meeting;
- Committee members must disclose to the Committee any actual or potential conflict of interest which may exist as soon as they become aware of the issue and take any necessary and reasonable measures to try and resolve the conflict; and
- The Chair will report the findings and recommendations of the Committee to the Director General after each Committee meeting, or as appropriate. The report will be published in the Annual Review.

8. Executive Support

Executive support to the Committee will be provided by the Geological Survey and Resource Strategy Division.

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9. Review

The Committee shall perform a review and evaluation, at least annually, of the performance of the Committee and its members, including reviewing the compliance of the Committee with this Charter. In addition, the Committee shall review and reassess, at least annually, the adequacy of this Charter and recommend to the Director General any improvements to this Charter that the Committee considers necessary or valuable. The Director General shall also issue an annual evaluation of the Committee's performance.

10. Induction of new members

New Members will be inducted by the Chair.

ENDORSED BY THE DEPUTY DIRECTOR GENERAL:

11. APPENDIX – Committee membership

<i>NAME</i>	<i>POSITION</i>	<i>DATE APPOINTED</i>	<i>DATE APPOINTMENT EXPIRES</i>
Jeff Haworth	Chair	15 March 2018	14 March 2021
Kevin Cassidy	Member for AMEC	15 March 2018	14 March 2021
Mark Devereux	Member for APPEA	15 March 2018	14 March 2021
Bill Beament	Member for CME	15 March 2018	14 March 2021
Marcus Willson	Member for consultants	15 March 2018	14 March 2021
Nicole Roocke	Member for MRIWA	7 June 2019	7 June 2022
Andrew Heap	Member for GA	15 March 2018	14 March 2021
Rob Hough	Member for CSIRO	15 March 2018	14 March 2021
Steve Rowins	Member for UWA	15 March 2018	14 March 2021
Andrew Putnis	Member for Curtin University	15 March 2018	14 March 2021
Phil Gorey	Deputy Director General, DMIRS.	4 Sept 2019	3 Sept 2022

12. APPENDIX – Minerals Technical Sub-committee membership

<i>NAME</i>	<i>POSITION</i>	<i>DATE APPOINTED</i>	<i>DATE APPOINTMENT EXPIRES</i>
Kevin Cassidy	Chair, Member for AMEC	15 March 2018	14 March 2021
Michael Mulroney	Member for CME	15 March 2018	14 March 2021
Paull Parker	Member for AIG	15 March 2018	14 March 2021
Marcus Willson	Member for consultants	15 March 2018	14 March 2021
Jon Hronsky	Member	15 March 2018	14 March 2021
Richard Blewett	Member for GA	15 March 2018	14 March 2021
Robbie Rowe	Member for UNCOVER	15 March 2018	14 March 2021
Sandra Occhipinti	Member for CSIRO	15 May 2019	15 May 2022
Anil Subramanya	Member for MRIWA	15 March 2018	14 March 2021
Michael Dentith	Member for UWA	15 March 2018	14 March 2021
Chris Kirkland	Member for Curtin University	15 March 2018	14 March 2021

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13. APPENDIX – Petroleum Technical Sub-committee membership

<i>NAME</i>	<i>POSITION</i>	<i>DATE APPOINTED</i>	<i>DATE APPOINTMENT EXPIRES</i>
Mark Devereux	Chair, Member for APPEA	15 March 2018	14 March 2021
Gerry Spanninga	Member for CME	17 September 2018	16 September 2021
Shelley Robertson	Other Industry Member	15 March 2018	14 March 2021
Mark Ballesteros	Member for consultants	15 March 2018	14 March 2021
TBA (replacement for Andrew Barrett)	Member for GA	15 March 2018	14 March 2021
Ben Clennell	Member for CSIRO	15 March 2018	14 March 2021
Julien Bourget	Member for UWA	15 March 2018	14 March 2021
Chris Elders	Member for Curtin University	15 March 2018	14 March 2021
Tim Hicks	Other Industry Member	15 March 2018	14 March 2021
Steve Molyneux	Other Industry Member	15 March 2018	14 March 2021

