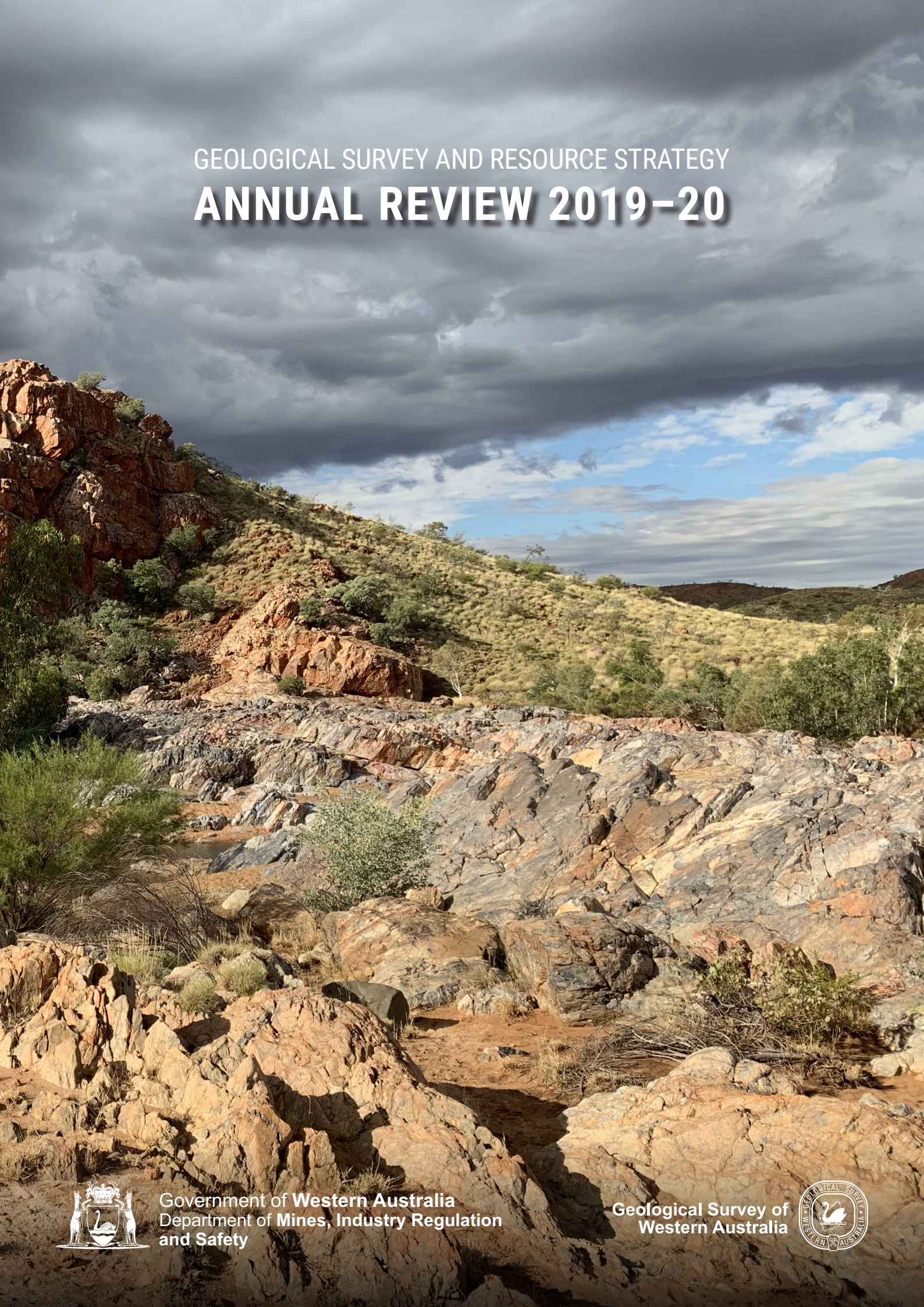
GEOLOGICAL SURVEY AND RESOURCE STRATEGY

ANNUAL REVIEW 2019–20



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

Geological Survey of Western Australia

GEOLOGICAL SURVEY AND RESOURCE STRATEGY

ANNUAL REVIEW 2019–20

MINISTER FOR MINES AND PETROLEUM
Hon Bill Johnston MLA

DIRECTOR GENERAL, DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY
David Smith

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY AND RESOURCE STRATEGY
Jeff Haworth

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Cover
Foreboding clouds cover the resistant outcrop of rhythmically banded jasper and chert in the upper part of the 3460 Ma Marble Bar Chert Member of the Duffer Formation, Marble Bar Pool, East Pilbara. The overturned, steeply dipping chert beds and underlying pillow basalts are sporadically washed by the ephemeral flow of the Coonegan River (photo by Leon Normore, DMIRS)

Frontispiece
Large, elongate, tabular, compound biostrome composed of nested, individual, subspherical, thrombolitic bioherms, Lake Clifton, Western Australia (photo courtesy SM Awramik, University of California, Santa Barbara)

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Ferruginous siltstone with thin chert interbeds, Backdoor Formation, CARDAWAN 1:100 000 map sheet (photo by Olga Blay, DMIRS)

Photos provided by GSWA.

Contents

Year in review

2019–20

With the onset of a global pandemic early in 2020, lockdowns and industry closures have severely impacted the world's economy. The Geological Survey of Western Australia (GSWA) was also impacted, with the 2020 field season shut down and the Work Program for 2020–21 revamped to focus on providing information to the resources industry quickly, especially the critical minerals and small to medium explorers who were adversely affected. I believe this is the first time the field season has been closed down except perhaps during the world wars. We were not alone, as geological surveys around Australia and the world also shut down their field seasons and reviewed their future programs. GSWA has grappled with virtual meetings and is now looking at generating webinars to send our message to investors both at home and overseas.

The past year has seen a changing of the guard in the Leadership Team. Michele Spencer was appointed Director, Mineral and Petroleum Resources in July 2019, and Simon Johnson appointed Director, Regional Geoscience in July 2020.

GSWA is developing a 10-year strategy due for release this financial year, which provides direction for the organization in four key areas:

- Garnering geoscientific knowledge — building our geological understanding of the State through pre-competitive 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.

Throughout the COVID-19 turmoil, GSWA has continued to publish manuscripts, maps and digital products as well as maintain its online databases in line with the 2019–20 Geological Survey work program. This resulted in 32 text publications, five geological maps and 17 digital products being released during the year. GSWA has also published the 2019–20 edition of the Mineral and Petroleum Statistical Digest along with the downloadable resources data files for 2019 and 2019–20, generated by the Resource Strategy team.

GSWA continued to generate exciting pre-competitive geoscience data with, for example, over 3500 new whole-rock geochemical analyses for the Greenstone Stratigraphic Geochemical Barcoding study in the Eastern Goldfields alongside 305 km of new, high-resolution active seismic data along seven lines in the same region. The Geoscience Directorate also completed the State regolith map at 1:500 000 scale.

The Statutory and Resource Information branch updated the policy guidelines and process for reviewing objections to the release of reports under the sunset clause resulting in the largest number of reports becoming publicly available and compliance to the sunset clause at its highest rate. A new Mines and Mineral Deposits database (MINEDEX) interface was released, and data entry into the system along with other system improvements continue. Commodity flyers had a makeover as did some of the Report covers and posters.

Year in review

The Energy Geoscience and Carbon Strategy branch planned and drilled a 2680.5 m-deep stratigraphic well in the Waukarlycarly Embayment, 214 km east of Marble Bar in the Canning Basin. Basement was intersected at a depth of approximately 2585 m. The basic volume of the well completion report is complete and post-well analysis is continuing.

Land Use Planning has been heavily involved in the government initiatives around Plan for Our Parks, the Yamatji Nation Southern Regional Agreement (formerly Geraldton Alternative Settlement Agreement) and other land use planning programs.

The Abandoned Mines Program (AMP) saw the completion of the Pro-Force pilot project and the commencement of the Donnybrook and Wheal Ellen shaft remediation projects. Work continued on the Bulong and Elverdton pilot projects and the AMP continues to manage the abandoned Ellendale Diamond Mine to minimize the safety, health and environmental risks at the site.

In 2019–20, the Exploration Incentive Scheme (EIS) Co-funded Exploration Drilling program was impacted by COVID-19 with regional restrictions impacting drilling of projects. Rounds 18 (2019) and 19 (2019–20) had completion rates of 55% and 47%, respectively, compared to the historical average of 58–59%. Significant outputs in pre-competitive data were also achieved, including geophysical, geochemical and geochronology projects. Notably, the acquisition of second-generation gravity for the Pilbara completed the State coverage.

The Western Australian resources sector was largely able to continue operating throughout the COVID-19 pandemic. However, it did have to adapt by changing operating models including fly-in, fly-out workforce arrangements, shift schedules and workplace interactions to comply with health and safety and physical distancing measures, as well as managing border restrictions.

The pandemic also had an impact on commodity prices. Importantly, while iron ore and gold producers continued to benefit from recent price rises, other parts of industry, including the oil and gas, alumina, nickel, lithium and base metals industries, did not manage as well. This was due to supply chain disruptions, and the impact of shutdowns on economic activity and demand, flowing through to lower prices and reduced revenues.

High iron ore and gold prices ultimately helped the Western Australian industry to deliver sales valued at a record $172 billion in 2019–20 and affirm its status as one of the world's major mining jurisdictions. The sector was also supported by a weaker Australian dollar (it was down by 6%), amplifying higher prices received for iron ore and gold and helping to offset price falls for others.

The mining industry solidified its position as the dominant activity in the State's resources sector during the year with $134 billion in sales, accounting for 78% of total sales.

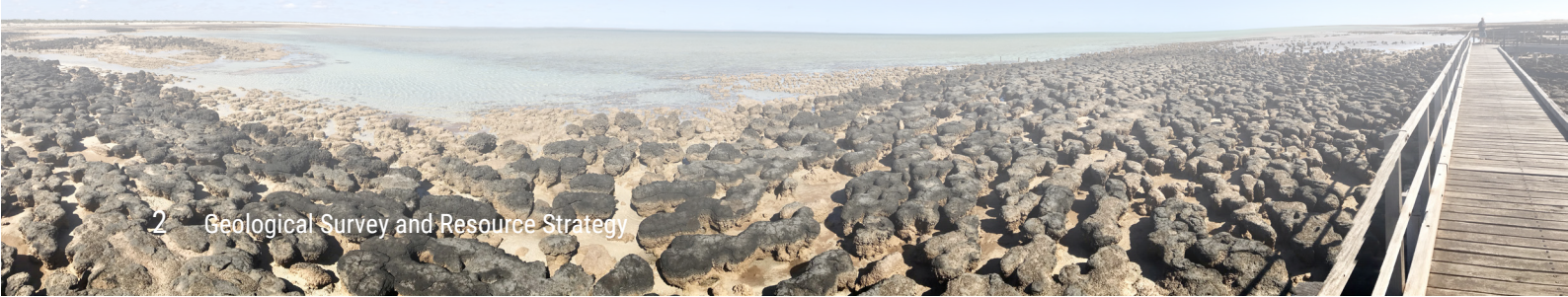
The value of petroleum sales fell to $27 billion, with its share of total sales dropping to 22% as oil prices declined to their lowest level in 20 years from a combination of excess supply amid a price war between Russia and Saudi Arabia, with subdued global demand due to the COVID-19 pandemic and related economic shutdowns.

While mineral exploration expenditure remained strong, it too was hit hard by the COVID-19 pandemic in the June quarter with the cancellation and scaling back of exploration programs, particularly in greenfields locations. With oil prices falling to a 20-year low, petroleum exploration did not fare as well and was down after its lowest June quarter spend since 1996.

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

Jeff Haworth

EXECUTIVE DIRECTOR



Overview of mineral exploration and development trends

Western Australia has a globally significant, diversified, resources sector. It is currently the world's largest supplier of iron ore, garnet and lithium, the second largest exporter of liquefied natural gas (LNG), alumina and diamonds, and was among the top five jurisdictions for the production of cobalt, gold, rare earth elements (REE) and zircon. The State was also in the top 10 for nickel, manganese, ilmenite, rutile and salt 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. In 2019–20, the State's resources sector successfully navigated and continued operating throughout the COVID-19 pandemic to deliver sales valued at a record $172 billion.

This result was principally driven by:

- iron ore sales valued at a record $103 billion on the back of the highest-ever sales volumes and an eight-year price high
- gold sales reaching another all-time high of almost $16 billion supported by a record annual average Australian dollar gold price of more than $2300 per ounce
- oil sales increasing to $2.6 billion, despite dramatic price falls across the first half of 2020, on higher output through the startup of new projects and the return to production of others
- nickel sales recovering amid higher prices in the second half of 2019 to more than $3.1 billion, the highest level since 2014–15.

The resources sector was also supported by a weaker Australian dollar, down by 6%, which amplifed the already higher prices received for some commodities and helped to offset price reductions for other commodities.

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. As of September 2020, Western Australia had resources projects in the development pipeline valued at an estimated $129 billion, up from the March 2020 estimate of $118 billion.

Recently announced significant new projects included Mineral Resources' iron ore development plans in the West Pilbara and Strike Energy's West Erregulla gas project. There was also a large number of gold projects announced and updated amid favourable market conditions including:

- Norton Gold Fields' Paddington mill expansion and Binduli heap leaching project
- Bardoc Gold's namesake gold project
- Newcrest Mining's and Greatland Gold's Havieron gold project
- growth options at Kalgoorlie Consolidated Gold Mines' Superpit, including Oroya Brownhill and Fimiston South
- Vango Mining's Marymia project
- ACH Minerals' Ravensthorpe gold project
- Poseidon Nickel's Windarra gold tailings project
- Ora Banda Mining's Davyhurst restart
- Ramelius Resources' Penny Gold and Eridanus underground projects.

Overview

Another significant development during the year was the announcement and commitment to investments in power generation projects built for the exclusive purpose of providing energy and transmission infrastructure to resource projects, specifically:

- Fortescue Metals Group's Pilbara Generation and Pilbara Transmission projects
- Alinta Energy's Chichester solar gas hybrid project
- Rio Tinto's Koodaideri solar project.

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 $1.7 billion, an increase of 17% from $1.4 billion in 2018–19. Growth in mineral exploration expenditure was mainly due to increased spending on gold (up $110 million) supported by record high prices. The next largest increases in spending were for copper (up $66 million), iron ore (up $38 million) and nickel/cobalt (up $32 million). The main targets for mineral exploration spending in Western Australia were gold (46%), iron ore (21%), copper (13%) and other minerals such as lithium, potash and manganese (9%).

While mineral exploration expenditure in Western Australia increased overall, spending in the June quarter declined compared to the same period in 2019. This was due, in part, to the impact of COVID-19 restrictions in Western Australia, including regional travel restrictions and the resultant cancellation and scaling back of exploration programs across the State. Exploration programs in greenfields areas were most affected by the restrictions, which contributed to a fall in the share of exploration on new deposits for the first time since 2014–15. This component of total exploration spending declined to 38% in 2019–20 from 42% in 2018–19.

After showing positive growth in 2018–19, petroleum exploration expenditure was down by 19% to $596 million. This was largely the result of the lowest June quarter spend since 1996, as exploration budgets were cut in response to the fall in oil prices to a 20-year low as well as COVID-19 restrictions.

Mineral exploration activities during the year targeted a range of prospects. Drilling results and resource upgrades for gold, nickel and platinum group elements (PGE), as well as copper, were particularly strong in 2019–20. The most notable were discoveries at Julimar, Ngapakarra (Winu), Havieron, Hemi, Rockford and Lantern prospects, as well as new gold lodes identified across a number of prospects in the Yilgarn Craton.

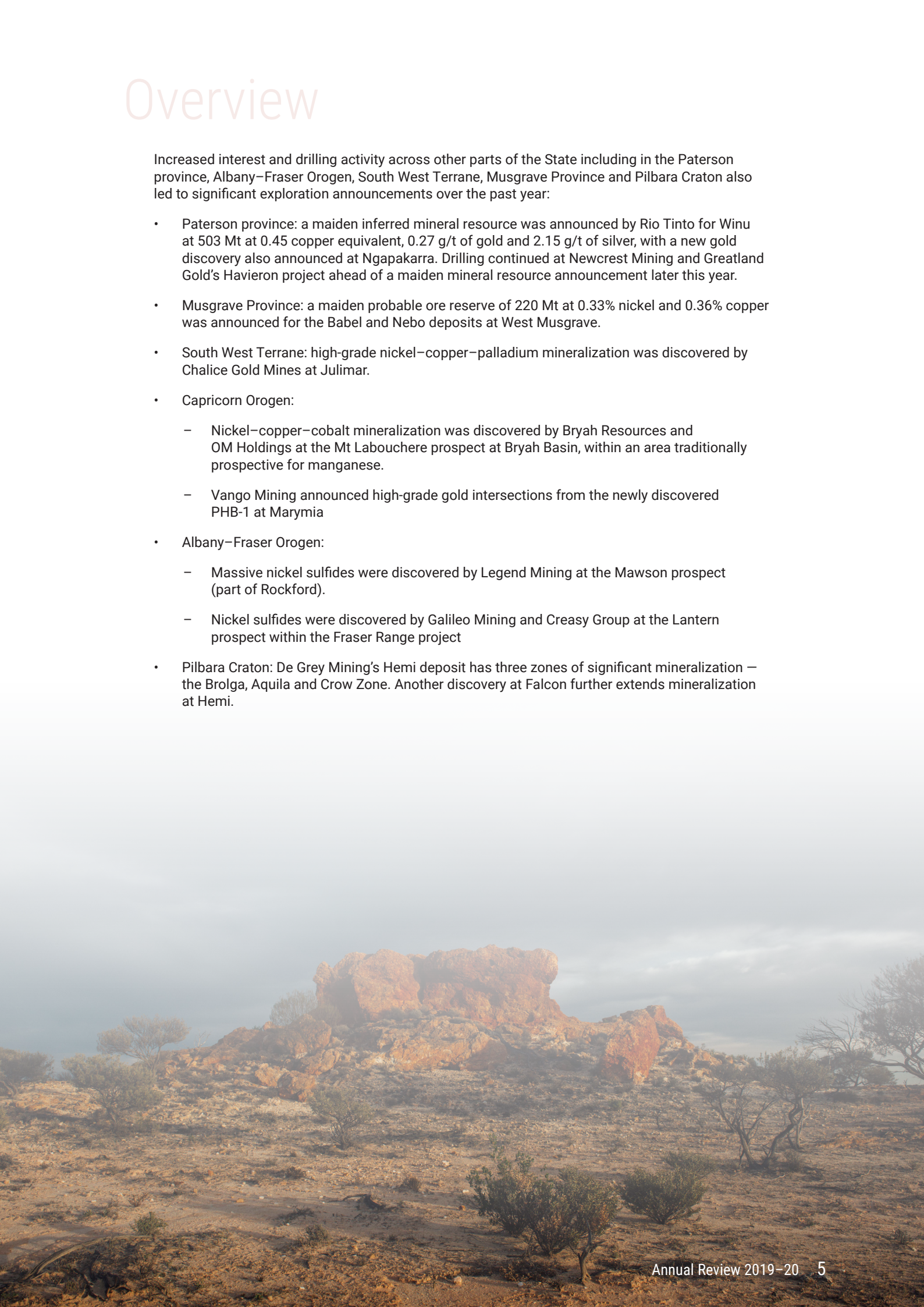
The Yilgarn remained a hotspot of exploration activity with significant discoveries that included:

- Bellevue Gold's discovery of a new high-grade lode in the historic Bellevue underground mine, as well as its announcement of significant drilling results for the Deacon and Viago lodes prospect. Total resources are now 7 million tonnes (Mt) at 10 grams per tonne (g/t)
- The discovery of high-grade gold prospects called Panda and Green Lantern at Central Norseman Gold Corporation's Central Norseman project
- Multiple high-grade results by Silver Lake Resources at Deflector South West with a maiden resource estimate announced of 634 thousand tonnes (kt) at 14.9% gold and 0.6% copper
- A nickel discovery by Toro Energy at the Dusty prospect, marking the first discovery of massive nickel sulfides within the typically gold-enriched Yandal greenstone belt
- The intersection of bonanza-grade gold by Estrella Resources from drilling north of the Munda pit as well as in the Starlight Lode and Break of Day.

