

GSWA ANNUAL REVIEW 2021–22



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

Geological Survey of
Western Australia



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



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Cover image: This is the c. 3350 Ma Euro Basalt in the Marble Bar greenstone belt of the East Pilbara Terrane, 20 km south-southeast of Marble Bar. The subvertical schistose fabric of the rocks resulted from intense flattening and stretching as the greenstone belt sank between granitic domes rising to the north and south. Photo by Stephen White

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Year in review

2021–22



As we emerge from Western Australia's COVID-19 isolation bubble and life slowly returns to the 'new normal', I reflect on another year and the achievements of our division.

I am particularly proud of the improvements we made to the Geological Survey of Western Australia (GSWA) Open Day. The revamped Open Day was held in November 2021 for the first time at the Hyatt Regency Hotel in East Perth. We had a record number of delegates who enjoyed the new format, with tickets sold out earlier than anticipated. We continue to engage virtually with our stakeholders via our popular and interactive webinar series, and our social media platforms, including the *Rocks Beneath Our Feet* podcast, which is performing well.

In addition to our business as usual, this year GSWA has been working on several key priorities as part of the GSWA strategy 2030:

- Garnering Geoscience Knowledge – we released our Geoscience Strategy (www.dmirs.wa.gov.au/gswastrategicpriorities) this year, aimed at building our geological understanding of the State by acquiring and synthesizing pre-competitive data utilizing collaborative research and strategic partnerships
- Transforming our Data – we commenced the Geoscience Data Transformation Program, a five-year program that will enable the delivery of the Geoscience Data Transformation Strategy. This program will modify the way we store, analyse and deliver our data to ensure it can move fluidly with emerging technology and innovation.

The Exploration Incentive Scheme (EIS) Co-funded Exploration Drilling Program continues to expand. Last year saw the first annual increase to \$12.5 million per annum (up from \$10 million) spent. Another important milestone was reached this year for the EIS when we passed 1 000 000 m drilled for the co-funded drilling component.

In recognition of the importance of Aboriginal engagement in the work we do, in early 2022 we recruited a full-time Senior Liaison Officer for Land Access and Aboriginal Engagement to ensure that GSWA continues to build honest and transparent relationships with Native Title groups and to facilitate land access.

This year the Geological Survey and Resource Strategy division (GSRSD) spent over \$37 million procuring pre-competitive geoscience data. The Hon Bill Johnston, Minister for Mines and Petroleum, opened the \$7 million expansion to the Joe Lord Core library in Kalgoorlie in November 2021. This tripled the site storage capacity and extended the outdoor core viewing area for more industry and academic use.

A significant volume (over 1100) of never-before-seen exploration reports was released under the Sunset Clause. The release of these data continues to de-risk exploration for the resources sector.

There has been considerable input by the Land Use Planning branch into the Government's Renewable Hydrogen Guidance – Land Tenure for Large Scale Renewable Hydrogen Projects. Also in the hydrogen space, GSWA investigated natural hydrogen and helium potential in sedimentary basins to illustrate the potential for natural plays of these resources.

Year in review

GSWA continues to conduct and create new, high-quality collaborative research projects with local universities and research organizations. We commenced a project in the southwest detecting distal alteration footprints and linking basement and cover geology through a three-year MRIWA project between ourselves, CSIRO and industry participants.

A collaboration with Curtin University and The University of Western Australia interpreting the nature of zircon oxygen isotope data from the Pilbara Craton granitic rocks provided evidence for the origin of the earliest continents on the planet. This work led to the publication of the results in two articles in the journal *Nature*. Further novel geochronology and mineral isotope work is being conducted on rocks in key regions across that State. The results are beginning to unravel the complex geological evolution of these key regions and provide insights into the location of major crustal structures, their hydrothermal fluid histories and the potential mineral systems they might conceal.

Following the success of two short petrophysical projects that acquired eight different petrophysical properties taken from 4000 samples, a longer five-year project was initiated. This project will focus on strategic core that demonstrates stratigraphy, mineralization and alteration across Western Australia. In addition, just shy of 50 000 m of core and 9000 m of chips and cuttings from 171 drillholes were scanned by the HyLogger with the data released to the National Virtual Core Library project.