Appendix 2.2

Report of the GSLC



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

Our ref A1440/201601
Enquiries Jeffrey Haworth
9222 3291
Jeffrey.HAWORTH@dmirs.wa.gov.au

Mr Richard Sellers
Director General
Department of Mines, Industry Regulation and Safety
Sent by Email
East Perth WA 6004

Through: Andrew Chaplyn, Deputy Director General Resources and Environmental Regulation

Dear Richard

REPORT OF THE GEOLOGICAL SURVEY LIAISON COMMITTEE – JULY 2021

The Geological Survey Liaison Committee (GSLC) met on 27 July 2021, to provide the Director General of the Department of Mines, Industry Regulation and Safety (DMIRS), through the Deputy Director General Resource and Environmental Regulation (DDG RER), feedback and review from industry, government geoscience organisations, and university research institutions on the upcoming work program for 2021-22 for the Geological Survey of Western Australia (GSWA).

- The chair welcomed new members Caroline Perring (CME), Annette George (UWA) and Claire Wilkinson (APPEA) and thanked outgoing members Mark Devereux, Bill Beament and Steffen Hagemann for their contribution to the committee.
- GSWA presented on several new initiatives in stakeholder engagement through webinars, podcasts and social media with more frequent visits to Kalgoorlie and the November GSWA Open Day at the Hyatt Regency. A new Podcast series called “Rocks beneath our feet” features 5 GSWA geologists speaking about their life in the Geological Survey.
- A further innovation is in Geotourism with StoryMaps on Wadjemup (Rottnest Island), Meteorite impact structures and the Murchison Region.

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Appendix 2.2

- With the aspirational target of zero net emissions by 2050, GSWA is focusing its mineral and energy systems towards critical minerals and “green” energy such as native hydrogen, hydrogen storage and greenhouse gas storage. Building on both the Accelerated Geoscience Program and the Mineral Systems Atlas.
- This has led to the development of a New Energy Systems group focusing on battery minerals, building an inventory of greenstone reservoirs for possible mineral carbonation or geothermal energy potential. This team will work closely with the Energy Geoscience and Carbon Strategy branch working on greenhouse gas storage.
- Work on the WAMEX and MINEDEX unlocking legacy data and introducing new data layers was explained. Some of the new enhancements for WAPIMS was described including data by depth, new displays and plots and increasing the number of GIS layers within the system.
- Discussed the Resource Investment direction of the survey and the future plans for the Abandoned Mines Program with restricted funding.
- There was discussion of Land Use Planning and the provision of information to tenement holders on Government Policy and its ramifications. This was in the context of the effectiveness of letters sent from DMIRS regarding Plans for our Parks, and whether a higher profile approach by government and representative bodies would better gain industry’s attention.
- Exploration Incentive Scheme (EIS) Co-funded Drilling Program:
 - The percentage of refunds allocated to completed drilling projects has been higher in recent rounds (R22 and R23) due to the extra \$5 million for EIS in 2020-21. At least one-third of successful applicants are searching for battery commodities dominated by nickel and nickel-cobalt exploration. Applications listing potash as the exploration target are now a regular occurrence for co-funding, reflecting an emerging industry sector.
 - The Energy Analysis Program (EAP) was introduced in 2020-21 with 8 applicants (pool of \$250,000).
 - EIS funds will purchase further seismometers and the new Hylogger 4 in 2021-22.