Overview

Increased interest and drilling activity across other parts of the State including in the Paterson province, Albany–Fraser Orogen, South West Terrane, Musgrave Province and Pilbara Craton also led to significant exploration announcements over the past year:

- Paterson province: a maiden inferred mineral resource was announced by Rio Tinto for Winu at 503 Mt at 0.45 copper equivalent, 0.27 g/t of gold and 2.15 g/t of silver, with a new gold discovery also announced at Ngapakarra. Drilling continued at Newcrest Mining and Greatland Gold's Havieron project ahead of a maiden mineral resource announcement later this year.
- Musgrave Province: a maiden probable ore reserve of 220 Mt at 0.33% nickel and 0.36% copper was announced for the Babel and Nebo deposits at West Musgrave.
- South West Terrane: high-grade nickel–copper–palladium mineralization was discovered by Chalice Gold Mines at Julimar.
- Capricorn Orogen:
  - Nickel–copper–cobalt mineralization was discovered by Bryah Resources and OM Holdings at the Mt Labouchere prospect at Bryah Basin, within an area traditionally prospective for manganese.
  - Vango Mining announced high-grade gold intersections from the newly discovered PHB-1 at Marymia
- Albany–Fraser Orogen:
  - Massive nickel sulfides were discovered by Legend Mining at the Mawson prospect (part of Rockford).
  - Nickel sulfides were discovered by Galileo Mining and Creasy Group at the Lantern prospect within the Fraser Range project
- Pilbara Craton: De Grey Mining's Hemi deposit has three zones of significant mineralization — the Brolga, Aquila and Crow Zone. Another discovery at Falcon further extends mineralization at Hemi.



Recurrent budget

The total budget for GSWA as noted in the Geological Survey work program 2019–20 was $32 million, revised later to $32.977 million. This total budget included the Geological Survey and Resource Strategy division's (GSRSD) entire recurrent budget (excluding departmentally funded projects) plus $10 million for the EIS, of which GSWA is included. For reference, the total expenditure against this $32.9 million was $31.352 million overall (salary and non-salary inclusive).

The branches and directorates that comprise GSWA reported in this document are listed in Table 1. As shown, the Geological Survey budget and expenditure comprise a smaller portion of the aforementioned and form a smaller part of the overall GSRSD at the Department of Mines, Industry Regulation and Safety (DMIRS). Figure 1 illustrates the Geological Survey salary and non-salary budgets vs actual expenses in 2019–20. All references to the EIS budget and expenses are discussed in a later section of this Annual Review (see Exploration Incentive Scheme — overview and major achievements).

With the government directive for the conversion of work undertaken by contractors into permanent positions in early 2019–20, GSWA increased its public sector employees by 23 permanent staff while reducing common use agreement (CUA) contractors to 17 employees. The total number of public sector staff employed by the Geological Survey at the end of the financial year was 165 people (inclusive of seven EIS; equivalent to 158.22 full-time equivalents [FTE]) with a revised recurrent salary budget allocation of $16.56 million. The seven EIS-funded positions occupied in 2019–20 had a budgeted value of $883 000.

GSRSD was within the overall budget allocation with minimal overspend in either salaries or non-salaries. The reduced expenditure in non-salary was predominantly in the Geoscience and Titles Information branch due to delays in software payments for 2019–20. Due to COVID-19, the field season ceased from March 2020 into the next financial year, which had minimal impact on the 2019–20 financial year, as expenditure outside of this remained relatively consistent.

Table 1. Comparison of allocated recurrent budget and expenditure for GSWA directorates and branches

Directorates and business areas	*Budget*		*Actual expenses*			*FTE***
	Salaries ($000)	*Non-salaries ($000)*	*Salaries ($000)*	*Non-salaries ($000)*	*Total ($000)*	
Executive and Administrative Support*	993	107	1045	116	1161	6.0
Minerals and Petroleum Resources	5676	911	5344	825	6169	50.1
Geoscience	4033	371	3893	315	4208	33.45
Core Library and Field Support	1061	1082	1109	1143	2252	16.0
Geoscience and Titles Information	4798	1396	4270	908	5178	45.67
Totals	16 561	3867	15 661	3307	18 968	151.22

* Excludes hydraulic fracturing and state batteries budget and expenses
** Does not include vacant positions (15) or filled EIS positions (7 FTE)

Recurrent budget

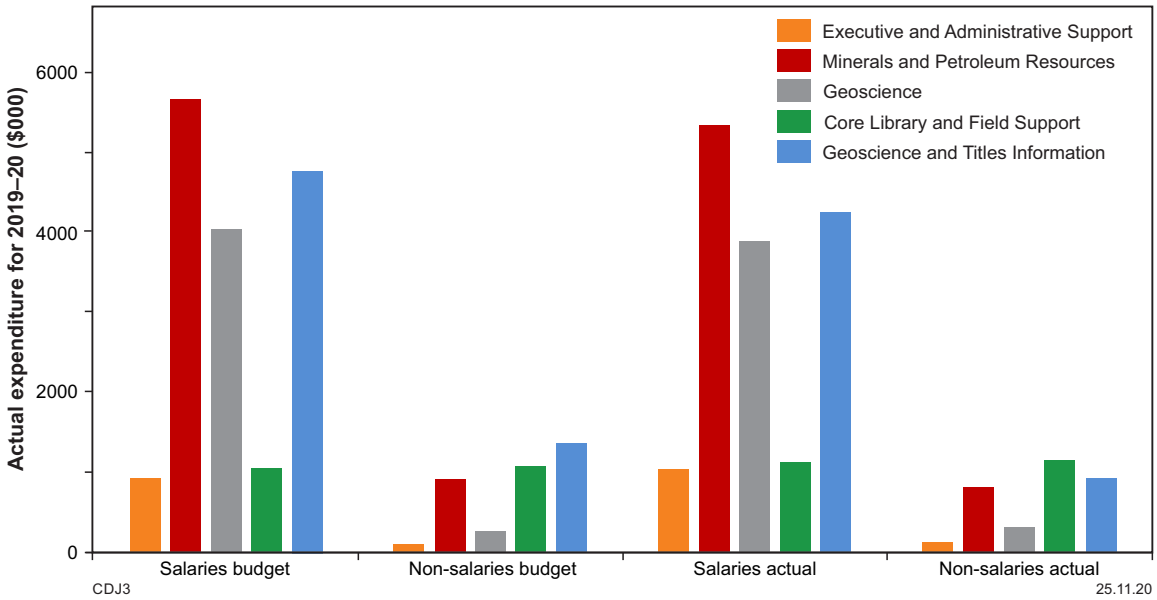


Figure 1. Comparison of budget for GSWA and actual expenditure for 2019–20 financial year

Staffing

During 2019–20, DMIRS followed the government directive based on a review of CUA contract usage as it was recognized that some contract positions were ongoing and seen as part of the permanent government workforce. GSWA added to the overall DMIRS submission and went through to summarize all GSWA contract positions that were in this category. After submission to treasury to receive Expenditure Review Committee (ERC) approval, the accepted equivalent value was granted to transfer DMIRS operational funds currently supporting the contractors, across to salary, hence moving those selected contract positions to a permanent public service position. This resulted in a total of 23 new positions in GSWA and a movement of ~$2.10 million from the GSWA operational budget to salary budget in 2019–20. GSWA employed 158.22 FTE and approximately 17 fee-for-service (FFS) contractors.

Collaborative projects

Thirty-four collaborative projects were commenced or ongoing in 2019–20 plus eight National Collaborative Framework Agreements between Geoscience Australia (GA) and DMIRS, which GSWA manages. Five projects were completed in 2019–20. Further details are provided in the Appendices.

Publications

As reported in the Geological Survey work program 2019–20, GSWA forecasted the publication of 12 maps, 38 text publications (not including posters) and 17 data packages. The final count for these categories on 30 June 2019 was five maps, 32 text publications and 17 digital products. For 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. It is anticipated this will continue in the future. In addition, GSWA also published a total of 70 posters compared to 82 in the previous financial year that were presented at conferences, GSWA Open Day and other events throughout the year.

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 2019–20.

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 petroleum system frameworks for Western Australia's onshore sedimentary basins. The aim is to encourage increased exploration for petroleum, coal and geothermal energy resources and assess the potential for CO_2 sequestration, and thus 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 Basin. 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 petroleum and helium potential of these older basins.

During late 2018, GA confirmed 'Exploring for the Future' funding for a GSWA-operated stratigraphic well to be drilled in the southern Canning Basin during the dry season of 2019. This new project resulted in a change of work priorities for several Canning, Moora and Amadeus Basin projects as staff were redirected to actively participate during the drilling campaign and in the post-well analysis. The well was the first deep hole to intersect the sedimentary succession and basement in the Waukarlycarly Embayment, Canning Basin. The post-well analysis included funding from the EIS, therefore this work will be discussed under ES47.

Highlights and activities

- Work continued on a palynological review of the southern Perth Basin, south of Bunbury that will lead to a future reassessment of the stratigraphy, which is currently closely tied to the northern Perth Basin stratigraphy despite large differences in depositional history
- Compilation of petroleum geochemistry data was completed and incorporated into a Report and digital data package on the petroleum source rocks of Western Australia. The Report was undergoing peer review as at the end of June 2020 and will be released during 2020–21
- Seismic interpretation and mapping of the southern Canning Basin continued. A second Report covering the Willara Sub-basin and Broome Platform was published early in the 2019–20 financial year. Work continued on 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 EIS-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 will be released early in 2020–21
- Results of dating basement rocks beneath the western Canning Basin suggests that the basin is underlain by the metamorphosed Neoproterozoic Centralian Superbasin in the south, and the Kimberley Basin in the north. Work continued on this project throughout 2019–20
- 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 will be released in the second half of 2020
- In collaboration with Curtin University, work progressed on the Western Australia unearthed book on the Mesozoic of Western Australia.

- GS10 projects placed on hold due to the drilling, post-well analysis and interpretation of Waukarlycarly 1 include:
  - compilation of Digital Core Atlases for Sally May 2 and 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.

Products released

- Report 193 A seismic interpretation of the Broome Platform, Willara Sub-basin and Munro Arch of the Canning Basin, Western Australia
- Report 206 Waukarlycarly 1 basic data well completion report
- GSWA Harvey 2, Perth Basin: Digital Core Atlas (interactive digital product)
- GSWA Harvey 3, Perth Basin: Digital Core Atlas (interactive digital product)
- GSWA Harvey 4, Perth Basin: Digital Core Atlas (interactive digital product)
- Extended abstract *in* Record 2020/2 Exploring the southwest Canning Basin: GSWA Waukarlycarly 1 and the Kidson Sub-basin seismic survey
- Extended abstract *in* Record 2020/2 World's oldest regional salt seal in the Amadeus and Officer Basins: implications for subsalt helium and hydrocarbons
- Table 2 lists all new pre-competitive sample analyses released in 2019–20 (not including Waukarlycarly 1, which is listed under ES47):
  - U–Pb detrital zircon geochronology:
    - Patience 2, Canning Basin, 4146.0 – 4184.0 m, *in* Wingate, MTD, Lu, Y, Fielding, IOH and Haines, PW 2019, 199493: sandstone, Patience 2; Geochronology Record 1625: Geological Survey of Western Australia, 7p.
    - Patience 2, Canning Basin, 3348.0 – 3390.0 m, *in* Wingate, MTD, Lu, Y, Fielding, IOH and Haines, PW 2019, 199494: sandstone, Patience 2; Geochronology Record 1626: Geological Survey of Western Australia, 7p.
    - Yapparu Claypan (Outcrop), Hidden Basin Beds, North Australia Craton, *in* Wingate, MTD, Lu, Y, Fielding, IOH and Haines, PW 2019, 220002: sandstone, Yapparu Claypan; Geochronology Record 1634: Geological Survey of Western Australia, 7p. (Murraba Basin)
    - Lake Hazlett (Outcrop), Hidden Basin Beds, North Australia Craton, *in* Wingate, MTD, Lu, Y, Fielding, IOH and Haines, PW 2019, 220001: sandstone, Lake Hazlett; Geochronology Record 1633: Geological Survey of Western Australia, 7p. (Murraba Basin)
  - Inorganic geochemistry, palynology and petrography
    - Petrography and geochemistry of basalt samples from mineral exploration drillcore, northwest Officer Basin, released through the Western Australian mineral exploration index (WAMEX)
  - Total organic carbon (TOC)-Rock-Eval
    - As part of the ongoing investigation into the source rock potential of the Perth and Carnarvon Basins, TOC-Rock-Eval analysis was undertaken on a variety of sample types and released through the Western Australian petroleum and geothermal information management system (WAPIMS)
- External publication — see Appendix 5

Table 2. New pre-competitive sample analyses released 2019–20

Analysis type	*Well*	*Depth (m)*	*Sample type*
U–Pb detrital zircon geochronology	Patience 2	4146.0 – 4184.0	Cuttings
U–Pb detrital zircon geochronology	Patience 2	3348.0 – 3390.0	Cuttings
U–Pb detrital zircon geochronology	Yapparu Claypan	Surface	Outcrop
U–Pb detrital zircon geochronology	Lake Hazlett	Surface	Outcrop
Inorganic geochemistry	Drillhole 07THD003	142.85 – 143.00	Core
Petrography	Drillhole 07THD003	142.95 – 143.00	Core
Inorganic geochemistry	Drillhole 07THD003	150.3 – 150.4	Core
Inorganic geochemistry	Drillhole 07THD003	154.75 – 154.85	Core
Petrography	Drillhole 07THD003	161.12 – 161.17	Core
Inorganic geochemistry	Drillhole 07THD003	161.02 – 161.12	Core
Petrography	Drillhole 07THD003	174.25 – 174.30	Core
Petrography	Drillhole 07THD003	192.00 – 192.05	Core
Petrography	Drillhole 07THD003	199.82 – 199.87	Core
Inorganic geochemistry	Drillhole 07THD003	199.87 – 199.97	Core
Petrography	Drillhole 09THD033	130.83 – 130.88	Core
Inorganic geochemistry	Drillhole 09THD033	130.88 – 130.98	Core
Inorganic geochemistry	Drillhole 09THD033	217.44 – 217.54	Core
Inorganic geochemistry	Drillhole 09THD033	270.31 – 270.41	Core
Petrography	Drillhole 09THD033	270.41 – 270.46	Core
Inorganic geochemistry	Drillhole 09THD033	358.06 – 358.16	Core
Petrography	Drillhole 09THD033	389.30 – 389.35	Core
Petrography	Drillhole 09THD033	450.65 – 450.70	Core
Inorganic geochemistry	Drillhole 09THD033	450.70 – 450.80	Core
Petrography	Drillhole 09THD033	465.10 – 465.15	Core
Palynology	Drillhole 07THD003	67.75 – 67.76	Core
Palynology	Drillhole 07THD003	72.44 – 72.45	Core
Palynology	Drillhole 07THD003	249.55 – 249.56	Core
Palynology	Drillhole 07THD003	250.35 – 250.36	Core
TOC/Rock-Eval	Merlinleigh Sub-basin	Surface	Outcrop
TOC/Rock-Eval	Hill River coal project drillcore CPCH67	55.3	Core
TOC/Rock-Eval	Hill River coal project drillcore PSCH2	19	Core
TOC/Rock-Eval	Hill River coal project drillcore PSCH2	16	Core
TOC/Rock-Eval	Hill River coal project drillcore PSCH2	11	Core
TOC/Rock-Eval	Hill River coal project drillcore BCH29	137.5	Core
TOC/Rock-Eval	Hill River coal project drillcore CACH5	43.3	Core
TOC/Rock-Eval	Pioneer Resources Bogadi BORC-02	51	Cuttings
TOC/Rock-Eval	Pioneer Resources Bogadi BORC-06	6	Cuttings
TOC/Rock-Eval	Waitsia 1	3364.3	Core
TOC/Rock-Eval	Waitsia 1	3356.37	Core

GS12 Land Use Planning

Manager: Warren Ormsby

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
- A large volume of assessments, recommendations and approvals was carried out to support the land component of the Yamatji Nation Southern Regional Agreement (YNSRA; previously known as the Geraldton Alternative Settlement Agreement) in the first half of the year. To assist with this process, external funding was obtained for a geologist. The YNSRA was registered on 7 February 2020
- 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 is playing a key role in consultation with the resources industry, prospectivity assessment and input into this whole-of-government project. A contract geologist assisted with the initial workload and additional assistance was obtained from within GSRSD where necessary to meet required timeframes.