The 2021–22 work program resulted in the release of five maps, four data packages, 11 digital layers, four online data releases, 35 text publications, as well as 40 posters and 25 commodity flyers. GSRSD also published the 2020–21 edition of the Mineral and Petroleum Statistical Digest along with the downloadable resources data files.

It was another successful year for Western Australia's resources sector. Operations achieved a sales record of \$231 billion driven by higher prices and volumes for many commodities. This was against a backdrop of global macroeconomic issues associated with COVID-19 and the Russia–Ukraine conflict, and despite local inflationary and labour challenges.

The iron ore industry remained the bedrock of the sector with sales valued at \$137 billion. Sales of gold, another pillar of the local industry, were valued at a record \$17 billion, supported by the highest local volumes in 20 years and overall stronger Australian dollar prices from a weaker currency.

The resources sector's record performance was supported by strength in battery and critical minerals essential to the global transition to electric vehicles, renewable energy and energy storage systems, as well as emerging high-end technologies.

The petroleum industry continued its recovery as demand improved in the aftermath of COVID-19, supporting an increase in oil and natural gas prices. There were all-time high levels of minerals exploration expenditure to increase the life of existing operations and finding the mines of tomorrow. Western Australia remained the leading destination for exploration investment in the world, as ranked by the Fraser Institute.

Michele Spencer

EXECUTIVE DIRECTOR

Note: all currencies are Australian dollars unless otherwise indicated.

Overview of exploration and development trends

Western Australia has a globally significant, diversified, resources sector that is a leading contributor to the Western Australian economy, delivering wealth, jobs and revenue to the State and its people.

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

The resources sector contributes almost half of the State's economic output and was responsible for employing an average of 157 704 on-site personnel in 2021–22. The State Government also collected \$12.8 billion in revenues from the sector in the past financial year.

Exploration is the lifeblood of the resources sector. Discoveries and subsequent resource development are critical to ensuring the sustainability and growth of the resources sector and its contribution to the State's economy and the community.

The future for the resources sector looks promising with all-time high levels of minerals exploration expenditure to increase the life of existing operations and to find the mines of tomorrow, while petroleum exploration spending has recovered from its 25-year lows.

There were also stronger levels of mining investment in addition to tens of billions of dollars in projects under development that will help support investment spending in the coming years, and ultimately sustain, and potentially expand, production in the near future.

Exploration

Minerals exploration expenditure in Western Australia reached a new single calendar- or financial-year high of \$2.5 billion in 2021–22.

This result reflected strong levels of spending on exploration targeting gold (a new single year record of \$1.1 billion), copper (\$255 million), and other minerals including lithium and REE. This reflects the move to green energy and transportation (also a new single year record of \$223 million), as well as growth in iron ore (to \$592 million), with renewed interest in magnetite deposits perhaps due to interest in its green steel potential, and nickel–cobalt (to \$241 million) exploration expenditure to the highest levels in nearly a decade.

These commodities also represented the main targets of mineral exploration: gold (45%), iron ore (24%), copper (10%), nickel–cobalt (10%) and other minerals (9%).

Most of the increased spending targeted brownfields areas or existing deposits with these areas attracting a new high of \$1.7 billion in expenditure. In comparison, spending in greenfields locations or on new deposits stabilized.

As a result, the share of expenditure in greenfields locations, compared to brownfields areas, was down compared to recent years. This suggests that even in the aftermath of COVID-19 restrictions that included limits on regional travel during 2020–21, exploration on existing deposits remains preferred over exploration targeting new deposits. It was also in keeping with an increase in exploration on mature ground for commodities which had not previously been targeted. Brownfields exploration is lower cost than greenfields exploration, and this preference is perhaps being reinforced by cost inflation.

Western Australia remained the leading destination for exploration investment in the country, accounting for 64% of the national spend. This is around the level it has been for several years.

Petroleum exploration expenditure in Western Australia was valued at \$567 million in 2021–22 in keeping with improved market conditions for oil and gas. While this was an increase on recent years, it remained weak against historical levels.