Appendix 2.2

- The liaison committee endorsed the GSWA Work Program for 2021–22.
 - Endorsed the GSWA’s focus on State Geoscience and developing a “live” map as well as developing a State 3D framework.
 - Strong support was expressed for the greenstone geochemical bar-coding project in the Yilgarn, and for the associated reanalysis of legacy samples, including granites originally collected by Geoscience Australia. This project accesses company drill core from mines and prospects to get as complete a coverage of the stratigraphy as possible.
- GSRSD has developed a data strategy, compatible with a national data strategy developed through the Geoscience Working Group of the National Federation Reform Council, and through the ARC-funded AuScope.
 - The aim is to modernise the way that GSWA’s extensive collection of pre-competitive geoscience data is stored and delivered with the move to a cloud-based ‘data lake’. Cloud storage is expensive, however the Pawsey Supercomputing Centre has received \$70M to upgrade computer hardware. GSRSD is investigating if it is available to store data.
 - GSRSD has developed a 5 year data strategy and a 10 year “Unearthing Western Australia” strategy. As part of these, GSRSD is looking to understand what stakeholders are downloading, and make that data easier to find and use, creating easier access for non-technical customers.
 - The data will require wholesale transformational change, and the resulting ‘intelligent data’ will not only revolutionise geoscience data delivery, but will be in a format that is amenable to cutting-edge exploration techniques like machine learning and artificial intelligence.
- Sub-committee review and feedback:
 - The Minerals Technical Subcommittee (MTSC) and the Petroleum Technical Subcommittee (PTSC) support the view that GSWA is a world-leading geoscience organisation and consistently delivers a geoscience program that is clearly impressive, well-structured and integrated, providing key precompetitive geoscience data and geological understanding of Western Australia.

Appendix 2.2

- EIS continues to fund pre-competitive data acquisition in a number of remote and under-explored provinces and basins that have substantial value to the minerals and petroleum industry.
- MTSC commends GSWA for the Accelerated Geoscience Program in response to the COVID-19 pandemic. PTSC continues to be impressed with WAPIMS, and with the efforts of staff to handle data requests and their efficient digitisation and transcription of legacy well log and seismic data.
- The MTSC and PTSC supports the Stakeholder Engagement Strategy. This is a real opportunity for further engagement with the resources industry through provision of targeted workshops and roadshows, and to include Geotourism and STEM education in schools. GSWA should develop an effective communication plan to advertise and confirm dates for the release of geoscience products.
- GSWA's Work Program continues to deliver comprehensive and seamless geophysical datasets, including key datasets of gravity, magnetics, airborne electromagnetic, seismic, magnetotellurics and electromagnetics. The MTSC notes that GSWA is acquiring AEM and also noted the slow progress with magnetotellurics across Western Australia.
- Studies into the architecture and nature of the reworked Proterozoic margins of Archean cratons may provide key information on their geological evolution and prospectivity, and are to be commended.
- The State Geoscience products and their delivery are appropriate and represent value for investment that will significantly assist exploration targeting at all scales. The annual updates to WAROX and other spatial datasets are very useful.
- MTSC endorses the release of 'Grandfather' WAMEX reports in 2020. The MTSC, however, again notes that there remains significant room for improvement in the key area of open-file exploration and mining datasets held by GSWA. This is largely relating to the WAMEX drill hole and geochemistry database and, in particular, to the provision of open-file data with a significantly reduced error.

Appendix 2.2

- In previous MTSC meetings, discussion has focussed on the digital capture of non-digital legacy WAMEX data. MTSC continues to hold the view that making such data available to the exploration industry has a very high potential to initiate further exploration in the short-term and in the medium-long term should provide a very high return on investment.
- Land-use planning issues remain a key potential impediment to mineral exploration in Western Australia. The potential loss of exploration access to an additional 5M hectares in the near future is a concern, and continuation of this trend will have impacts on exploration effectiveness and results. The MTSC and PTSC recommend early, widely circulated information on this issue through stakeholder engagement, including industry forums.
- The investigations into Helium and Hydrogen potential are extremely interesting and highlight the possible expansion of targets for oil and gas explorers in Western Australia.
- The ongoing collaboration between GSWA and Geoscience Australia is welcomed to maximise the return to Western Australia of GA's 4-year, \$100 million Exploring for the Future program across northern Australia.