Work continued on the assessment of potential land tenure changes associated with the South West Native Title Settlement project. 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 — 2020 (map)

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 stakeholders via MINEDEX and other publications. The SRI branch also has a regulatory role, performing compliance assessments relating to the *Mining Act 1978* and related legislation. The branch includes the Statutory Mineral Exploration Information section (GS91) and Statutory Petroleum Exploration Information section (GS92). The results for these sections are reported elsewhere in this document.

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. Just over 50% of users are new users
- MINEDEX map products account for three of the top 10 product downloads for GSWA products:
  - MINEDEX database download (fourth most downloaded product)
  - Mines — operating and under development map (sixth most downloaded product)
  - Major resource projects map (eighth most downloaded product).

In November 2019, a new user interface was released for the MINEDEX database. The new interface is the most modern in DMIRS and provides users with powerful search options and compatibility with tablet and mobile devices. MINEDEX is the first DMIRS online database to conform to the standards of the Office of Digital Government, and has been recognized for its accessibility to users with disabilities by the DMIRS Diversity and Inclusion subcommittee.

Products released

- Mines — operating and under development, Western Australia 2020 (map)
- Major resource projects, Western Australia 2020 (map)
- Exciting discoveries (Hotspots) Q3 2019 (poster), Exciting discoveries (Hotspots) Q1 2020 (poster)
- Investment opportunities flyers for the following commodities: potash, REE, nickel–cobalt, gold, manganese, vanadium, lithium, titanium–zircon, graphite, lithium, copper

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 2019–20 financial year, 80% of applications were reviewed on time.

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

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 GSWA 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 geographic information system (GIS) packages, and internal and external publications.

Highlights and activities

The branch continued its studies of selected mineral systems and deposits:

- nickel sulfide mineralization in the northeastern Yilgarn
- syngenetic gold mineralization at Mount Clement, Capricorn Orogen
- hydrothermal vein-and-breccia-hosted heavy rare earth element (HREE) deposits in northern Western Australia
- metallogeny of Archean banded iron-formation (BIF)-hosted iron ore in the Yilgarn and Pilbara Cratons
- ‘gold fingerprinting’ techniques in the Kurnalpi region, Yilgarn Craton.

The study of nickel prospectivity of the northeastern Yilgarn Craton continued. The results of the analysis of the fertility of komatiites in the Mount Fisher region for nickel sulfide mineralization were published (GSWA Report 198), and similar studies were completed on komatiites in the Collurabbie region farther east.

The study of the Mount Clement gold deposit was completed, and the results were released as a Report in late 2020.

A study of fluid inclusions in vein and breccia infill from the John Galt REE deposit was completed to place constraints on the physical and chemical conditions of mineralization.

Some of the results of investigations into the metallogeny of Archean BIF-hosted iron ore in the Yilgarn Craton were published in Ore Geology Reviews and Mineralium Deposita.

Branch staff also collaborated in the production of HyLogger records summarizing key mineralogical features of diamond drillcore used in these mineral system studies.

An investigation into the provenance and prospectivity of gold in the Pilbara Craton also commenced, using 'gold fingerprinting' techniques developed in the pilot study of the Kurnalpi region. Several companies and prospectors active in the region agreed to collaborate in this study, providing samples of 'alluvial' nuggets and 'bedrock gold'. Preliminary morphological analysis of this material has been completed (see ES43 for details).

A study of copper–gold–molybdenum mineralization at the Obelisk deposit in the Paterson Orogen was initiated and included the evaluation of drillcore at the Perth Core Library. A Report will be released in 2020–21.

The branch continued to develop content for the Mineral Systems Atlas. Systematic analyses of rare-element pegmatite and orthomagmatic vanadium systems were completed to define mappable geological proxies for critical metallogenic processes. These analyses of mineral systems were published in two GSWA Records, and GIS layers have been developed for several dozen geological proxies. This new content will be promoted to the Mineral Systems Atlas in 2020–21.

The Minerals Exploration Geoscience branch continued to monitor — and, where relevant, be involved with — collaborative minerals-oriented research initiatives funded by GSWA (refer to ES43).

Products released

- Report 198 Komatiite characteristics of the Fisher East nickel sulfide prospects: implications for nickel prospectivity in the northeastern Kurnalpi Terrane
- Extended abstract *in* Record 2020/2 Rare-element pegmatites in the Mineral Systems Atlas
- Record 2020/7 Rare-element pegmatites: a mineral systems analysis
- Record 2020/9 Layered intrusion-hosted vanadium: a mineral systems analysis
- 20 HyLogger records (2020/1–20) in collaboration with GSWA HyLogger staff
- External publications — see Appendix 5

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. The effects that mantle plumes have had on the magmatic stratigraphy of the greenstones is reflected by the local abundance of komatiites and associated basalts. However, systematic geological mapping and the acquisition of a substantial body of geochronological and geochemical data indicate that evolutionary models involving rifting of an autochthonous basement also need to be (re)evaluated. These different models can lead to different interpretations on the nature of magma source regions and the evolution of translithospheric structures that form pathways for mineralizing magmas and fluids. 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 2019 Ora Banda – Kambalda high-resolution seismic survey
- Interpretation of bedrock geology across the entire Eastern Goldfields Superterrane at 1:500 000 scale
- Field traverses and geochemical, geochronological and isotopic sampling of the granite–greenstone belt across the Kalgoorlie Terrane
- Geochemical sampling of diamond drillholes (GSWA and company core libraries) from well-established stratigraphies in support of the Greenstone Stratigraphic Geochemical Barcoding project
- Acquisition of high-resolution seismic data between Ora Banda and Kambalda
- Work commenced on creating a virtual field guide of important geological localities in the East Yilgarn.

Products released

- East Yilgarn 1:500 000 interpreted bedrock geology, 2020 (for release in upcoming East Yilgarn 2020 GIS)
- External publications — see Appendix 5

GS53 Chief Geoscientist and Terrane Custodians

Manager: Simon Johnson

Objectives

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

Highlights and activities

- Collaborative study with the Commonwealth Scientific and Industrial Research Organization (CSIRO) on K–Ar dating of fault rocks to identify the most recent fault movement on major faults in the Edmund and Collier Basins, West Capricorn
- Compilation of the 1:500 000 State interpreted bedrock Geology, Cenozoic geology and linear structures digital layers (GeoVIEW.WA)
- Release of the 1:500 000 State regolith map for the southern half of Western Australia, completing the coverage of the State at this scale (included entering additional 400 regolith codes)
- Started development of the geochronology component of the geochronology, isotope and mineral chemistry system (WAGIMS)
- Continued editing, approval and publication of over 200 lithostratigraphic, tectonic and orogenic events explanatory notes
- Updated GSWA Code Builder with most recent stratigraphic and tectonic codes
- Contributed to transition from Digital Paper to Geodocs document delivery system
- Obtained robust pressure–temperature data from over 20 localities across the Yilgarn Craton, which enabled the identification of new metamorphic trends in the South West Terrane. In addition, metamorphic data collected by B Goscombe across the Yilgarn Craton has been collated and is ready for upload into the Western Australia field observation database (WAROX)
- Released Bulletin 147, which formally standardizes the terminology and approaches used in studying microbialites. Condensing nearly 50 years of research and practical experience into a single volume, this book provides a comprehensive guide to the methods for describing and interpreting fossil and recent microbialites

- Continued biostratigraphic studies of the Centralian Superbasin, participating in cross-border correlation discussions. Work continued on a Northern Territory Geological Survey Record on revised stratigraphy of Northern Territory / western Amadeus Basin drillholes to be published next financial year
- Assisted Murchison georegion stakeholders with provision of geological information and in geoheritage matters
- Commenced work on paleontological sampling and study of the Waukarlycarly 1 well, and acquired new Artec 3D scanners to support studies of fossils in core, with the intention to extend their use into other paleontological and outcrop scanning projects
- Commenced a program to visit and image (using a drone) all Geoheritage Reserves and Sites in the State. An internal report is written for each site as they are visited, updating reserve condition, significance and vulnerabilities
- Expanded the Paleontology Report series to include reports prepared by external consultants contracted by GSWA for project work. Paleontology Reports are released externally via eBookshop
- Developed a policy document and disaster preparedness plan for the GSWA Paleontology collection, coupled with work towards improving collection maintenance and condition
- Reviewed stromatolite specimen selection, preparation and content in conjunction with Western Australian Museum staff for Origins gallery in the New Museum Project
- Provided technical advice to Department of Conservation, Biodiversity and Attractions for new Kalbarri National Park signage
- Presented outreach activities including three school talks and keynote speech at Centre of Resources Excellence (CoRE) Pilbara educators' summit.

Products released

- Compilation of WAROX data, 2020 (digital data package)
- 1:500 000 State interpreted bedrock geology, Cenozoic geology and linear structures digital layers, 2020 (GeoVIEW.WA)
- 1:100 000 State interpreted bedrock geology (polygons and lines) and linear structures digital layers, 2020
- Six 1:100 000 digital geological maps covering the 1:250 000 Nabberu sheet (SG 51-5), East Capricorn
- Meteorite impact structures of Western Australia, virtual tour, 2020
- Calendar 2020
- Paleontology Report 2020/01: F53427–F53433: macrofossils from the Maxicar beds, southern Perth Basin
- Paleontology Report 2020/46: Lower Devonian thelodont *Turinia australiensis* Gross 1971 from petroleum well Wilson Cliffs 1 (Core 5, 1353–1355 m, Tandalgoo Formation)
- 44 consultant Paleontology Reports (Paleontology Report 2020/02–45)
- Bulletin 147 Handbook for the study and description of microbialites
- External publications — see Appendix 5

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 determining the timing of geological events and to understanding the geological history of Western Australia (Fig. 2). 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 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 the Centre for Microscopy, Characterization and Analysis (CMCA) at The University of Western Australia (UWA). 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.

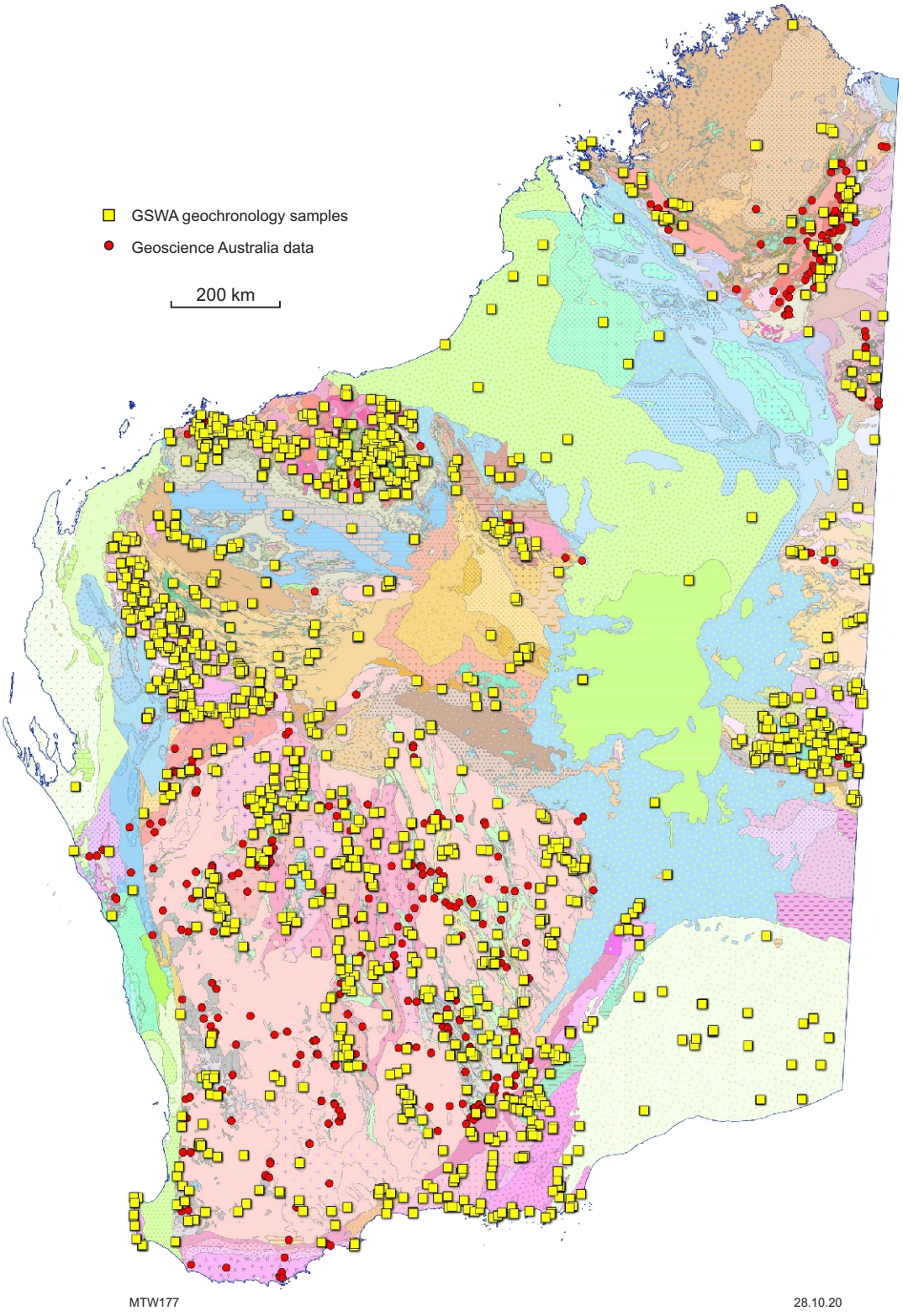


Figure 2. Locations of geochronology samples analysed by GSWA from 1994 to 2020, and those compiled by GA, superimposed on a geological map of Western Australia (1:500 000 Interpreted Bedrock Geology, 2016)

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 and ES37 Eastern Goldfields Seismic Survey
- 81 new company airborne survey datasets containing about 400 000 line-km of data were received for inclusion in the Airborne Geophysics Index (MAGIX) data repository. At 30 June 2020, the repository contained some 11.1 million line-km of company data from 2549 surveys. Open-file datasets are available for download via the department's GeoVIEW.WA online system
- Datasets from GSWA's new regional airborne gravity surveys and suitable open-file company surveys were incorporated into a new version of the section's statewide compilation available online (**www.dmirs.wa.gov.au/geophysics**).

Product released

- Gravity anomaly grid (400 m) of Western Australia (2020 — version 1)

GS58 West Yilgarn

Manager: Tim Ivanic

Objectives

The western part of the Archean Yilgarn Craton 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. It has a long and complex geological history. An understanding of the tectonic evolution of the Youanmi Terrane, including its structure and stratigraphy, is essential to understanding the controls on formation and distribution of mineralization in the region.

Highlights and activities

- Mapping, sampling and collection of new analytical data, including geochemistry, geochronology and isotopic data continued in the Weld Range and Murgoo areas
- Extensive geochemical sampling was undertaken across the Youanmi Terrane, including the Murgoo, Twin Peaks and Ravensthorpe areas
- 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

- Murchison, 2019 GIS data package
- Report 192 Mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton
- Record 2020/3 The geodynamic context of Archean volcanism in the western Yilgarn Craton
- Record 2020/4 The Deflector Au–Cu deposit
- Dalgaranga 1:100 000 geology as digital layers
- Murchison Supergroup and granitic suites update in ENS

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

Highlights and activities

- Results obtained from the 2014–18 Capricorn Orogen passive seismic array have been processed and placed into a lithosphere-scale 3D model of the Capricorn Orogen
- The Murchison fault model was finalized and published
- Yalgoo–Singleton greenstone belt 3D geomodel has been built, and tested against geophysical data
- Mapping within the area of the Eastern Goldfields high-resolution seismic traverses in preparation for their interpretation
- Successful Australian Research Council (ARC) Linkage bid for a passive seismic network in the southwestern Yilgarn with the Australian National University (ANU), GA and the Department of Fire and Emergency Services (LP170100890).

Product released

- Murchison 3D, 2019: 3D Geomodel Series data package

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

- Fieldwork and geochemistry sampling of felsic volcanics in the northern Pilbara
- Acquisition of new geochemical and isotopic data from drillcore sampling in the Fortescue Group
- Detailed Report on the geology, crustal evolution and mineralization of the east Pilbara Craton for release in 2020–21
- 1:100 000-scale digital surface geology of the northwest Pilbara for release on GIS package
- Approximately 50 ENS lithostratigraphic unit reports completed for the east Pilbara Craton and a further 50 ENS lithostratigraphic unit reports submitted.

Products released

- Report 203 Geology of the Hardey Syncline – the key to understanding the northern margin of the Capricorn Orogen
- External publications — see Appendix 5

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.

Highlights and activities

- Completed the production of the State regolith map (EIS funded) with the release of the southern half of the State. Together with the 2019 release of the northern half of the State, this concludes regolith mapping at 1:500 000 scale
- Conducting research and preparing for potential drilling campaigns under the MinEx CRC National Drilling Initiative (NDI; see ES36)
- Continuing the benchmarking geophysical methods to refine cover information, for example, depth and character of cover.