Overview

A greater increase in petroleum exploration spending in Western Australia, compared to the rest of the country (an increase in expenditure in the Northern Territory was offset by a decline in expenditure in Queensland and Victoria), meant Western Australia's share of the national spend increased to 49%.

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

There were 23 new discoveries reported during the year, and a further eight discoveries of new mineralized zones at known deposits. Selected highlights by region are outlined below.

• Mid West

- Several discoveries were reported for the Manindi project:
 - » Drilling at the Brushtail prospect found new mineralization associated with mafic intrusive-hosted nickel, copper, cobalt and vanadium–titano–magnetite-bearing sulfides, similar to the mineralization style seen at the Gabanintha and Australian Vanadium projects.
 - » A significant zone of disseminated sulfides was intersected down-plunge of known mineralization at the Kultarr prospect.
 - » The identification of several lithium–caesium–tantalum-bearing pegmatites led to new lithium–rubidium discoveries at nearby Dibbler, Quoll and Foundation North.
- Drilling identified new zinc–lead–silver discoveries at the Tonka and Chinook prospects at the Earraheedy project. The Chinook–Tonka–Navajoh mineralization now occurs over a strike length of 18 km and is still open in all directions.
- Excellent drilling results were reported for several prospects in the Cue–Mooyagee project with the Mineral Resource Estimate updated to 12.3 Mt at 2.3 g/t Au for 927 000 ounces Au. This includes a maiden Mineral Resource Estimate at White Heat – Mosaic of 185 kt at 11.0 g/t Au for 65 000 ounces and Big Sky for 4.65 Mt at 1.2 g/t Au for 173 000 ounces.
- A Maiden JORC 2012 compliant Mineral Resource Estimate of 1.84 Mt at 21% Mn was announced for the Bryah Basin project covering the Area 74, Brumby Creek, Black Hill and Horseshoe prospects.
- The Mineral Resource Estimate for the Weld Range platinum group elements project was increased to 2.8 Moz contained 3E PGM with a 31% increase in contained copper to 104 000 t. High-grade, high-value rhodium and iridium mineralization was also discovered at Parks Reef.
- The maiden Mineral Resource for the Sabre prospect at the Fisher East was announced and comprises 1.8 Mt at 1.4% Ni for 24.5 Kt of contained nickel. The Mineral Resource Estimate for the Fisher East project, comprising the Camelwood, Cannonball and Musket prospects, was 4.2 Mt at 1.9% Ni.
- Massive to semimassive sulfides continued to be intersected at the Dusty project (discovered in 2020) in the Yandal Greenstone Belt. Assays include 7.2 m at 1.05% Ni and 0.26% Cu from 252 m including 0.7 m at 3.0% Ni, 0.23% Cu and 0.1% Co from 255.2 m and 1.6 m at 2.3% Ni, 0.36% Cu and 0.08% Co from 257.6 m.
- The Indicated Mineral Resource Estimate at the Yarrabubba iron–vanadium project increased to 36.6 Mt at 0.8% V_2O_5 , 38.1% Fe and 9.8% TiO_2 .
- For the Gabanintha project, an updated Ore Reserve was announced of 30.9 Mt grading at 1.09% V_2O_5 , including proved reserves of 10.5 Mt at 1.11% V_2O_5 and probable reserves of 20.4 Mt at 1.07% V_2O_5 . A 15% increase in the previously reported Mineral Resource within the deposit was also reported up to 36.0 Mt at 766 ppm nickel, 212 ppm copper and 231 ppm cobalt.