Yours sincerely



Jeffrey Haworth
Executive Director Geological Survey and Resource Strategy
Geological Survey and Resource Strategy Division
20 September 2021

Appendix 3

Products and services delivered

Category	Product/service type	Total
Maps	ALL	6
Text publications	ALL (not including external publications)	52
Data packages	Data packages	14
Digital layers (new 2020/21)	Digital layers	3
	Explanatory Notes System (ENS) online	34
	HyLogger scanning (per metres scanned)	44 000
	Aeromagnetic survey (line km)	0
	EIS Co-funded Drilling – diamond drilling (metres released)	26 465
	EIS Co-funded Drilling – other (metres released)	37 759
	Gravity (ground; per station)	0
	Gravity (airborne; line km)	0
	Electromagnetic survey (per line km)	32 761
Data acquisition	Deep crustal seismic survey (per line km) – acquisition	0
	Deep crustal seismic survey (per line km) – reprocessing	262
	Passive seismic survey (stations)	120
	Geochemistry (sample)	2678
	Geochronology (report per sample)	86
	Hyperspectral scanning summary (drillhole)	0
	Paleontology Reports	6
	Isotope analysis (sample)	208
	GSWA stratigraphic drilling (metres drilled)	0
	Core Library – core released (pallets)	397
	Core Library – cuttings and vials released (pallets)	26
Information and advice services	Core Library – pallets laid out for viewing	2314
	Industry exploration reports – minerals reports released only	3365
	Industry exploration records – petroleum reports released only	10 106
Information and advice services – Statutory and Resource Information	Geological advice re Mining Act administration (Mining Lease applications, expenditure exemptions, extensions of term, Retention Licence, retention status, SPL reports for the Warden)	716
Information and advice services – Land Use	Geological Advice (Mining Act s.16(3)) – South West Native Title Settlement – full assessments	178
	Geological Advice (Mining Act s.16(3)) – South West Native Title Settlement – indicative assessments	56
	Geological advice – land use referrals assessed	707
Mining Title and Native Title Services – Titles Information	Native title claims delivered to SSO/NNTT ^(a)	44
	Native title maps: Right to Negotiate/resource access for SSO/NNTT ^(b)	331
	Number of Granted Leases issued for survey ^(c)	288

(a) Native title claims delivered Research/capture current/historical mining tenures requested that fall within native title claim. These are delivered to the State Solicitors Office (SSO) and National Native Title Tribunal (NNTT) for native title determinations

(b) Native titles maps for SSO/NNTT These are requested ad hoc over the course of the year for the SSO and NNTT – 150 in one year and 200 the following year does not reflect improved performance, just an increase in volume

(c) Granted Leases issued for survey The number of Granted Leases which have been issued for survey. Statutory Requirement Sec 80 *Mining Act 1978*: first condition of grant is survey

Appendix 4

Maps, books and data products released

Accelerated Geoscience Program

Over four project areas, 1088 interpreted data layers were produced and three standalone Geological Exploration Packages:

- Southwest Yilgarn, 2021
- Far East Yilgarn, 2021
- Critical minerals, 2021

Maps

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia – 2021
by KJ Ridge

Interpreted bedrock geology of the east Pilbara Craton (plate to accompany Report 143 East Pilbara Craton: a record of one billion years in the growth of Archean continental crust)
by Hickman, AH

Major resource projects, Western Australia – 2021
by Sargent, SN, Wyche, NL, D'Ercole, C, Jones, JA and Murray, SI

Mines – operating and under development, Western Australia – 2021
by Jones, JA, Sargent, SN, Wyche, NL, D'Ercole, C and Murray, SI

Mineral deposits and major petroleum projects Western Australia – 2021
by Sargent, SN, Wyche, NL, D'Ercole, C, Jones, JA, Murray, SI and Strong, CA

Western Australia Atlas of mineral deposits and major petroleum projects 2021
by Sargent, SN, Wyche, NL, Jones, JA, D'Ercole, C, Murray, SI and Irimies, F

Data products

Data packages

East Albany–Fraser Orogen Geological Information Series

East Yilgarn Geological Information Series, 2020

Northwest Pilbara Geological Information Series, 2020 (includes 1:100 000-scale layers)