Product released

EXPLORATION INCENTIVE SCHEME

- 1:500 000 State regolith geology of southern Western Australia

GS65 Proterozoic Margins

Manager: Catherine Spaggiari

Objectives

Proterozoic Margins is a new section that was designed to amalgamate the activities of two previous sections — GS56 North Australian Craton and GS61 Albany–Fraser Orogen and Eucla basement project — and currently resides within the 4D Geodynamics 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 2019–20 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

- Completion of new 1:100 000 and 1:500 000 pre-Carboniferous interpreted bedrock geology layers, and updated 1:500 000 pre-Mesozoic interpreted bedrock geology layers of the east Albany–Fraser Orogen GIS package
- Addition of unmanned aerial vehicle (UAV) photogrammetry and structural 3D models to the east Albany–Fraser Orogen GIS package
- 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
- Completion of the analysis of stratigraphic, co-funded EIS and donated drillcores that intersect basement beneath the Nullarbor Plain
- Analysis of the age, character and correlations of Paleoproterozoic–Neoproterozoic sedimentary basin outliers in the Kimberley region
- Advancement of entries into the ENS database for the Kimberley Basin
- Detailed logging and sampling of 10 drillcores from the West Arunta and basement to the Canning Basin, including whole-rock geochemistry data acquisition of 140 samples and integration with the work of the GSWA embedded MinEx CRC researcher
- Submission and acceptance of two National Argon Map (NAM) project proposals. Samples for the first of these have been sent for irradiation from ANU
- Participation in the interpretation of the basement geology imaged in the Marble Bar to Kiwirrkurra Kidson seismic line (collaborative project).

Program review

Products released

- East Albany–Fraser Orogen, 2020, Geological Information Series data package
- Kimberley, 2020, Geological Information Series data package, including:
  - Montague Sound Second Edition 1:250 000 Geological Series map
  - updates to the 1:100 000 and 1:500 000 layers
- Report 204 Stratigraphic and co-funded drilling of the Eucla basement — the Proterozoic geology beneath the Nullarbor Plain
- External publications — see Appendix 5

GS80 Editing and Publishing • GS81 Mapping and Events • GS82 Graphics • GS83 GIS Services • GS84 Spatial Systems • GS87 Data Capture • GS88 Data Integrity • GS89 Spatial Projects • GS90 Native Title

Manager: Stephen Bandy

Objectives

Experienced, well-qualified staff are critical to the quality and delivery of geoscience and titles information. These staff members include geoscience editors, cartographers, graphics officers, product designers, desktop publishers, database managers, geospatial officers, online coordinators, business analysts and GIS specialists.

Highlights and activities

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

The following online Geoscience and Titles Information systems were released:

- MINEDEX user interface
- Electronic lodgement of survey field books
- Release of 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
- Decommissioning of NORM2 data files used to upgrade Landgate data in TENGRAPH.

The team has:

- produced geoscientific maps, manuscripts, digital datasets and promotional materials
- provided online applications and database training
- produced the Handbook for the study and description of microbialites publication showcasing 50 years of research
- helped to develop geotourism products
- data captured and delivered maps related to native title historical tenure.

Products released

- 32 manuscripts
- 5 geological maps at other scales
- 17 digital products

GS85 Resources Investment Information

Manager: Gaomai Trench

Objectives

The objective of GS85 Resource Investment Information is to facilitate the provision of resource-related information to investors for mineral and petroleum investment into Western Australia to accelerate mineral exploration and discovery. This involves providing geoscientific policy and regulations information to assist with attracting new resource investment while at the same time nurturing relationships with existing investors.

Highlights and activities

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

- delivery of high-impact presentations and funding of exhibition booths at major investment conferences and seminars
- conducting investment workshops and seminars for small groups
- publication of maps, posters and flyers
- responding to ad hoc investor requests for information and advice relating to geoscience, policies and regulations
- liaising with Chinese mining companies with offices in Western Australia
- coordinating the China Geological Survey – GSWA Technical Cooperation Program.

Industry engagement

In 2019–20, the branch funded Western Australia's presence at a number of key international events including:

- Annual Prospectors and Developers Association of Canada Annual Convention, Trade Show and Investors Exchange (PDAC)
- Annual NAPE (Oil and Gas) Expo
- Annual China Mining Conference
- Exploration and mining investment seminars in Asia, including Beijing (China), Seoul (Korea) and Tokyo (Japan), in cooperation with Austrade and Australia Minerals
- Annual Diggers and Dealers Mining Forum in Kalgoorlie.

Due to the COVID-19 pandemic travel restrictions, the branch actively worked with the Department of Jobs, Tourism, Science and Innovation and its overseas office providing investment information to companies and investors based in Perth, which included: Korean company POSCO; Indian company Legacy Iron Ore Ltd and Chinese company Accent Resource NL.

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:
  - 3743 mineral exploration reports and data were reviewed
  - 3654 reports were released to open file
  - Over 95% of reports are received via the online submission wizard
  - 2256 drill collar files and related data files uploaded into the drillholes database comprising 104 171 individual drillholes and associated downhole data
  - 2352 surface geochemistry files uploaded into the drillholes database comprising 670 410 individual samples and associated geochemistry data
- HTML version of GeoVIEW.WA with WAMEX, Drillholes and Geochemistry went into production at the beginning of the year. The release met with a mixed response and further modifications took place and are planned to improve service
- Data requests:
  - 115 core library (mineral core) viewing and sampling requests approved
  - The Guidelines for Mineral Exploration Reports on Mining Tenements were gazetted in July 2019
  - 551 Combined Reporting Groups were granted or amended
  - Under the provisions of Regulation 96(4) of the Mining Act, commonly known as the ‘sunset clause’, 1202 reports received in 2014 and 77 reports received in 2008 (lapsed objections) were advertised on the website for release. A total of 1093 of the 2014 reports and eight of the 2008 reports did not receive objections and were released
  - In addition, a list of 1476 reports submitted between 1985 and 2001 (the Grandfather reports) was advertised on the website for release. A total of 889 reports was released without objection and a further 152 reports were released following consultation with the companies involved.

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 received and reviewed within 90 calendar days of receipt
- Achievements — the team has maintained the number of reports awaiting review to fewer than 350 for the year even during the COVID-19 shutdown when most staff were working at home (Fig. 3)
- Data requests — currently 100% of data requests responded to within five calendar days
- Core sampling requests — currently 100% of sampling requests responded to within five calendar days.

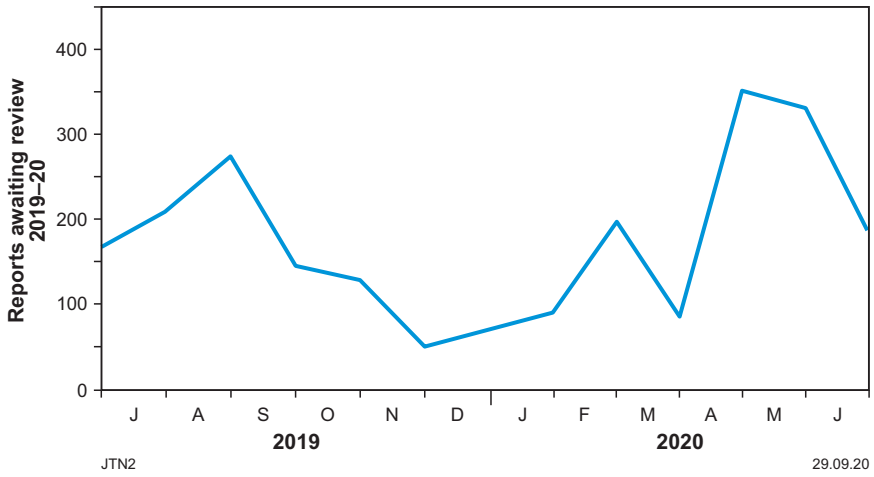


Figure 3. Mineral exploration reports awaiting review

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.

Highlights and activities

- WAPIMS main enhancements
  - 'Data by Depth' functionality now available for external clients
  - WAPIMS/public — easy data access from the home page to the main projects (Core Atlas, Core Analysis, South West Hub Carbon Storage)
  - Dynamic SQL interface
  - Redesign sampling approvals workflows and forms as part of the core information management system (CIMS) development — ongoing
- Data remastering — transcribed petroleum data to a modern stable media for industry and government
  - 400 tapes transcribed to a new media and data loaded in WAPIMS
  - Finalized S Files scanning (8754 files) – data to be loaded in WAPIMS
- Data received and reviewed
  - 311 reports, 18 logs, 103 survey data, 2925 slides and residues
  - 1132 reports reviewed and information captured (new and legacy)
  - Other WAPIMS entries: monthly production (11 543), facility utilization (138), production tests (195), underground storage daily data (6579), underground storage monthly data (276), CO_2 injection by well (2754), water injection by well (642), water production by well (1253)

Program review

- Data released — reports, well logs, survey data published in WAPIMS: 276 documents, 7735 slides and residues
- Sampling approval requests processed: 222 from 314 wells
- Statistics and metrics 2019–20
  - 57 906 documents downloaded from WAPIMS
  - 7028 users accessed WAPIMS, more than half from Australia
  - 96% of reports received accessioned within 14 days
  - 97% of the sampling approvals processed within five days
  - 89% of the slides and residues received accessioned and archived within 14 days
- Achievements
  - Started capturing Gorgon CO_2 data in WAPIMS
  - Finished scanning S Files (all correspondence between GSWA and petroleum companies regarding statutory requirements)
  - Planned and approved the relocation of thin sections at Perth Core Library.

GS94 and GS96 Core Library Services

Manager: Paul Stephenson

Objectives

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

Highlights and activities

- Kalgoorlie Open Day — November 2019
- New outdoor core viewing area in Kalgoorlie
- New microscope facilities in Kalgoorlie
- New shade sails erected to outdoor viewing area in both Carlisle and Kalgoorlie.

Products released

- Incremental updates of WAPIMS and CIMS

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Objectives

The GSWA HyLogger facility is one of six State and Territory geological survey-based nodes that were established in 2009 as part of the National Collaborative Research Infrastructure Strategy (NCRIS), to provide objective mineralogical data and interpretations from drillcore (and other rock samples), thereby improving our understanding of the composition of the Australian crust. HyLogger technology collects mineral reflectance spectra in the visible near-infrared (VNIR), 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 also available upon request.

Highlights and activities

- From July 2019 to June 2020, 56 140 m of core from 232 drillholes were scanned and 100% of data were processed to at least level 1. These comprised 90 EIS co-funded holes, 37 historical and donated mineral holes, and 105 petroleum wells (Fig. 4). In addition, an innovative method for scanning rock cuttings was developed and 18 000 m of petroleum ditch cuttings were scanned for the northern Perth Basin project. AuScope, as part of an NCRIS grant scheme, funded delivery and data processing of up to 4000 m of core from 16 mineral historical drillholes from the Joe Lord Core Library in Kalgoorlie
- High-resolution core images and hyperspectral data for over 240 000 m of drillcore were delivered to the AuScope national portal and GeoVIEW.WA using the HyLogger database. To the end of June 2020, 153 datasets had been processed to level 1 and 114 datasets processed and interpreted to level 2 were uploaded
- HyLogger staff were actively involved in several GSWA, GA and CSIRO research projects, including the northern Perth Basin petroleum system, Waukarlycarly 1 stratigraphic drilling, alteration assemblages of Minayari and Obelisk mineral systems in the Paterson Orogen. HyLogger staff also contributed to the EIS drilling program delivering hyperspectral data and high-resolution images of 90 drillholes to 31 exploration companies
- The HyLogger team provided seven tours for international and State delegations visiting the Perth Core Library before March 2020, and manually delivered 443 datasets, excluding external portals
- Hyperspectral data were validated using portable X-ray diffraction (pXRD) and scanning electron microscope energy dispersive X-ray spectroscopy (SEM-EDX)
- The innovative online HyLogger workshop, in collaboration with CSIRO, was delivered in June to academic and industry State, national and international personnel to promote the use of the hyperspectral technology.

Products released

- HyLogging data processing and interpretation for assorted drillcores (20 HyLogger records)
- External publications — see Appendix 5

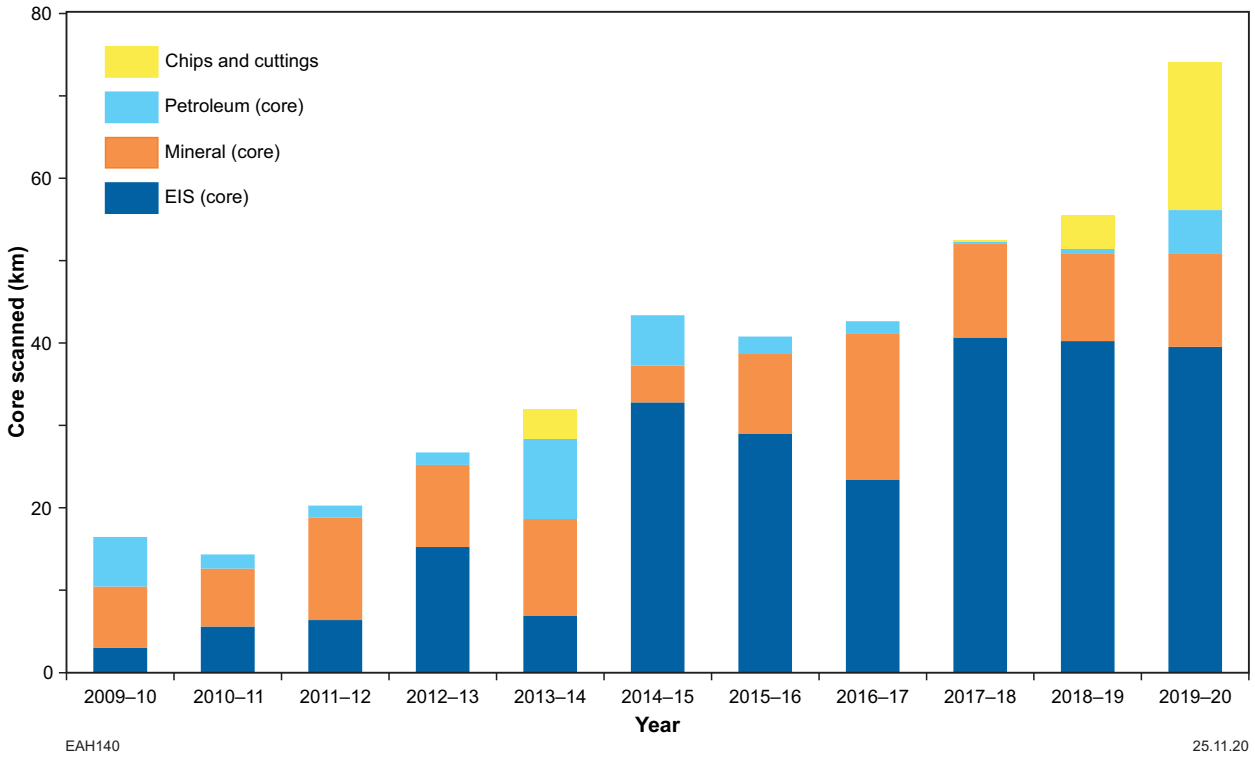


Figure 4. GSWA HyLogger data production. A total of 418 721 m from 1416 drillholes has been scanned, including chips and cuttings

EIS program review

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 2019–20 financial year, the EIS had received $160.54 million (Fig. 5a–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 2019–20, the budget appropriation was $10 million sourced from MTR.

The impact of the COVID-19 pandemic on the EIS was most acutely seen in the completion rate of the co-funded drilling program. Only 47% of successful applicants completed their drilling programs, compared to the historical completion rate of 58%. Prior to the end of the 2019–20 financial year, projected underspend in the co-funded drilling was redirected to forward payments in active, collaborative EIS projects. These projects included MinEx CRC (ES36), AusAEM20-WA (ES30) and Minerals Research Institute of Western Australia (MRIWA) project M532 (ES43).