Overview

- **Goldfields**

- A Maiden Larkin Mineral Resource comprising Measured and Indicated 1.44 Mt at 2.6 g/t Au for 119 000 oz Au and Inferred 2.17 Mt at 2.3 g/t Au for 162 000 oz Au was released for the Kambalda gold project, increasing its Measured and Indicated Mineral Resource inventory to 2.71 Moz Au.
- New nickel prospects were discovered at the Kambalda project (Baker) and the Norseman project (Callisto). The potential of several nickel projects also increased, with new mineralized zones identified at Emu Lake project, a significant Mineral Resource increase at the Rosie nickel deposit (Duketon project) and Beta Hunt project, and a maiden Mineral Resource Estimate for Golden Swan (Black Swan project).
- New gold discoveries included Trevor Bore (Gwalia–Leonora project), Strauss (Paris project), and Thistle (Salmon Gums project).
- A potentially new style of mineralization for Western Australia was identified at Helios (Nullarbor copper–gold project). Significant hematite, magnetite, and pyrite alteration was intercepted that is commonly indicative of Iron Oxide Copper Gold (IOCG)-style deposits, potentially representing a major advance in the potential prospectivity of the Madura Province.
- Significant new mineralization was found below the existing Mt Weld pit with grades intersected of up to 13.67% REO over 23 m from 42 m below the current mine floor, confirming the presence of primary rare earth mineralization at depth.
- Three other projects in the Goldfields highlighted the area’s potential for rare earth mineralization. These projects are interesting in that the mineralization occurs in clays and regolith. This style of mineralization is the dominant REE mineralization style in several countries, including China, and may represent a new style of rare earth mineralization in Western Australia.
 - » At the Mt Stirling project, the discovery of the Ytria rare earth prospect in 2022 (containing HREE over a 1.1 km strike length), was followed by the discovery of yttrium at a second prospect known as Wishbone. Scandium and cobalt have also been identified.
 - » Re-assay of gold core at the Circle Valley project identified significant intervals of regolith clay-hosted REE mineralization with high-grade intersections that include 4 m at 1269 ppm total rare earth oxides (TREO).
 - » Drilling at the Cascade project, located 45 km to the southwest of Circle Valley, also assayed significant REE intervals including 7 m at 3826 ppm TREO.
- A maiden Ore Reserves Estimate of 237 Mt of magnetite ore was announced for the Lake Giles project.
- Several lithium projects announced new or updated Mineral Resource Estimates including:
 - » A Mineral Resource of 11.2 Mt at 1.21% Li₂O for the Dome North project.
 - » A maiden Inferred JORC Mineral Resource Estimate of 9.9 Mt at 1.14% Li₂O and 49 ppm Ta₂O₅ for the Manna project.
- New lithium–tantalum prospects were also identified at the Buldania project (Northwest prospect), the Mt Ida project (Sister Sam, Timoni and Sparrow), and the Mt Deans East project (with elevated tin, tantalum and caesium).

Overview

• Wheatbelt

- A maiden Mineral Resource Estimate was released for the Gonneville deposit, part of the Julimar project. The Indicated and Inferred, Mineral Resource Estimate is 330 Mt at 0.94 g/t 3E1, 0.16% Ni, 0.10% Cu, 0.016% Co (~0.58% NiEq2 or ~1.6g/t PdEq3), containing 10 Moz 3E, 530 kt Ni, 330 kt Cu, 53kt Co (~1.9 Mt NiEq or ~17 Moz PdEq). This represents the largest nickel sulfide discovery in Western Australia in over 20 years and the largest platinum group elements discovery in Australian history.
- A maiden Ore Reserves Estimate of 553 Mt at 0.25% Cu with 1.36 Mt contained copper was released for the Caravel project, confirming it as one of Australia's largest undeveloped copper deposits.
- A maiden JORC Mineral Resource Estimate of 135 Mt at 4% total heavy minerals (THM), including Indicated 88 Mt at 3.8% THM and Inferred 47 Mt at 4.5% THM was released for the Port Gregory project. This estimate includes 4.9 Mt contained garnet (90% garnet, 4% ilmenite, 1% rutile and 0.6% zircon).
- A maiden JORC Mineral Resource Estimate was released for the Boomerang prospect at the Airfield project, identifying 93.3 Mt of kaolinized granite (Indicated Mineral Resource of 15.2 Mt and an Inferred Mineral Resource of 78.1 Mt).
- Drilling at the Rio Prospect to follow up on historical drilling at the Split Rocks Lithium Project intersected thick pegmatites with anomalous lithium with the best result including 20 m at 1.0% Li₂O, including 10 m at 1.7% Li₂O.