Youanmi Geological Information Series, 2020

Data layers

1:500 000 State interpreted bedrock geology of Western Australia, 2020

GSWA Geochronology

Public index of geophysical surveys in MAGIX database

Appendix 4

Text publications

Reports

- Report 143 East Pilbara Craton: a record of one billion years in the growth of Archean continental crust
by Hickman, AH
- Report 207 Mid-Carboniferous – Lower Permian palynology and stratigraphy, Canning Basin, Western Australia
by Backhouse, J and Mory, AJ
- Report 208 A passive seismic experiment in the Perth Basin, Western Australia
by Murdie, RE, Yuan, H, Dentith, MC and Lin, X
- Report 209 Syngenetic gold mineralization at Mount Clement – an underexplored mineralization style in the northern Capricorn Orogen
by Guilliamse, JN
- Report 210 Genetic and chemical characterisation of the host succession to the Archean Jaguar VHMS deposit
by Belford, SM
- Report 211 Reference section, revised stratigraphy and facies analysis of the Ordovician Nambheet Formation, Canning Basin, Western Australia
by Dent, LM, Normore, LS and Martin, SK
- Report 212 Provenance fingerprinting of gold from the Kurnalpi Goldfield
by Hancock, EA and Beardsmore, T
- Report 213 Reservoir quality of Permian sandstones of the onshore northern Perth Basin – an assessment using HyLogger spectral data and petrography
by Copp, IA, Wawryk, M and Hancock, EA
- Report 214 Dating Proterozoic fault movement using K–Ar geochronology of illite separated from lithified fault gouge
by Cutten, HN, Zwingmann, H, Uysal, T, Todd, A and Johnson, SP
- Report 216 Kidson Sub-basin Seismic Survey – a panorama of the southern Canning Basin
by Zhan, Y and Haines, PW

Records

- 2020/1 Geological Survey work program for 2020–21
- 2020/10 1:500 000 State regolith geology map – compilation methodologies
by Jakica, S, de Souza Kovacs, N, Hogen-Esch, J and Granado, IMT
- 2020/11 Imaging a magmatic underplate by 3D gravity modelling: east Albany–Fraser Orogen margin
by Brisbout, LI and Murdie, RE
- 2020/12 Proterozoic dolerite dykes in the western Capricorn Orogen, Western Australia
by Blay, OA, Wingate, MTD, Johnson, SP, Thorne, AM and Kirkland, CL
- 2020/13 Stratigraphy, petrography and structure of Archaean rocks in the Rothsay mining area, western Yilgarn Craton
by Price, JJ, Blenkinsop, TG, Goodenough, KM and Kerr, AC
- 2020/14 The utility of the metamorphic rock record: constraining the pressure–temperature–time conditions of metamorphism
by Korhonen, FJ, Kelsey, DE, Fielding, IOH and Romano, SS
- 2021/4 Accelerated Geoscience Program abstracts, 2021
- 2021/5 Eastern Goldfields greenstone geochemical barcoding project – notes to accompany 2021 data release
by Lowrey, JR, Smithies, RH and Grech, L
- 2021/6 Yilgarn Granite Project – notes to accompany 2021 data release
by Lowrey, JR, Smithies, RH and Champion, DC
- 2021/7 Applying geophysics for 3D paleochannel imaging in the Gascoyne Province, Western Australia
by Jakica, S, Brisbout, L and de Souza Kovacs, N

Appendix 4

Miscellaneous books

- A traveller's guide to Geoheritage in Western Australia
by Martin, SK
- An Economic Assessment of the Exploration Incentive Scheme: 10 years from 2009 to 2020
by Fogarty, JJ
- Compilation of HyLogger records, 2021 (Greenbushes)
by Hancock, E
- GSRS Annual Review 2019–20
- GSWA calendar 2021
- Fieldnotes: GSWA newsletter July 2020 number 95
- Fieldnotes: GSWA newsletter October 2020 number 96
- Fieldnotes: GSWA newsletter January 2021 number 97
- Fieldnotes: GSWA newsletter April 2021 number 98
- Paleo Report 2020/47 – Waukarlycarly 1: palynology of 7 samples
by Backhouse, J
- Paleo Report 2020/48 – RUD0007: palynology of 9 samples
by Backhouse, J
- Paleo Report – WRD-1 (Worrall Range), Canning Basin, palynology of 5 samples
by Backhouse, J
- PR2021/1 Preliminary paleontological summary of Barnicarndy 1 stratigraphic well, Canning Basin
by Martin, SK and Allen, HJ, Haines, PW and Phillips, C
- PR2021/2 Preliminary conodont studies of Barnicarndy 1 stratigraphic well, Canning Basin
by Zhen, Y-Y, Allen, HJ and Martin, SK
- PR2021/3 Paleontological assessment of a purported 'fossil forest' located on the northern edge of Wangine Lake
by Allen, HJ, Krapf, CBE and Martin, SK