Table 3. Funding sources for the EIS since 2009

EIS phase	*Year*	*Royalties for Regions*	*Consolidated revenue*	*Mining tenement rent (MTR)*
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	2019–20			$10 000 000

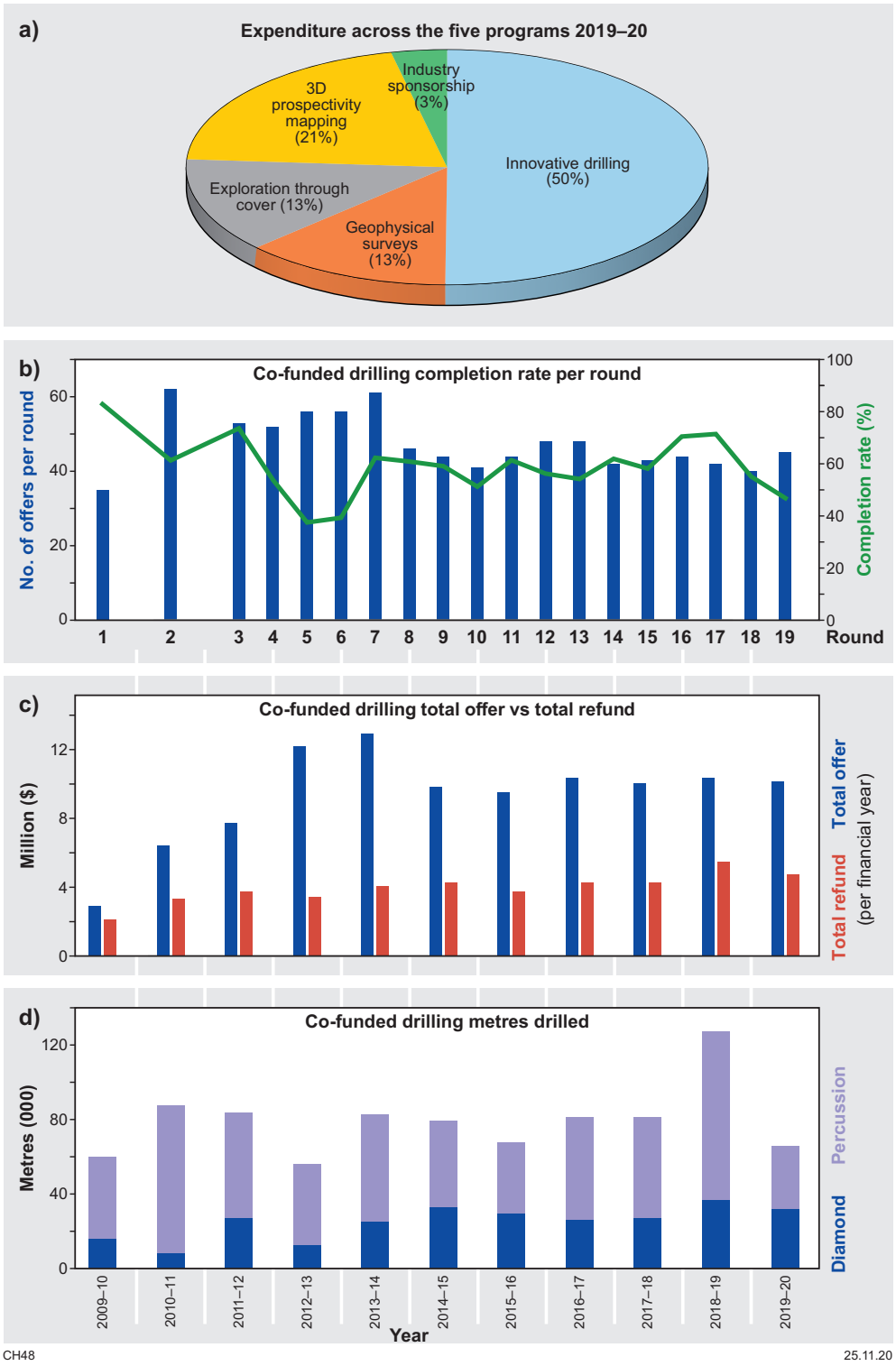


Figure 5. **Dashboard view of the EIS: a) pie chart showing the expenditure across the five EIS programs for 2019–20; b) percentage of applicants offered a grant that completed a proposed drilling program for each round. From Round 3 onwards, there have been two application periods six months apart. 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). In 2018–19, one drilling program had an extensive auger program and, combined with a high completion rate across two rounds, resulted in and higher than usual total metres drilled for that year**

Major programs

Five comprehensive programs provided 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 the most attractive minerals investment destination. Most of the activities within the programs are focused in underexplored greenfields regions. The five programs were:

1. Innovative drilling
    - 1.1. Co-funded Government–Industry drilling
2. Geophysical surveys
    - 1.1. Airborne gravity surveys
    - 1.2. Deep crustal seismic and magnetotelluric surveys; passive seismic
3. Encouraging exploration through cover
    - 1.1. Drilling decision support and targeting
    - 1.2. Depth of the cover and its interfaces
    - 1.3. Basement geology and evolution
    - 1.4. Mineral systems analysis
4. 3D prospectivity mapping
    - 1.1. Mineral systems
    - 1.2. Petroleum systems
    - 1.3. WA Geology Online
    - 1.4. Exploration data analysis
    - 1.5. 3D lithospheric visualization
    - 1.6. Mapping geodynamic setting
    - 1.7. Enhanced geochronology and isotopic fingerprinting
5. Promoting strategic research with industry
    - 1.1 MRIWA support

Major highlights and activities

- The COVID-19 pandemic at the beginning of 2020 affected the resources industry and the ability for drilling to be undertaken. Most affected were companies in Round 19, which had until 31 June 2020 to finish drilling. Only 47% of applicants in Round 19 finished compared to the historical average of 58%
- ES20 Co-funded Exploration Drilling — Rounds 18 (2019) and 19 (2019–20) had completion rates of 55% and 47%, respectively
- ES20 Co-funded Exploration Drilling — Rounds 20 and 21 opened for applications in 2019–20 (Table 4)
- ES20 Co-funded Exploration Drilling — 65.5 km of drilling with 51 projects completed in the 2019–20 financial year (Table 5)
- ES30 Airborne and Ground Geophysical Surveys — processing of all second-generation gravity coverage of Western Australia was completed and released
- ES30 Airborne and Ground Geophysical Surveys — under a new 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
- ES37 Eastern Goldfields Seismic survey — processing and interpretation of the seven 2D seismic lines was completed and the dataset was released in September 2019
- Release of the 1:500 000 State regolith map for the southern half of Western Australia
- ES46 Enhanced Geochronology and Isotopic Mapping — 89 new Geochronology Records and U–Pb datasets released; 2973 new whole-rock geochemistry analyses released; new isotope data for 64 whole-rock Sm–Nd samples (1046 total), 112 zircon Lu–Hf samples (597 total), and 73 zircon oxygen samples (115 total) released online
- ES47 Petroleum Systems — release of Waukarlycarly 1 post-well analysis results for palynology, petrology, routine core analysis and core gamma
- ES49 Greenstone Stratigraphic Geochemical Barcoding Project released 2000 whole-rock major and trace element geochemical data to open file. GSWA Record 2020/6 was published to accompany the data release
- MRIWA M0470 final report — Mineral systems on the margins of cratons: Albany–Fraser Orogen / Eucla basement case study was completed and an executive summary released (Record 2020/5).

Table 4. Application statistics for EIS Co-funded Exploration Drilling Rounds 20 and 21

Round	*Number of applications*	*Number of successful applications*
20	64	41 (36 general, 5 prospector)
21	61	49 (42 general, 7 prospector)

Table 5. EIS Co-funded Exploration Drilling statistics for the 2019–20 financial year

Diamond drilling (m)	*Percussion drilling (m)*	*Total (m)*	*Co-funding offers*	*Projects completed*
32 696	32 752	65 448	86	51

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*

- The COVID-19 pandemic at the beginning of 2020 affected the completion rate for Round 19, which had until 31 June 2020 to finish drilling. Only 47% of applicants in Round 19 finished compared to the historical average of 58%. In particular Round 19, and to a lesser extent Round 20, was impacted by the first wave of the pandemic that saw: a) State government-imposed regional boundary restrictions; b) Federal government biosecurity restrictions within Western Australia. Most travel restrictions were lifted in all regions of Western Australia by early June 2020, except those in remote Aboriginal communities
- Peako Limited maiden reverse circulation (RC) drilling program targeting anomalous induced polarization (IP) and anomalous geochemistry at its Landrigan prospect confirmed Cu–Ag–Au mineralization and a new stratigraphy and structural framework
- Brightspark Graphite (prospector application) intersected multiple graphite-rich zones, with one zone up to 20 m wide at its Brightspark project east of Manjimup
- Kingston Resources Limited progressed its Livingstone Gold project to a ~5000 m resource definition RC drilling program, designed from knowledge gained with previous EIS co-funding
- Round 18 — 12-month drilling period ended 31 December 2019 with a 55% completion rate
- Round 19 — 12-month drilling period ended 30 June 2019 with a 47% completion rate
- First 12-month period where the funding source was from MTR.

Products released

- The total number of EIS Co-funded Exploration Drilling reports released to open file was 68, including 18 with battery elements listed in target commodity (nickel, cobalt, lithium, manganese, nickel, REE and graphite). Reports to open file reported on 11 791 m of diamond drilling and 15 958 m of percussion or rotary drilling

* Information provided, unless otherwise specified, was derived from sources that include DMIRS data (WAMEX) and Australian Securities Exchange reports

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

- Processing of all outstanding airborne gravity data was completed from the Kidson 2017, Kimberley Basin 2018, Little Sandy Desert 2018, Great Victoria Desert 2018 and Pilbara 2019 surveys. Release of these datasets brought to a conclusion a second generation of gravity coverage of Western Australia that commenced in 2005 (Fig. 6)
- A new NCF agreement was made with GA to extend the AusAEM 20-km line spacing survey program across the remainder of southern Western Australia. A tendering process was completed and contracts prepared for a program of data acquisition of approximately 24 000 line-km of AEM data in the Southwest and East Yilgarn areas (Fig. 7).

Products released

- Kidson 2017 (R71234) airborne gravity data
- Horizontal component data from the 2018 airborne gravity surveys: Kimberley Basin (R71317), Little Sandy Desert (R71316); Great Victoria Desert (71318)
- Pilbara 2019 (R71470) airborne gravity data

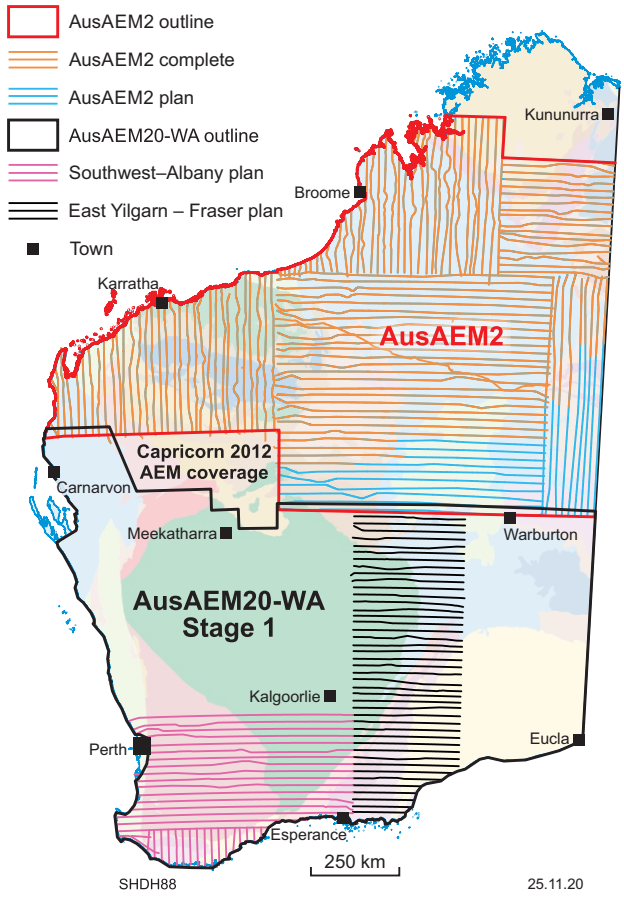


Figure 7. Location of AusAEM20–WA Stage 1 survey areas

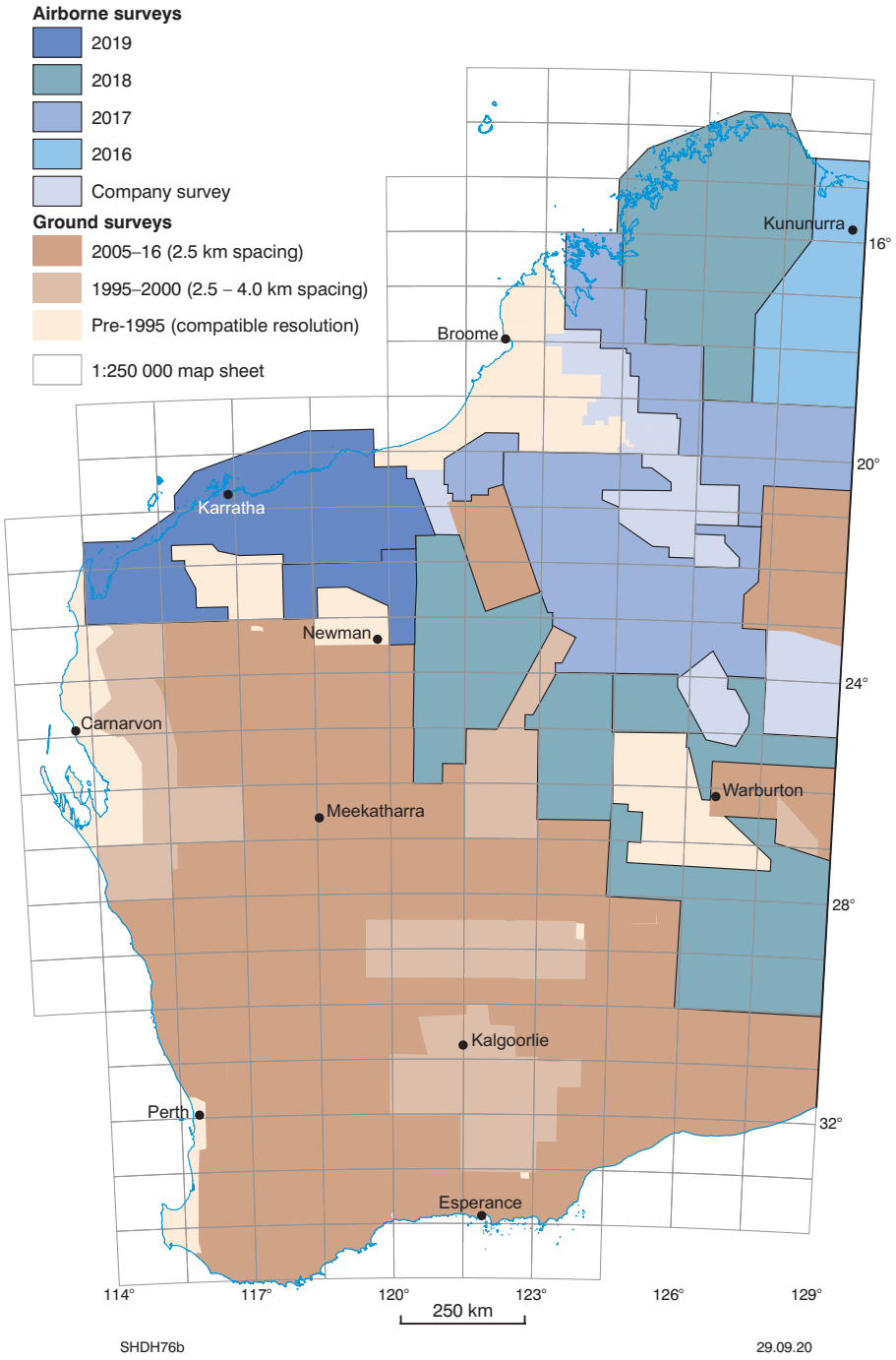


Figure 6. Progress of second-generation gravity coverage of Western Australia

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 MT surveys. These activities are described in detail in the GS62 3D Geoscience section.

Highlights and activities

- Interpretation of 872 km of gravity and deep crustal reflection data of the Kidson Sub-Basin 2D seismic survey 18GA-KB1.

Product released

- Basement interpretation of the Kidson seismic survey 18GA-KB1

ES36 Participation in MinEx CRC

Manager: Richard Chopping

Objectives

Project ES36, which commenced in 2018, and is linked to GS64 Geoscience Mapping Through Cover, manages GSWA's involvement in the MinEx Cooperative Research Centre. 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 of an embedded researcher from the University of South Australia in GSWA.

Embedded researcher (Dr Emily Finch) has been placed with GSWA from the University of South Australia for three years from January 2020 to December 2022. 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

- Recruitment of postdoctoral researcher (Dr Emily Finch) engaged through the University of South Australia and placed within GSWA
- Continuing focus on NDI work in Western Australia within 'The Gap'
- Supervision of students
- Acquisition of UltraFine+ chemistry analysis on regolith geochemistry samples from the West Arunta region
- Supporting the sampling for geochronology and geochemistry in the Paterson and West Arunta regions (reported in GS65, Proterozoic Margins).

Products released

No products were scheduled for release in 2019–20

ES37 Eastern Goldfields Seismic Survey

Manager: David Howard

Objectives

The objective of ES37 Eastern Goldfields Seismic Survey is to provide mineral explorers in the region with subsurface information in a depth range from about 300–5000 m or more in the area between Ora Banda and Kambalda (Fig. 8). As well as delineating areas that might be suitable for more detailed 3D seismic exploration surveys, we expect that interpretation of the data integrated with GSWA's field mapping, recent passive seismic and MT survey projects, and other regional datasets will provide a substantially improved understanding of the geological framework in this region.

Highlights and activities

Following completion of data acquisition along an aggregate 300 km in seven traverses on established roads and tracks in March and April 2019, data processing and interpretation were completed in September 2019, and the data released.