Online/3D geomodels

- Wadjemup / Rottneest Island – geology explorer
- Mineral Systems Atlas – 2021 update
by Morin-Ka, S, Beardsmore, T, Duuring, P, Guiliamse, JN and Burley, L
- Mineral Systems Atlas Guide, 2021 – layered intrusion-hosted vanadium
by Morin-Ka, S, Beardsmore, T, Duuring, P, Guiliamse, JN and Burley, L
- Sally May 2, Canning Basin: Digital Core Atlas
by Dent, LM, Normore, LS and Symonds, A
- Southern Perth Basin 3D, 2020
by Thomas, CM
- Southwest Canning Basin – Broome Platform 3D, 2020
by Zhan, Y
- West Musgrave Province 3D, 2013
by Aitken, ARA, Joly, A, Dentith, MC and Murdie, RE
- Eastern Yilgarn Craton 3D, 2019
by Lindsay, MD, Spratt, J, Occhipinti, SA, Aitken, ARA and Dentith, MC
- Yilgarn – Officer – Musgrave Province 3D, 2013
by Jones, T, Brennan, T, Goodwin, JA, Nicoll, MG and Murdie, RE

Posters/Flyers

- 16 geoscience posters
- 20 commodity flyers

Appendix 5

External publications on Western Australian geoscience

GS10 Energy Geoscience and Carbon Strategy

- Haines, P** 2021, Preservation of ancient eolian landscapes beneath flood basalt: an example from the Officer Basin, Western Australia: The Geological Society of Australia, Australian Earth Science Convention abstracts, 1p., viewed 27/07/21, <www.aesconvention.com.au/preservation-of-ancient-eolian-landscapes-beneath-flood-basalt-an-example-from-the-officer-basin-western-australia/>.
- Kenkmann, T, **Haines, PW**, Sweet, IP and Mitchell, K 2021, The Cleanskin impact structure, Northern Territory and Queensland, Australia: A reconnaissance study, *in* Large Meteorite Impacts and Planetary Evolution VI, *edited by* WU Reimold and C Koeberl, Geological Society of America Special Paper 550, p. 69–80, doi:10.1130/2021.2550(03).
- Thomas, C** 2021, Permian source rocks of the onshore and nearshore Carnarvon Basin: The APPEA Journal 2021, v. 61, p. 726–730.

GS20 Mineral Systems Studies

- Dunga, J, Sully, D, Hagemann, SG, **Duuring, P** and Danyushevsky, L 2020, Structural setting, wall rock alteration and gold mineralisation of the Mt. Percy gold deposit, Kalgoorlie, Western Australia: Mineralium Deposita, v. 39, p. 536, 22p., doi:10.1007/s00126-020-00993-7.
- Enkhsaikhan, M, Holden, E-J, **Duuring, P** and Liu, W 2021, Understanding ore-forming conditions using machine reading of text: Ore Geology Reviews, v. 135, article no. 104200, 15p., doi:10.1016/j.oregeorev.2021.104200.
- Enkhsaikhan, M, Liu, W, Holden, E-J and **Duuring, P** 2021, Auto-labelling entities in low-resource text: a geological case study: Knowledge and Information Systems, doi:10.1007/s10115-020-01532-6.

GS52 East Yilgarn

- Barnes, SJ, Williams, M, **Smithies, RH**, Hanski, E and **Lowrey, JR** 2021, Trace element contents of mantle-derived magmas through time: Journal of Petrology, doi:10.1093/petrology/egab024.
- Hasenstab, E, Tusch, J, Schnabel, C, Marien, C, Van Kranendonk, M, **Smithies, H**, **Howard, H**, Maier, W and Münker, C 2021, Evolution of the early to late Archean mantle from Hf-Nd-Ce isotope systematics in basalts and komatiites from the Pilbara Craton: Earth and Planetary Science Letters, v. 553, doi: 10.1016/j.epsl.2020.116627.
- Smithies, RH**, **Lu, Y**, Kirkland, CL, Johnson, TE, Mole, DR, Champion, DC, Martin, L, Jeon, H, **Wingate, MTD** and **Johnson, SP** 2021, Oxygen isotopes trace the origins of Earth's earliest continental crust: Nature, London, v. 592, no. 7852, p. 70–75, doi:10.1038/s41586-021-03337-1.
- Tusch, J, Münker, C, Hasenstab, E, Jansen, M, Marien, CS, Kurzweil, F, Van Kranendonk, MJ, **Smithies, H**, Maier, W and Garbe-Schönberg, D 2021, Convective isolation of Hadean mantle reservoirs through Archean time: Proceedings of the National Academy of Sciences, PNAS, v. 118, no. 2, doi:10.1073/pnas.2012626118.

Appendix 5

GS53 State Geoscience and Chief Geoscientist

Martin, SK 2020, What's geoheritage got to do with it? A guide to protecting Western Australia's rock stars, in 2020 Global Eco Asia-Pacific Tourism Conference Proceedings, Margaret River, 1–3 December 2020, <<https://globaleco.com.au/speakers/2020/sarah-martin>>.

Normington, VJ, **Allen, HJ**, Edgoose, CJ, **Haines, PW**, Grey, K 2020, Revised stratigraphy for NTGS stratigraphic drillholes LA05DD01 and BR05DD01, western Amadeus Basin, Northern Territory: Northern Territory Geological Survey.

GS55 Geophysics Acquisition and Processing

Howard, D 2020, AusAEM20-WA progress update: Preview, 2020, issue 209, p. 22, doi:10.1080/14432471.2020.1855773.

Howard, D 2020, AusAEM20-WA Stage 1 underway: Preview, 2020, issue 207, p. 23, doi:10.1080/14432471.2020.1800395.

GS58 West Yilgarn

Langford, RL, Arculus, RJ, **Ivanic, TJ**, Mavrogenes, J and Wills, KJA 2021, Ti–V magnetite stratigraphy of the Upper Zone of the Windimurra Igneous Complex, Western Australia: *Ore Geology Reviews*, v. 128, 103922, doi:10.1016/j.oregeorev.2020.103922.

Parmenter, S, **Ivanic, TJ**, **Korhonen, FJ**, Bouvier, A, Kendrick, JL and Yakymchuk, C 2020, Metamorphism of the Mougooderra Formation: Implications for Neoproterozoic tectonics in the western Youanmi Terrane, Yilgarn Craton, *Precambrian Research*, v. 350, 105862, doi:10.1016/j.precamres.2020.105862.

GS62 3D Geoscience

Haig, DW, Rigaud, S, McCartney, E, Martini, R, Barrose, IS, **Brisbout, L**, Soares, J and Nano, J 2021, Upper Triassic carbonate-platform facies, Timor-Leste: Foraminiferal indices and regional tectonostratigraphic association: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 570, doi:10.1016/j.palaeo.2021.110362.

GS64 Geoscience Mapping Through Cover

De Souza Kovacs, N and **Lu, Y** 2021, Soil geochemistry imaging gold prospectivity in the South West Terrane of Yilgarn Craton, Western Australia: Australian Earth Sciences Convention, Hobart, 9–12 February.

Finch, EG and **Kelsey, DE** 2021, Characterising fluid composition and source in a greenfields terrane: west Arunta Orogen, Western Australia: Australian Earth Sciences Convention, Hobart, 9–12 February.

GS65 Proterozoic Margins

Kelsey, DE, Spaggiari, CV, **Wingate, MTD**, **Lu, Y**, **Fielding IOH** and Finch, EG 2021, Way out west – does the Arunta Orogen continue westward beneath the Canning Basin?: Australian Earth Sciences Convention, Hobart, 9–12 February.