Product released

- Eastern Goldfields 2019 seismic survey dataset (MAGIX R71404)

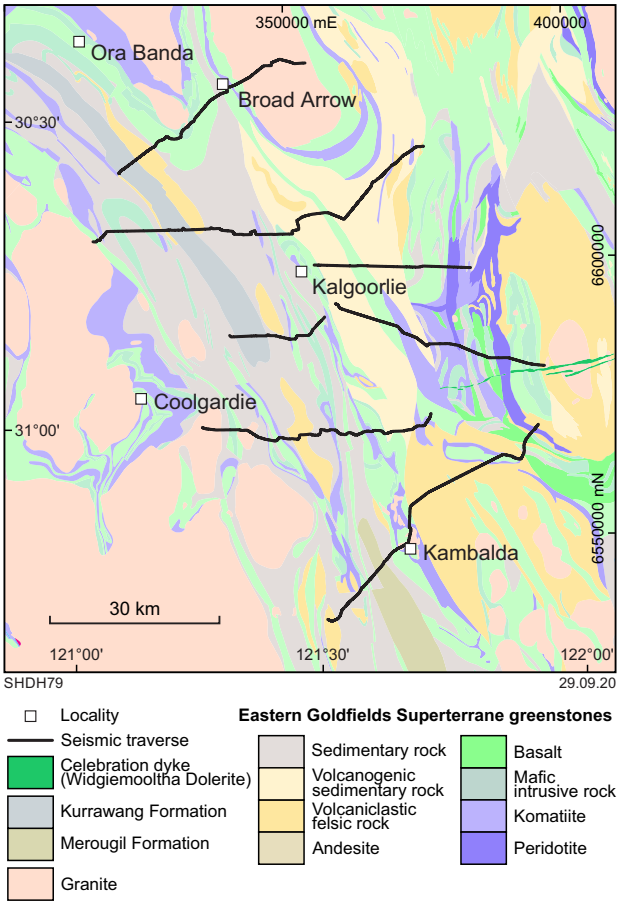


Figure 8. Location of seismic traverses

ES38 Proterozoic Margins

Manager: Catherine Spaggiari

Objectives

Proterozoic Margins 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. 9). 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

- Completion of the MRIWA M470 project on the Albany–Fraser Orogen and associated PhD projects and publications, and establishment of a new MRIWA follow-up project, 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

- Record 2020/5 MRIWA M0470 fnal report — Mineral systems on the margins of cratons: Albany–Fraser Orogen / Eucla basement case study, an executive summary. This includes a data repository with all results from the project
- External publications — see Appendix 5

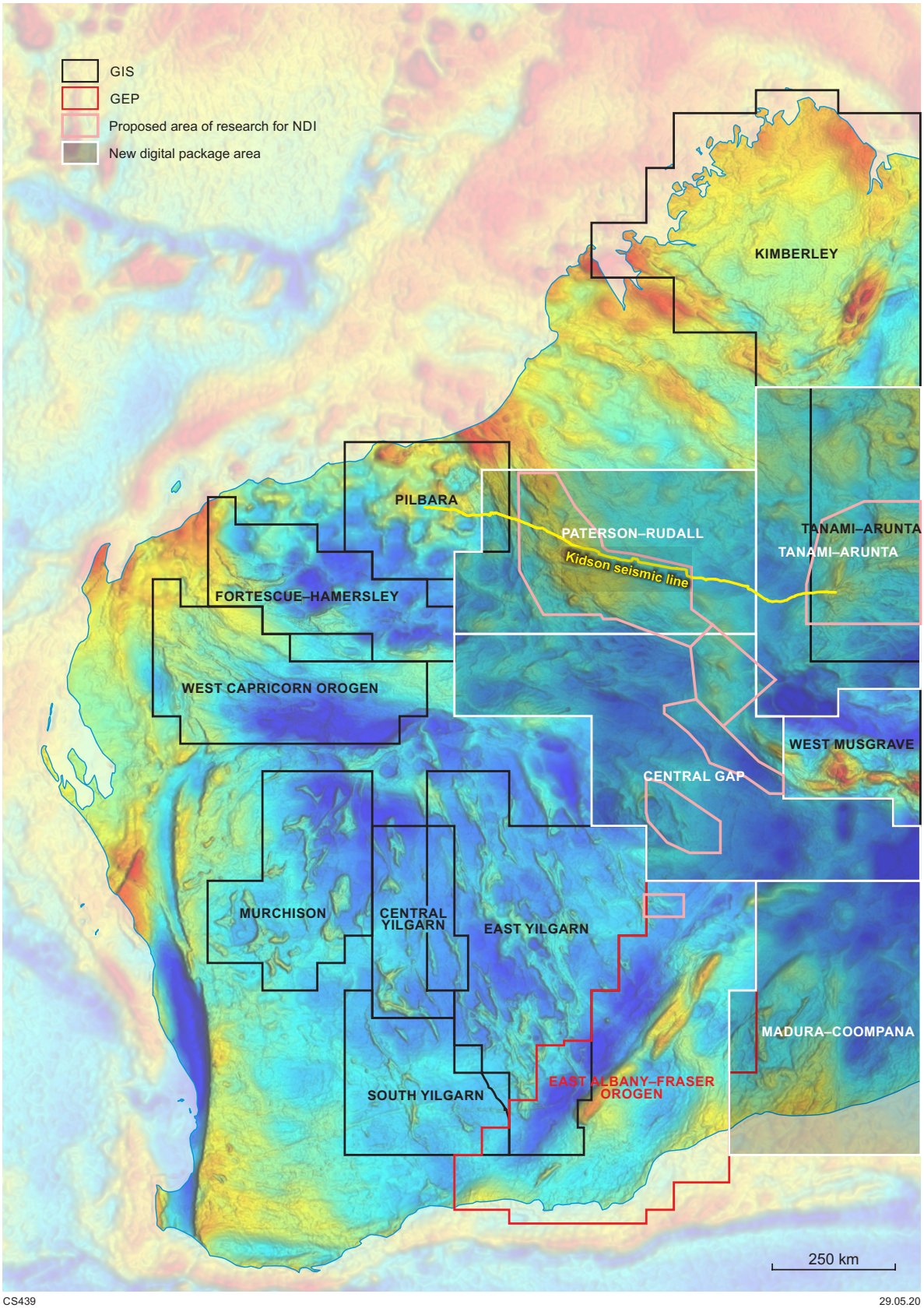


Figure 9. Gravity image showing the project areas covered by ES38 in red outlines. The region is informally defined as 'The Gap', reflecting the basement regions between the North, West and South Australian Cratons

ES40 Geology Online

Manager: Stephen Bandy

Objectives

In addition to better integration of GSWA's online data, the Geology Online project develops and facilitates the population of new databases and data services to GSWA clients and supports the production of geoscience reports and derivative maps on demand.

These databases are complemented by the development of data entry and query interfaces with reporting functions. The online interface will allow clients to generate customized geoscience reports and derivative maps.

Highlights and activities

- Enhancement to Pubstats (K2) and Geodocs systems
- Ongoing upgrade of GeoVIEW.WA to make it GDA2020 compliant
- Upgrade of the MINEDEX database and user interface.

ES42 3D Lithosphere Visualization project

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 therefore 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. These activities closely relate to the GS62 3D Geoscience section.

Highlights and activities

- Completion of the acquisition of passive seismic data over the Canning Basin. This is a major collaborative project with IGG-CAS and Macquarie University
- Interpretation of the Eastern Goldfields high-resolution seismic traverses – presentation of line work in Kalgoorlie in November 2019
- Involvement in MRIWA project M521 – interpretation of Kidson Seismic Line basement; supervision of PhD student Polyanna Moro
- Grant success as partners in ARC Linkage project LP190100146 'Evolution of Proterozoic multistage rift basins – key to mineral systems'
- Commencement of ARC Linkage project LP180101118 'Enhanced 3-D seismic structure for Southwest Australia' with ANU, GA, and the Western Australian Department of Fire and Emergency Services
- Linkage Project LP170100985 'Enabling 3D stochastic geological modelling' – visit and invited seminar at the Geological Survey of Canada, presentations and workshop participation at the mid-project meeting in Busselton, Western Australia
- Presentation on Archean Geology at the Prospectors and Developers Association of Canada 2020 meeting.

Products released

- External publications — see Appendix 5

ES43 Mineral Systems Atlas

Manager: Trevor Beardsmore

Objectives

Under ES43 Mineral Systems Atlas, GSWA has entered into collaborative research agreements with other government, university and/or industry partners to evaluate specific aspects of Western Australian mineral systems and promote the mineral potential of underexplored regions of Western Australia. Many of these projects are managed or monitored by GSWA's Minerals Geoscience branch, and in some instances have received in-kind funding from the GS20 recurrent budget; however, the majority of these minerals-oriented research projects have been partly to fully funded by the EIS. Projects underway in 2019–20 were:

- Pilbara gold fingerprinting ($25 000 per annum over two years)
- Rare earth resource potential of northern Australia ($20 000 per annum over three years)
- MRIWA M532 — Geology, mineralogy and metallurgy of eMaterial resources in Western Australia ($250 000 over two years).

Highlights and activities

The Pilbara gold 'fingerprinting' project commenced in 2019–20, and characterized the provenance and metallogenesis of gold mineralization across the Pilbara Craton, using morphometry, microstructure, associated minerals and trace element composition of bedrock-hosted and placer gold grains/nuggets. The first batch of 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 SEM-EDX (energy dispersive X-ray spectroscopy) and LA-ICP-MS, with the assistance of John Watling (TSW Analytical). Results are being evaluated.

The 'Rare earth resources of northern Australia' project was successful in receiving ARC Linkage funding, hence is able to commence in 2020–21. Principal investigators at Adelaide University (originally James Cook University) and ANU are 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.

MRIWA project M532 aims to provide a comprehensive understanding of the geology and mineralogy of Western Australian lithium–cesium–tantalum (LCT) pegmatite-hosted lithium deposits, 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. Early work by researchers at the John de Laeter Centre at Curtin University on spodumene-bearing pegmatites from several operating mines has included development of a preliminary 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. A shortfall in funding arising from withdrawal of some industry sponsorship has subsequently been underwritten by GSWA, making it now the principal project sponsor (after MRIWA). The final report is expected in mid-2021.

Products released

- No products were released in 2019–20

ES45 Mapping Geodynamic Settings program

Manager: Hugh Smithies

This cost centre was used to pay for contract staff working within other mapping projects, specifically within GS58 and GS52 (Stephen Wyche). The role undertaken by Stephen Wyche was to validate legacy ENS entries for the eastern and western Yilgarn Craton and his contributions are primarily accounted for within products and outcomes attached to those projects.

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. This project enhances GSWA's core geochronology program (see GS54) with the addition of Lu–Hf and oxygen isotope and trace element analysis of zircons, Sm–Nd isotope analysis of whole-rock samples, and additional isotope-related techniques (such as whole-rock Lu–Hf and lead isotopes) conducted in collaboration with university research groups. These techniques enable construction of a range of isotope maps, which are powerful in imaging lithospheric and crustal architecture, identifying metallogenic terranes and geodynamic environments favourable for mineralization, and constraining the 4D evolution of the lithosphere.

Highlights and activities

- SHRIMP and LA-ICP-MS U–Pb geochronology of 96 zircon, monazite, titanite and baddeleyite samples, mainly from the South West, Youanmi and Kalgoorlie Terranes of the Yilgarn Craton, the Capricorn, Albany–Fraser and Wunaamin Miliwundi Orogens (formerly the King Leopold Orogen), and the Yeneena and Canning Basins
- Refinements to LA-ICP-MS U–Pb geochronology of monazite in thin section have successfully overcome initial instrument-related analytical difficulties, ensuring accurate and precise data to constrain the timing of peak and retrograde metamorphism (see GS53). Results for the Marboo Formation and Mount Joseph Migmatite in the west Kimberley indicate metamorphic events at 1850–1820 and c. 500 Ma, the latter age for monazite rims potentially associated with the final stages of the 670–510 Ma Wunaamin Miliwundi Orogeny
- The basal Canning Basin succession and unconformably underlying Yeneena Basin have been characterized by SHRIMP U–Pb zircon geochronology of initial samples from Waukarlycarly 1, the deep stratigraphic well drilled in late 2019 to intersect the Canning sedimentary succession and basement rocks in the Waukarlycarly Embayment (see ES47)
- Ongoing SHRIMP U–Pb zircon geochronology of drillcore samples from western Arunta Orogen rocks beneath the eastern margin of the Canning Basin (see GS65) indicates protolith crystallization ages of c. 1875 Ma for granitic gneisses, and 3039–1822 Ma detrital zircons, dominated by c. 1870 Ma age components, in paragneisses. Zircon rims in all samples indicate high-grade metamorphism at c. 1610 Ma
- New zircon trace element data for the Calingiri Cu–Mo–Ag and Boddington Au–Cu–Mo deposits have improved criteria for distinguishing fertile from infertile Archean granitic rocks (Fig. 10). Recent wide recognition of this work by industry emphasizes the significance of this exploration tool for fingerprinting magmatic–hydrothermal systems and locating mineralization in Archean terranes
- Mantle-like zircon oxygen isotope values for most granitic rocks in the Pilbara Craton are consistent with reworking of igneous material at depth. However, elevated values for c. 2.9 Ga granitic rocks in inliers along the southern Pilbara margin indicate Mesoarchean reworking of upper crustal material, whereas sub-mantle values at c. 3.55 Ga in the Sylvania Inlier and c. 3.44 Ga in the northern Pilbara are consistent with Paleoarchean recycling of crustal material subjected to high-temperature hydrothermal alteration, such as observed in post-Archean rift systems or calderas

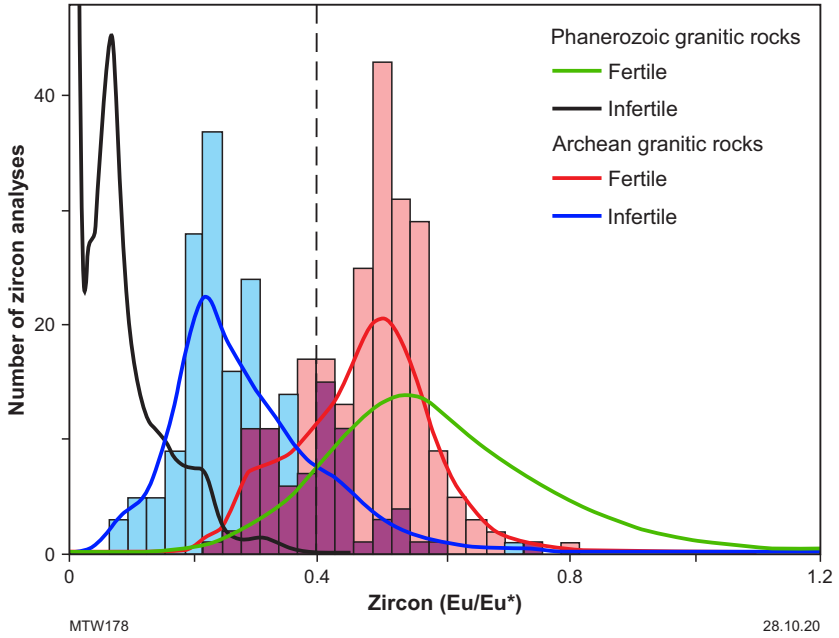


Figure 10. Normalized probability density diagram of zircon europium anomalies (Eu/Eu*, measured [Eu] over expected [Eu*] concentration) for fertile and infertile Archean granitic rocks in the Yilgarn Craton and those of Phanerozoic age (see GSWA Report 197 for details). Data for Archean samples are also shown as overlapping histograms. A granitic rock may be classified as fertile if the majority of zircon analyses in a sample indicate Eu/Eu* values above the fertility threshold of 0.4 (dashed line)

- Some late Archean granitic rocks in the Yilgarn Craton also yield high zircon oxygen isotope values, indicating incorporation of upper crustal material, although low values for the Calingiri Cu–Mo–Ag deposit and in the Narryer Terrane suggest high-temperature hydrothermal alteration at c. 3.01 and 2.67 Ga
- The Boogardie Orbicular Granite in the central Murchison region of the Youanmi Terrane is now dated at c. 2692 Ma, and interpreted as a late-stage component of the 2732–2686 Ma Big Bell Suite. Recognized worldwide and highly prized as an ornamental stone, this iconic and spectacular rock is the oldest dated orbicular granite in the world. This result was published in a feature article in The Australian Geologist (June 2020) and presented at the 2019 Astro Rocks Fest, an annual geotourism event held in Mount Magnet
- GSWA is a participant, together with Curtin University and Northern Star Resources Ltd, in an ARC Linkage project, entitled 'New tools for old rocks: first cycle provenance information', aimed at enhancing stratigraphic understanding of sedimentary sequences in Western Australia by applying novel provenance fingerprinting tools in K-feldspar (lead isotopes) and apatite (U–Pb, strontium isotopes and mineral chemistry)
- GSWA, UWA and CSIRO sponsored a successful ARC Linkage Infrastructure, Equipment and Facilities (LIEF) proposal led by Curtin University for a collision-reaction cell multicollector (CRC-MC)-ICP-MS at the GeoHistory Facility in the John de Laeter Centre. This next-generation instrument is aimed at producing significant isotope datasets that will improve mineral exploration success

- GSWA has committed in-kind support, together with seven Australian universities, for a pending ARC LIEF application to purchase next-generation, multicollector mass spectrometers and ultraclean gas line systems, capable of revolutionizing noble-gas ($^{40}Ar/^{39}Ar$) 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
- Contributions to GSWA publications and data packages:
  - Report 203 Geology of the Hardey Syncline — the key to understanding the northern margin of the Capricorn Orogen
  - Report 192 Mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton
  - Geological Information Series: Kimberley 2020, Murchison 2019, West Musgrave 2019
  - Several GSWA and Petroleum Open Day posters
  - GSWA Fieldnotes and social media pages
- The functional specifications were updated and expanded for the design of a geochronology, isotope and mineral chemistry database (WAGIM).

Products released

- 89 new Geochronology Records and U–Pb datasets released to online applications, published maps and digital products (GeoVIEW.WA and eBookshop)
- Compilation of geochronology information 2020, now featuring 1710 Geochronology Records, together with corresponding digital isotope datasets
- 2973 new whole-rock geochemistry analyses released via GeoChem Extract
- New isotope data for 64 whole-rock Sm–Nd samples (1046 total), 112 zircon Lu–Hf samples (597 total), and 73 zircon oxygen samples (115 total) released to online applications (GeoVIEW.WA and/or GeoChem Extract)
- Report 204 Stratigraphic and co-funded drilling of the Eucla basement — the Proterozoic geology beneath the Nullarbor Plain
- Report 197 Zircon fingerprinting of magmatic–hydrothermal systems in the Archean Yilgarn Craton
- Report 196 Geochronology of metasedimentary and granitic rocks in the Granites–Tanami Orogen: 1885–1790 Ma geodynamic evolution
- Article The last gasp of King Leopold: new insights into the evolution of the West Kimberley
- GSWA Open Day posters:
  - Geochronology and Geochronology
  - Zircon fingerprinting of magmatic–hydrothermal systems in the Archean Yilgarn Craton
  - Revised evolution of the West Kimberley
  - Integration of new analytical techniques
- External publications — see Appendix 5

ES47 Petroleum Systems

Manager: Deidre Brooks

Objectives

The objective of this program is to collect pre-competitive data to assist in determining the State's potential for petroleum and alternative energy sources that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms some of which were completed during the 2019–20 financial year.

Highlights and activities

- The project assessing coal resources within Western Australia was completed at the end of June 2019. The first two Records were published in June 2019. One additional record and a GIS database of coal drillholes in the Eucla, Canning and northern Perth Basins were released in 2019–20
- A study of the parameters influencing the reservoir quality of Permian sandstones in the northern Perth Basin was completed in 2019–20. The Report was in the peer review process at the end of June 2020 and will be released in 2020–21
- The Waukarlycarly 1 stratigraphic well was drilled during 2019–20. The drilling was funded by the Commonwealth Government Exploring for the Future program, administered by GA. The post-well analysis performed by GSWA is funded by the EIS. Analyses completed during 2019–20 are listed in the products released section below.