Appendix 5

ES42 3D Lithosphere Visualization

- Gessner, K, Smithies, RH and Lu, Y** 2021, Chasing lower crustal tectonic domains in the Yilgarn Craton: Australian Earth Sciences Convention, Hobart, 9–12 February.
- Kirilova, M, Toy, V, Sauer, K, Renard, F, **Gessner, K**, Wirth, R, Xiao, X and Matsumura, R 2020, Micro-and nano-porosity of the active Alpine Fault zone, New Zealand: *Solid Earth* v. 11, p. 2425–2438, doi:10.5194/se-11-2425-2020.
- Lin, X, Yuan, H, Dentith, MC, **Murdie, R, Gessner, K** and Nayak, A 2021, Improved full waveform moment tensor inversion of Cratonic intraplate earthquakes in southwest Australia: *Geophysical Journal International*, v. 227, issue 1, p. 123–145, doi:10.1093/gji/ggab214.
- Selway, K, Dentith, M and **Gessner, K** 2021, Lithospheric-scale magnetotellurics over the Eastern Goldfields Superterrane, Yilgarn Craton: Australian Earth Sciences Convention, Hobart, 9–12 February.

ES46 Enhanced Geochronology and Isotopic Mapping

- Lu, Y, Smithies, RH**, Champion, DC, **Wingate, MTD, Johnson, SP**, Martin, L, Jeon, H, Poujol, M, Zhao, J, Maas, R and Creaser, RA 2021, Neodymium and oxygen isotope maps of Western Australia: Australian Earth Sciences Convention, Hobart, 9–12 February.
- Mole, DR, Thurston, PC, Marsh, JH, Stern, RA, Ayer, JA, Martin, L and **Lu, YJ** 2021, The formation of Neoproterozoic continental crust in the south-east Superior Craton by two distinct geodynamic processes: *Precambrian Research*, v. 356, p. 106104, doi:10.1016/j.precamres.2021.106104.
- Sun, X, **Lu, Y**, Li, Q and Li, R 2021, Downgoing Indian lithosphere control on along-strike variability of porphyry mineralization in the Gangdese Belt of Southern Tibet: *Economic Geology*, v. 116, p. 29–46.
- Xu, B, Hou, Z-Q, Griffin, WL, **Lu, Y**, Belousova, E, Xu, J-F and O'Reilly, SY 2021, Recycled volatiles determine fertility of porphyry deposits in collisional settings: *American Mineralogist*, v. 106, no. 4, p. 656–661, doi:10.2138/am-2021-7714.

ES47 Petroleum Systems

- Normore, L, Haines, PW**, Carr, LK, Henson, P, **Zhan, Y, Wingate, MTD**, Zhen, YY, **Lu, Y, Martin, S, Kelsey, D, Allen, H** and **Fielding, I** 2021, Barnicarndy Graben, southern Canning Basin: stratigraphy defined by the Barnicarndy 1 stratigraphic well: *The APPEA Journal*, v. 61, no. 1, p. 224–235, doi:10.1071/AJ20160.
- Wang, L, Edwards, DS, Bailey, A, Carr, LK, Boreham, CJ, Grosjean, E, **Normore, L**, Anderson, J, Jarrett, AJM, MacFarlane, S, Southby, C, Carson, C, Khider, K, Hensen, P, **Haines, P** and Walker, M 2021, Petrophysical and geochemical interpretations of well logs from the pre-Carboniferous succession in Barnicarndy 1, Canning Basin, Western Australia: *The APPEA Journal*, v. 61, no. 1, p. 253–270, doi:10.1071/AJ20038.
- Zhan, Y** 2021, Velocity anomalies and out of plane reflections in Barnicarndy 1, APPEA 2021, poster.
- Zhan, Y** 2021, Velocity anomalies and out-of-plane reflections in Barnicarndy 1, Canning Basin: *The APPEA Journal* 2021, v. 61, p. 271–290, doi:10.1071/AJ20082.

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