Products released

- Record 2019/10 Coal resources of the Canning Basin, Western Australia: exploration and evaluation history
- Drillholes related to coal exploration in the Canning, Eucla, northern Perth and Southern Carnarvon Basins (USB; non-series data package)
- Waukarlycarly 1 post-well analysis (see Table 6 for details):
    - 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

Table 6. Waukarlycarly 1 post-well analyses undertaken by GSWA during 2019–20

Analysis type	*No. of samples*
Palynology	11
Petrography	47
SEM	34
Cathodoluminescence	9
RCA	40
Spectral core gamma	Various intervals

Note: Abbreviation: RCA, Routine Core Analysis

ES48 Pilbara Field Mapping

Manager: Heather Howard

Objectives

This cost centre was used to fund the salary of Senior Geologist David Martin in the field mapping component of the Pilbara and Hamersley project until October 2019. The aims and activities for the Pilbara Field Mapping are outlined under GS63 Pilbara and Hamersley project.

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

- Approximately 2000 new samples were submitted for whole-rock major and trace element geochemistry
- New sampling was mainly concentrated in the Kalgoorlie Terrane and was aimed at assisting with, and complementing, the interpretation of the high-resolution seismic survey that was conducted in early 2019 by GSWA, between Ora Banda and Kambalda.

Products released

- Greenstone Geochemical Barcoding Project – 2020 data release (Record 2020/6 Eastern Goldfields Geochemical barcoding dataset Appendix 1)
- Record 2020/6 Eastern Goldfields greenstone geochemical barcoding project: notes to accompany 2020 data release

Appendices

Appendix 1

GSWA collaborative research projects

Completed projects 2019–20

Geological studies of gabbroic rocks intruding the Arid Basin in the Albany–Fraser Orogen

Project Manager: Tim Johnson (Curtin University)

Partner researchers/institutions: Chris Clark, Chris Kirkland (Curtin University)

GSWA contact: Catherine Spaggiari

Duration of project: 2015–18

Project description

The principal aims of the proposed research were to:

- determine the depth of magmatism and the *P* and *T* of metamorphism of the gabbroic rocks that intrude the sedimentary rocks of the Arid Basin
- compare these to the metamorphic *P–T* of the sedimentary rocks (i.e. Snowys Dam Formation) of the Fraser Zone
- determine emplacement mechanisms and timing of gabbroic intrusions and their relationship to metamorphism.

GSWA deliverables

Glasson, K 2018, A petrographic and geochronological assessment of the gabbroic and metagabbroic rocks of the Fraser Zone, Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Record 2018/5, 57p.

Glasson, KJ, Johnson, TE, Kirkland, CL, Gardiner, NJ, Clark, C, Blereau, E, Hartnady, MIH, Spaggiari, CV and Smithies, RH, 2019, A window into an ancient backarc? The magmatic and metamorphic history of the Fraser Zone, Western Australia: Precambrian Research v. 323, p. 55–69.

EXPLORATION INCENTIVE SCHEME

MRIWA project M470 — Mineral systems on the margin of cratons: Albany–Fraser Orogen/Eucla basement case study

Project Manager: Chris Kirkland (Curtin University)

Partner researchers/institutions: Chris Clark, Katy Evans, Steve Reddy (Curtin University); Oliver Kiddie (Ponton Minerals)

GSWA contact: Catherine Spaggiari

Duration of project: 2016–19

Project description

Research focused on the partially covered terrain of the Albany–Fraser Orogen and the covered Eucla basement of Western Australia. The project used a lithosphere-scale mineral systems approach to establish the fundamentals (timing, scale and material) of mass transfer processes within the crust. A broad range of geochronology techniques was used to enhance GSWA's regional U–Pb zircon

coverage and applied crustal evolution studies via novel analytical equipment to rapidly delimit domains of enhanced mantle input.

This research project included three modules:

- Isotopic monitors of crustal evolution; through cutting edge split stream LA-ICP-MS instrumentation (hafnium in zircon, neodymium in rutile).
- Petrochronology; by coupling U–Pb geochronology (on a wide range of different mineral phases) to the grain-scale mineral chemistry as a proxy for the conditions of the crust during specific periods in time.
- Sulfide sources and budgets; through the use of multiple sulfur isotopes combined with trace element ratios to develop a robust fingerprint of sulfur mobility and metal reservoirs in the region.

GSWA deliverables

Kirkland, CL, Evans, KA, Hartnady, MIH, Walker, AT, Chard, J, Clark, C, Spaggiari, CV, Quentin de Gromard, R, Reddy, S, Smithies, RH, Kiddie, OC and Barham, M 2020, MRIWA M0470 final report – Mineral systems on the margins of cratons: Albany–Fraser Orogen / Eucla basement case study, an executive summary: Geological Survey of Western Australia, Record 2020/5, 23p.

PhD theses

Chard, JA 2019, Petrochronology of accessory minerals related to metamorphism and fluid-flow events in the Albany–Fraser Orogen and Eucla basement, Western Australia: PhD thesis, Curtin University, Perth.

Hartnady, MIH 2019, Crustal evolution of the Albany–Fraser Orogen, Western Australia: PhD thesis, Curtin University, Perth, 339p.

Walker, AT 2019, Sulphur isotopes and trace element signatures within mineralised occurrences in the Fraser Zone, Western Australia: PhD thesis, Curtin University, Perth, 169p.

Journal articles

Hartnady, MIH and Kirkland, CL 2019, a gradual transition to plate tectonics on Earth between 3.2 and 2.7 billion years ago: Terra Nova, v. 31, no. 2, p. 129–134.

Hartnady, MIH, Kirkland, CL, Clark, C, Spaggiari, CV, Smithies, RH, Evans, NJ and McDonald, BJ 2019, Titanite dates crystallisation: slow Pb diffusion during super-solidus re-equilibration: Journal of Metamorphic Geology, v. 37, no. 6, p. 823–838.

Hartnady, MIH, Kirkland, CL, Smithies, RH, Poujol, M and Clark, C 2019, Periodic Paleoproterozoic calc-alkaline magmatism at the south eastern margin of the Yilgarn Craton: implications for Nuna configuration: Precambrian Research, v. 312, article no. 105400.

Walker, AT, Evans, KA, Kirkland, CL, Martin, L, Kiddie, OC and Spaggiari, CV 2019, Tracking mineralisation with in situ multiple sulphur isotopes: a case study from the Fraser Zone, Western Australia: Precambrian Research, v. 332, article no. 105379.

Walker, AT, Evans, KA, Kirkland, CL 2020, A novel application of image analysis to interpret trace element distributions in magmatic sulphides: Lithos, v. 362–363, article no. 105451.

Structural and metamorphic evolution of the east Albany–Fraser Orogen

Project Manager: Catherine Spaggiari

Partner researchers/institutions: Chris Clark, Tim Johnson, Nick Timms, Chris Kirkland (Curtin University), Tom Blenkinsop, Jan-Marten Huizenga (Economic Geology Research Centre [EGRU], James Cook University), Eric Tohver (UWA)

GSWA contact: Catherine Spaggiari

Duration of project: 2013–20

Project description

Research into the structural and metamorphic history of the Fraser and Biranup Zones, focusing on *P–T–t* evolution. Methodology included structural mapping, sedimentological analysis, microprobe analysis, psuedosections and phosphate, titanite and Ar–Ar dating.

GSWA deliverables

Scibiorski, E 2019, The cooling and exhumation of the Albany–Fraser Orogen, Western Australia, constrained by $^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb thermochronology: Geological Survey of Western Australia, Report 195, 675p.

Scibiorski, E, Tohver, E, Jourdan, F, Kirkland, CL and Spaggiari, CV, 2016, Cooling and exhumation along the curved Albany–Fraser Orogen, Western Australia: Lithosphere, v. 8, no. 5, p. 551–563.

Stokes, MA 2014, Structural Evolution of the Pleiades Lakes Region; Northeastern Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Record 2014/15, 145p.

Waddell, PJ-A, Timms, NE, Spaggiari, CV, Kirkland, CL and Wingate, MTD 2015, Analysis of the Ragged Basin, Western Australia: Insights into syn-orogenic basin evolution within the Albany–Fraser Orogen: Precambrian Research, v. 261, p. 166–187.

Waddell, P-J 2014, Sedimentological and structural evolution of the Mount Ragged Formation, Nornalup Zone, Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Report 129, 116p.

WA Reconnaissance Airborne Electromagnetic Surveys 2013–20: National Collaboration Framework CMC G40003A-PA4

Project Manager: David Howard

Partner researchers/institutions: GA

GSWA contact: David Howard/John Brett

Duration of project: 2013–20

Completed date: April 2020

Project description

The project was designed to provide broad-acre, wide line-spacing, airborne AEM data over the approximately 70% of the area of Western Australia that is underlain by Precambrian rocks that occur within about 300 m of the surface. Previously commissioned surveys with line-spacings of 5–6 km have confirmed the value of such reconnaissance surveys in providing valuable datasets.

Because of the large funding requirements of this project, it proceeded in a series of individual 'project stages', the magnitude and timing of which were defined depending on available DMIRS funding in any year and GSWA program of works. The precise area of each survey block was defined in a quotation request for that project stage.

GSWA deliverables

Stage 1 commenced in October 2013 over the central part of the Capricorn Orogen in the northwest of Western Australia. The 30 000 line-km survey was completed in January 2014 at a total cost of $2.45 million. Final data were released in June 2014. The data are available from **GSWA's GeoVIEW.WA platform** under MAGIX Registration No. 70825 and from GA's **data catalogue**.

No further surveys were undertaken under this project, primarily as funds were redirected to completion of second-generation gravity coverage of Western Australia under NCF Project CMC G40003A-PA5; and then as GA embarked on its 2017 **AusAEM program** of 20 km line-spacing AEM survey across an extensive area of Queensland and the Northern Territory as part of its Exploring for the Future program. In 2019, GA extended the AusAEM project across into northern Western Australia as AusAEM2, under a separate NCF Project Agreement with GSWA, CMC G4003A 000668-1 — GA Ref. 003995.

The project agreement expired in April 2020, having been replaced with a new agreement between GSWA and GA to extend the 20 km line-spacing coverage of AusAEM2 over the remainder of Western Australia as the new NCF program, AusAEM20–WA.

WA Reconnaissance Gravity Surveys 2013–20 (WARGRAV2) National Collaboration Framework CMC G40003A-PA5

Project Manager: David Howard

Partner researchers/institutions: GA

GSWA contact: David Howard/John Brett

Duration of project: 2013–20 (with option of two two-year extensions)

Project description

Designed to complete the coverage of Western Australia with gravity measurements at a 5 km-wavelength resolution or less (equivalent to a station spacing of 2.5 km or less). Approximately 60% of Western Australia remains to be covered in this standard.

GSWA deliverables

Completion of second-generation gravity coverage of Western Australia with ground and airborne gravity surveys at a wavelength resolution of 5–8 km. Located data are available via GSWA's **GeoVIEW.WA** platform and the National Geophysical Archive Data Delivery System (**GADDS**). A data compilation summary in the form of a statewide grid, and corresponding images, was published on 18 March 2020 as the 'Gravity anomaly grid (400 m) of Western Australia (2020 — version 1)', available from the **DMIRS website**.

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

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.

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.

6.2.2 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.

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.

11. APPENDIX — Committee membership

NAME	*POSITION*	*DATE APPOINTED*	*DATE APPOINTMENT EXPIRES*
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

NAME	*POSITION*	*DATE APPOINTED*	*DATE APPOINTMENT EXPIRES*
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

Appendix 2.1

13. APPENDIX — Petroleum Technical Sub-committee membership

NAME	POSITION	DATE APPOINTED	DATE APPOINTMENT EXPIRES
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

Your ref Enter Your Ref (optional)
Our ref A1440/201601
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Mr David Smith
Director General
Department of Mines, Industry Regulation and Safety
Sent by Email
East Perth WA 6004

Through: Dr Phil Gorey, Deputy Director General Resources and Environmental Regulation

Dear David

REPORT OF THE GEOLOGICAL SURVEY LIAISON COMMITTEE – DECEMBER 2019

The Geological Survey Liaison Committee (GSLC) met on 10 December 2019, 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 performance of the Geological Survey of Western Australia (GSWA).

- The committee accepted the revised Terms of Reference, which were approved by the DDG RER following discussion at the June GSLC meeting.
- Exploration Incentive Scheme (EIS) Co-funded Drilling Program:
    - The percentage of refunds allocated to completed drilling projects has been higher in recent rounds (R16 and R17), and this will impact on budget available for precompetitive geoscience data acquisition.
    - 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.
    - An internal review of ten years of the EIS Co-funded Drilling Program is underway, to be completed by the end of March 2020. This will be made

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public and can form the basis of an independent economic impact study of EIS to follow on from the 2015 ACIL Allen Consulting study.

- The liaison committee endorsed the GSWA Annual Review for 2018–19.
    - It was noted that GSWA no longer produces 'hard copy' maps, reports or records. All products and data are available now for searching and download on-line through eBookshop, GeoVIEW.WA, the Data and Software Centre and the various mapping, mining and exploration databases.
    - 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 is developing a data strategy, compatible with a national data strategy developed through the Geoscience Working Group of the COAG Energy 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 to investigate if it is available to store data.
    - Planning is for a 5 year strategy and a 10 year strategy. 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.
- GSWA has appointed a Stakeholder Engagement Coordinator to raise its profile and to promote good news for geoscience and the resources industry in Western Australia. This will emphasise greening the future through the discovery and mining of strategic minerals, and future battery commodities to generate and store renewable energy.
- 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.

- Sub-committee review and feedback:
    - The Technical Subcommittees (MTSC and 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.
    - Dr Jon Hronsky provided a Discussion Paper to MTSC relating to the development of 'Discovery Technology Packages' for the resources industry, funded from an expanded Exploration Incentive Scheme. Aspects of the proposal may be covered by existing programs and projects as part of MinEx CRC. EIS funding is fully committed until the end of 2020-21. The proposal could be funded potentially through MRIWA, although a revised, better constructed proposal is required.
    - The EIS continues to provide substantial benefit to the minerals industry. For the most recently completed round of co-funded drilling, refunding exceeded the nominal $5 million commitment to co-funded drilling. In addition, the completion rate of the last two rounds was greater than 70%, exceeding the average historic completion rate of 58%.
    - The Petroleum Technical Subcommittee (PTSC) suggests that, given the continued low numbers of applications to petroleum companies under the co-funded drilling program, GSWA consider alternative models to attract increased participation and exploration.
    - A review of the co-funded drilling program will be undertaken in 2020. In addition to its current terms of reference, other exploration methods, such as geophysical data acquisition, should be included as part of the co-funded program of the EIS. It is view of many of the industry representatives of the MTSC that where such data genuinely opens up a new search space, that co-funding should be permissible. There was feedback also recommending review of the drilling methods with some requesting that percussion and air core drilling be downgraded relative to diamond drilling.
    - 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.
    - The MTSC and PTSC note that the draft Geological Survey and Resources Division Annual Review 2018-19 demonstrates that GSWA is achieving its' ambitious, structured Work Program that is both appropriate and will assist the minerals and petroleum industry in Western Australia.

- GSWA is providing a mixture of acquisition and delivery of precompetitive geoscience data with collaborative research that follows their primary objective. The Annual Review highlights how the Division aligns with broader geoscience community agendas, such as the National Drilling Initiative, the National Mineral Exploration Strategy, and UNCOVER's 'Unlocking Australia's hidden potential, An Industry Roadmap'.
- MTSC commends GSWA for making its 'on-line' web-based platforms, including GeoView WA, Mineral Titles Online and Tengraph, accessible by commonly used and maintained web browsers. 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 and magnetotellurics. The MTSC commends GSWA for completion of the acquisition of gravity datasets 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.
- MTSC strongly endorses the Geochemistry Barcoding technique, and the work to-date has made significant advances in understanding the evolution and potential mineralisation targeting of the Yilgarn.
- 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 intended 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.

- 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.
- The Waukarlcarly1 stratigraphic well in the Canning Basin, funded by GA and managed by GSWA, was drilled to a depth of 2680.53 metres. This project highlights the important role of Government in opening up new geological provinces through pre-competitive data acquisition. PTSC is looking forward to the release of the post-well analysis and well completion reports.

Yours sincerely

Jeff Haworth
Executive Director Geological Survey
Geological Survey and Resource Strategy Division

28 January 2020

Appendix 3

Products and services delivered

Category	*Product/service type*	*Total*
Maps *		5
Text publications **		32
Data packages #		17
Data acquisition	Explanatory Notes System (ENS) online — for series and non-series maps (per unit)	209
	HyLogger scanning (metres scanned)	74 102
	Aeromagnetic survey (line-km)	0
	EIS Co-funded diamond drilling (metres released)	52 013
	EIS Co-funded drilling other (metres released)	60 914
	Gravity (ground; stations)	0
	Gravity (airborne; line-km)	145 910
	Electromagnetic survey (line-km)	0
	Deep crustal seismic survey (line-km) — acquisition	305
	Deep crustal seismic survey (line-km) — reprocessing	0
	Passive seismic survey (station)	29
	Geochemistry (sample)	2973
	Geochronology (report per sample)	89
	Hyperspectral scanning summary (drillhole)	20
	Paleontology record	46
	Isotopic analysis (per sample)	229
	GSWA stratigraphic drilling (metres drilled)	2681
Information and advice services	Core Library — core released (pallets)	370
	Core Library — cuttings and vials released (pallets)	19
	Core Library — pallets laid out for viewing	2356
	Industry exploration reports — minerals reports released only	3654
	Industry exploration records — petroleum reports released only	7755
Information and advice services — Statutory and Resource Information	Geological advice regarding Mining Act administration (mining lease applications, expenditure exemptions, extensions of term, retention licence, retention status, Special Prospecting Licence reports for the Warden)	561
Information and advice services — Land Use	Geological Advice (Mining Act s 16(3)) — South West Native Title Settlement and GASA – full assessments	470
	Geological Advice (Mining Act s 16(3)) — South West Native Title Settlement and GASA – indicative assessments	1264
	Geological advice — land use referrals assessed	474

* Includes State and series maps — 1:100 000 and 1:250 000, non-series maps, project maps, plates, miscellaneous maps — major and minor update and/or new

** Includes Memoirs, Bulletins, Reports, Records, books, external publications, newsletters, Fieldnotes and posters or equivalent

Data packages, including 3D geological models — major and minor update and/or new and miscellaneous data packages — non-series, minor

Appendix 4

Maps, books and datasets released

Maps

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2020
by KJ Ridge

Basement Interpretation of the Kidson Seismic Survey 18GA-KB1

Kimberley mineral resources and petroleum projects, 2020

Major resource projects, Western Australia — 2020

Mines — operating and under development, Western Australia — 2020

Text publications

Bulletin

Bulletin 147 Handbook for the study and description of microbialites
by K Grey and S Awramik

Reports

Report 192 Mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton
by TJ Ivanic

Report 193 A seismic interpretation of the Broome Platform, Willara Sub-basin and Munro Arch of the Canning Basin, Western Australia
by Y Zhan

Report 196 Geochronology of metasedimentary and granitic rocks in the Granites–Tanami Orogen: 1885–1790 Ma geodynamic evolution
by DW Maidment, MTD Wingate, JC Claoue-Long, S Bodorkos, DL Huston, JA Whelan, L Bagas, A Lambeck and Y Lu

Report 197 Zircon fingerprinting of magmatic–hydrothermal systems in the Archean Yilgarn Craton
by Y Lu, RH Smithies, MTD Wingate, NJ Evans, TC McCuaig, DC Champion and MD Outhwaite

Report 198 Komatiite characteristics of the Fisher East nickel sulfide prospects: implications for nickel prospectivity in the northeastern Kurnalpi Terrane
by L Burley and SJ Barnes

Report 199 Stratigraphy and structure in the Neoarchaean of the Kalgoorlie district, Australia: Critical controls on greenstone-hosted gold deposits
by GI Tripp

Report 201 Structural and geochemical evolution of the Yalgoo Dome, Yilgarn Craton (Western Australia)
by F Clos

Report 202 Gravitational Instabilities Beneath the Continents
by APJ Beall

Report 203 Geology of the Hardey Syncline — the key to understanding the northern margin of the Capricorn Orogen
by DMcB Martin

Report 204 Stratigraphic and co-funded drilling of the Eucla basement — the Proterozoic geology beneath the Nullarbor Plain
by CV Spaggiari, RH Smithies, CL Kirkland, MTD Wingate and RN England

Report 206 Waukarlycarly 1 basic data well completion report
by LS Normore and M Rapaic

Records

Record 2019/1 Geological Survey work program for 2019–20 and beyond

Record 2019/9 Application of rapid benchtop X-ray powder diffractometry for identification and characterization of mineral phases in geological materials
by M Wawryk and EA Hancock

Record 2019/10 Coal resources of the Canning Basin, Western Australia: exploration and evaluation history
by SL Simons

Record 2020/2 GSWA 2020 extended abstracts: advancing the prospectivity of Western Australia

Record 2020/3 The geodynamic context of Archean volcanism in the western Yilgarn Craton
by I Koutsoumbis

Record 2020/4 The Deflector Au–Cu Deposit: Defining an anomalous Yilgarn Craton mineralisation style using trace element geochemistry
by JFB Egan

Record 2020/5 MRIWA M470 final report – Mineral systems on the margins of cratons: Albany–Fraser Orogen / Eucla basement case study, an executive summary
by CL Kirkland, KA Evans, MIH Hartnady, A Walker, J Chard, C Clark, CV Spaggiari, R Quentin de Gromard, S Reddy, RH Smithies, O Kiddie and M Barham

Record 2020/6 Eastern Goldfields greenstone geochemical barcoding project: notes to accompany 2020 data release
by RH Smithies and JR Lowrey

Record 2020/7 Rare-element pegmatites: a mineral systems analysis
by P Duuring

Record 2020/9 Layered intrusion-hosted vanadium: a mineral system analysis
by JN Guilliamse

Miscellaneous books

Calendar 2020: Geological Survey of Western Australia

Compilation of HyLogger records, 2020 (includes 20 individual records)
by EA Hancock, P Duuring, JN Guilliamse, L Burley, M Wawryk and LS Normore

F53427–F53433: macrofossils from the Maxicar beds, southern Perth Basin
by SK Martin and JD Stilwell

Fieldnotes: GSWA newsletter July 2019 number 91

Fieldnotes: GSWA newsletter October 2019 number 92

Fieldnotes: GSWA newsletter January 2020 number 93

Fieldnotes: GSWA newsletter April 2020 number 94

Geological Survey of Western Australia annual review 2018–19

Lower Devonian thelodont *Turinia australiensis* Gross, 1971 from petroleum well Wilson Cliffs 1 (Core 5, Tandalgoo Formation)
by HJ Allen, K Trinajstic and PW Haines

Meteorite impact structures of Western Australia, virtual tour 2020
by SC Goss

Appendix 4

Datasets

Geological Information Series

Kimberley, 2020

Murchison, 2019

West Musgrave, 2019

Data packages

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

1:500 000 State regolith geology of southern Western Australia
by J Jakica and N de Souza Kovacs

Compilation of geochronology information, 2020 (includes 90 new individual records)

Compilation of WAROX data, 2020

Drillholes related to coal exploration in the Canning, Eucla, northern Perth and Southern Carnarvon Basins
by S Simons

East Yilgarn 1:500 000 interpreted bedrock geology, 2020
by J Sapkota

DMP Harvey 2, Perth Basin: Digital Core Atlas
by S Gamarra and A Symonds

DMP Harvey 3, Perth Basin: Digital Core Atlas
by S Gamarra and A Symonds

DMP Harvey 4, Perth Basin: Digital Core Atlas
by S Gamarra and A Symonds

Murchison 3D, 2019
by RE Murdie, I Zibra, TJ Ivanic, S Wyche and JR Lowrey

Update of 1:100 000 State interpreted bedrock geology digital map layer

Digital layers

Dalgaranga 1:100 000 digital layers (*in* Murchison, 2019)

Montague Sound 1:250 000 digital layers update (*in* Kimberley, 2020)

Nabberu SG51-5 1:250 000 digital layers

Posters

70 geoscience posters

Appendix 5

External publications on Western Australian geoscience

GS10 Energy Geoscience and Carbon Strategy

Boreham, CJ, Edwards, DS, Sohn, JH, Palatty, P, Chen, JH and **Mory, AJ** 2020, Gas systems in the onshore Canning Basin as revealed by gas trapped in fluid inclusions: *in* Exploring for the Future: Extended Abstracts *edited by* K Czarnota, S Abbott, M Haynes, N Kositcin, A Ray and E Slatter: Geoscience Australia, Canberra 4p., doi:10.11636/135207.

Carr, LK, Edwards, DS, Southby, C, Henson, P, **Haines, P, Normore, L, Zhan, A, Brooks, D**, MacFarlane, S, Boreham, CJ, Grosjean, E, **Mory, AJ**, Wang, L and Gunning, M-E 2020, Kidson Sub-basin seismic survey and Waukarlycarly 1 stratigraphic well: an acquisition program for evaluating Canning Basin petroleum systems, *in* Exploring for the Future: Extended Abstracts *edited by* K Czarnota, S Abbott, M Haynes, N Kositcin, A Ray and E Slatter: Geoscience Australia, Canberra, 4p., doi:10.11636/134073.

Haines, PW and **Allen, H-J** 2019, Hydrocarbon and helium prospectivity of the Amadeus and Murraba basins in Western Australia, *in* The Sedimentary Basins of Western Australia V *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, Western Australia, 2–5 September 2019, 17p.

Keeman, J, Turner, S, **Haines, PW**, Belousova, E, Ireland, T, Brouwer, P, Foden, J and Wörner, G 2020, New U-Pb, Hf and O isotope constraints on the provenance of sediments from the Adelaide Rift Complex - Documenting the key Neoproterozoic to early Cambrian succession: Gondwana Research, v. 83, p. 248–278, doi:10.1016/j.gr.2020.02.005.

Morón, S, Cawood, PA, **Haines, PW**, Gallagher, SJ, Zahirovic, S, Lewis, CJ and Moresi, L 2019, Paleozoic to Triassic continental-scale sediment provenance of the Canning, Officer and Northern Carnarvon Basins, Western Australia, *in* The Sedimentary Basins of Western Australia V *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, Western Australia, 2–5 September 2019, 20p.

Peyrot, D, Keep, M, Scibiorski, J, McCartain, E, Baillie, P, Soares, J, Haig, DW and **Mory, AJ** 2019, The Foura Sandstone type section (*Samaropollenites speciosus* Zone, Carnian–early Norian; early Late Triassic), Timor–Leste: preliminary correlation between Timor and the Bonaparte Basin: ASEG Extended Abstracts, v. 2019, no. 1, 5p., doi:10.1080/22020586.2019.12073150.

Peyrot, D, Playford, G, Mantle, DJ, Backhouse, J, Milne, LA, Carpenter, RJ, Foster, C, **Mory, AJ**, McLoughlin, S, Vitacca, J, Scibiorski, J, Mack, CL and Bevan, J 2019, The greening of Western Australian landscapes: the Phanerozoic plant record: Journal of the Royal Society of Western Australia, v. 102, p. 52–82.

Southby, C, Carr, L, Henson, P, **Haines, P, Zhan, Y**, Anderson, J, MacFarlane, S, Formin, T and Costelloe, R 2019, Exploring for the future: Kidson Sub-basin seismic interpretation: ASEG Extended Abstracts, v. 2019, no. 1, 3p., doi:10.1080/22020586.2019.12073007.

Thomas, CM and **Martin, SK** 2019, Tectonostratigraphy and structures of the southern Perth Basin, *in* The Sedimentary Basins of Western Australia V *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, Western Australia, 2–5 September 2019, 21p.

Zhan Y, 2019, Seismic interpretation of salt occurrences in the southern Canning Basin, Western Australia, *in* The Sedimentary Basins of Western Australia V *edited by* M Keep and SJ Moss: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, Western Australia, 2–5 September 2019, 15p.

Zi, J-W, **Haines, PW**, Wang, X-C, Jourdan, F, Rasmussen, B, Halverson, GP, Sheppard, S and Li, C-F 2019, Pyroxene $^{40}Ar/^{39}Ar$ dating of basalt and applications to large igneous provinces and Precambrian stratigraphic correlations: Journal of Geophysical Research: Solid Earth, v. 124, 18p., doi:10.1029/2019JB017713.

GS20 Minerals Systems Studies

Duuring, P, Angerer, T, Hagemann, SG and Banks, DA 2020, Iron deposits hosted by banded iron-formations in the Yilgarn Craton: Products of sequential iron enrichment by magmatic, marine and meteoric fluids: Ore Geology Reviews, v. 116, p. 103251, 25p., doi:10.1016/j.oregeorev.2019.103251.

Duuring, P, Hagemann, SG, Laukamp, C and Chiarelli, L 2019, Supergene modification of magnetite and hematite shear zones in banded iron-formation at Mt Richardson, Yilgarn Craton, Western Australia: Ore Geology Reviews, v. 111, 16p., doi:10.1016/j.oregeorev.2019.102995.

Duuring, P, Santos, JOS, **Fielding, IOH, Ivanic, TJ**, Hagemann, SG, Angerer, T, **Lu, Y-J**, Roberts, M and Choi, J 2019, Dating hypogene iron mineralization events in Archean BIF at Weld Range, Western Australia: insights into the tectonomagmatic history of the northern margin of the Yilgarn Craton: Mineralium Deposita, doi:10.1007/s00126-019-00930-3.

Morin-Ka, S, **Beardsmore, TJ**, **Duuring, P**, **Guilliamse, J** and **Burley, L** 2019, The Mineral Systems Atlas — delivering greater value from precompetitive geoscience data: ASEG Extended Abstracts, v. 2019, no. 1, 3p., doi:10.1080/22020586.2019.12073210.

GS52 East Yilgarn (Kalgoorlie office)

Fischer-Gödde, M, Elfers, B, Münker, C, Szilas, K, Maier, WD, Messling, N, Morishita, T, Van Kranendonk, M and **Smithies, RH** 2020, Ruthenium isotope vestige of Earth's pre-late-veneer mantle preserved in Archaean rocks: Nature, v. 579**,** p. 240–244, doi:10.1038/s41586-020-2069-3.

Smithies, RH, Lu, Y, Johnson, TE, Kirkland, CL, Cassidy, KF, Champion, DC, Mole, DR, **Zibra, I, Gessner, K, Sapkota, J, De Paoli, MC** and Poujol, M 2019, No evidence for high-pressure melting of Earth's crust in the Archean: Nature Communications, v. 10, no. 5559, doi:10.1038/s41467-019-13547-x.

GS53 Chief Geoscientist and Terrane Custodians

Fielding, IOH and **Johnson, SP** 2019, Gold Metallogeny of the northern Capricorn Orogen: ASEG Extended Abstracts, v. 2019, no. 1, 6p., doi:10.1080/22020586.2019.12073049.

Johnson, SP 2019, Australia: Proterozoic: Reference Module in Earth Systems and Environmental Sciences: Elsevier, doi:10.1016/B978-0-12-409548-9.12103-7.

Johnson, SP 2019, Twenty years of pre-competitive geoscience data in the Capricorn Orogen: the link between mineral systems and crustal evolution: ASEG Extended Abstracts, v. 2019: no. 1, 3p., doi:10.1080/22020586.2019.12073250.

Piechocka, AM, Zi, J-W, Gregory, CJ, Sheppard, S, **Korhonen, FJ**, Fitzsimons, ICW, Johnson, TE and Rasmussen, B 2019, The Mangaroon Orogeny: Synchronous c. 1.7 Ga magmatism and low-P, high-T metamorphism in the West Australian Craton: Precambrian Research, v. 333, p. 105425, doi:10.1016/j.precamres.2019.105425.

GS54 Geochronology and Geochemistry

Holwell, DA, Fiorentini, M, McDonald, I, **Lu, Y**, Giuliani, A, Smith, DJ, Keith, M and Locmelis, M 2019, A metasomatized lithospheric mantle control on the metallogenic signature of post-subduction magmatism: Nature Communications, v. 10, no. 3511, doi:10.1038/s41467-019-11065-4.

Lu, Y 2019, Zircon fingerprinting of magmatic-hydrothermal systems in Archean Craton and Phanerozoic terranes: Team WA Workshop – Fertility Indicators of Magmatic and Hydrothermal Systems, 27 May 2019, Perth, Western Australia.

Lu, Y, **Smithies, H**, **Wingate, MTD**, Evans, NJ, McCuaig, C, Champion, DC and Outhwaite, M 2019, Zircon fingerprinting of magmatic-hydrothermal systems in the Archean Yilgarn Craton: Society of Economic Geologists 2019 conference, South American Metallogeny: Sierra to Craton, Santiago, Chile, 7–10 October 2019, poster.

Lu, Y, Smithies, H, Wingate, MTD, Evans, NJ, McCuaig, TC, Champion, D and Outhwaite, M 2019, Zircon fingerprinting of magmatic-hydrothermal systems in the Archean Yilgarn Craton: Extended Abstract, Society of Economic Geologists 2019 conference, South American Metallogeny: Sierra to Craton, Santiago, Chile, 7–10 October 2019.

Ramsay, RR, Eves AE, Denyszyn, SW, **Wingate, MTD**, Fiorentini, M, Gwalani, LG and Rogers KA 2019, Geology and geochronology of the Paleoproterozoic Hart Dolerite, Western Australia: Precambrian Research, v. 335, doi.org/10.1016/j.precamres.2019.105482.

Sun, X, Hollings, P and **Lu, Y** 2020, Geology and Origin of the Zhunuo Porphyry Copper Deposit, Gangdese belt, southern Tibet: Mineralium Deposita, doi:10.1007/s00126-020-00970-0.

Ware, B, **Wingate, MTD**, Jourdan, F and McInnes, BIA 2019, Expanding the understanding of the $^{40}Ar/^{39}Ar$ geochronology of pyroxene: Conference abstracts, Thermochronology and Noble Gas Geochronology and Geochemistry Organisation (TANG3O) Conference, Hobart, 6–7 November 2019, p. 24.

Wingate, MTD 2020, Geochronology of the Boogardie Orbicular Granite: The Australian Geologist, v. 195, p. 24–26.

GS55 Geophysics Acquisition and Processing

Bates, M, Elieff, S, Kaski, K, **Howard, D, Brett, J** and Lane, R 2019, Regional airborne gravity surveys in Western Australia: Considerations for the end user ASEG Extended Abstracts, v. 2019, no. 1, 5p., doi:10.1080/22020586.2019.12072976.

Bates, M, Elieff, S, Kaski, K, **Howard, SHD**, **Brett, J** and Lane, RJL 2019, Levelling large-scale airborne gravity surveys without control lines in Western Australia: KEGS Symposium 2019 Challenges in Modern Geophysics: Toronto, Canada, 2 March 2019.

Howard, SHD 2019, Geological Survey of Western Australia: Data released from Eastern Goldfields 2019 seismic survey: Preview, 2019: v. 202, p. 18, doi:10.1080/14432471.2019.1669282.

Howard, SHD 2019, Geological Survey of Western Australia: Regional and crustal-scale geophysical programmes in 2019: Preview, 2019: v. 201, p. 14–15, doi:10.1080/14432471.2019.1646694.

Howard, SHD 2020, Geological Survey of Western Australia: AusAEM20–WA Project: Preview, 2020: v. 205, p. 18, doi:10.1080/14432471.2020.1751781.

GS58 West Yilgarn

Lowrey, JR, Wyman, DA, **Ivanic, TJ** and **Smithies, RH** 2019, Archean Boninite-like Rocks of the Northwestern Youanmi Terrane, Yilgarn Craton: Geochemistry and Genesis: Journal of Petrology, v. 60, no. 11, p. 2131–2168, doi:10.1093/petrology/egaa002.

GS62 3D Geoscience

Brisbout, L and **Murdie, R** 2019, Imaging a mafic underplate in 3D: an example from the east Albany–Fraser Orogen and Yilgarn Craton margin, *in* AEGC Extended Abstracts 2019: Australasian Exploration Geoscience Conference, Perth, Western Australia, 2–5 September 2019, 4p.

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