• Gascoyne

- REE were discovered at the Mick Well project that included new styles of massive monazite mineralization, and kaolinite clays and weathered bedrock mineralization.
 - » Drilling at Mick Well intersected 12 m at 1.12% TREO with 0.21% Nd₂O₃ and Pr₆O₁₁ from 40 m including 4 m at 1.84% TREO, 0.34% Nd₂O₃ and Pr₆O₁₁ from 41 m.
 - » Clay-hosted ionic type REE in the regolith was discovered at the Tower prospect (Mt Clere project) with the highest assay results from the first batch of the reconnaissance aircore drilling including 15 m at 1395 ppm TREO, 12 m at 1130 ppm TREO, 10 m at 1251 ppm TREO.

• Pilbara

- High-grade silver continued to be intersected at the Elizabeth Hill project, with assays including 9.7 m at 8326 g per t silver (267 oz/t Ag), and 24.8 m at 829 g per t silver including 11.7 m at 1735 g per t silver (56 oz/t Ag) and 1.7 m at 19 865 g per t silver (639 oz/t Ag), and 8 m at 4233 g per t silver (149 oz/t Ag).
- An updated Mineral Resource substantially increased the size of the Havieron Mineral Resource and Ore Reserve to 5.5 M oz Au and 218 kt Cu or 6.5 M oz AuEq. Mineral Resources included 33 Mt at 3.28 g/t Au and 0.48% Cu (containing 3.5 M oz Au and 158 kt Cu or 4.2 M oz AuEq) in the South East Crescent Zone. Probable Ore Reserves now stand at 2.4 M oz Au and 109 kt Cu or 2.9 M oz AuEq.
- At the Winu deposit, the Mineral Resource Estimate also increased to 608 Mt at 0.40% Cu, 0.30 g/t Au or 0.49% CuEq.
- The Indicated Mineral Resource Estimate at the Flanagan Bore manganese project was upgraded to 104 Mt at 10.5% Mn containing 11 Mt of manganese at the FB3 (maiden resource) and LR1 deposits.
- The Mineral Resource Estimate for the Oakover project increased to 172 Mt at 9.9% Mn (7% Mn cut-off).

Overview

- An updated Nifty Copper Mineral Resource Estimate was released with a 208 000 t (28.4%) increase in the contained copper metal to 940 200 t. The total oxide Mineral Resource Estimate increased to 16.1 Mt at 0.9% Cu for 144 300 t of contained copper metal.
 - The Hemi Mineral Resource Estimate at the Mallina gold project increased to 213 Mt at 1.2 g/t Au for 8.5 Moz.
 - Alien Metals Ltd announced a maiden Mineral Resource Estimate of 10.4 Mt at 60.4% Fe for the Sirius Extension, Ridge E and Ridge C prospects at the Hancock Range project.
 - CZR Resources announced that the final assays from 2021 drilling at the Robe Mesa deposit in the Yarraloola project revealed extensive Direct Shipping Ore mineralization from surface outside earlier pit designs. At a 53% Fe cut-off (60% Fe calcined), the significant intercepts from the drilling, in the central to southern half of the Robe Mesa deposit averaged 55.6% Fe (62.3% Fe calcined), 6.3% SiO₂, 2.9% Al₂O₃ and 0.03% P.
- **Kimberley**
 - High-grade near-surface copper and silver results from drilling in Onedin Deposit at the Koongie Park project included 105.3 m at 1.94% copper, 0.76% zinc, 0.70% lead, 55 g/t silver and 106 ppm Mo.
 - Phosphate mineralization was discovered at Cummins Range project (Northern Phosphate Zone) with assay results of 71 m at 15% P₂O₅ from 71.5 m. This mineralization is separate from the rare earth mineralization at the project. This is the first time primary phosphate has been intersected at the project, which is considered a higher value fertilizer product.
 - **South West**
 - The Mineral Resource and Ore Reserve Estimates for the Greenbushes project were updated based on the first report of an estimate for the Kapanga deposit of 42.5 Mt at 1.8% Li₂O. At 31 December 2021, Greenbushes had a global Mineral Resource Estimate of 340.5 Mt at 1.6% Li₂O, with a remaining Ore Reserve of 168.1 Mt at 2.0% Li₂O.
 - **Great Southern**
 - A maiden Inferred Mineral Resource Estimate of 12.5 Mt of kaolinized granite, with an Al₂O₃ content of 36.6% and an ISO brightness of 84.8, was announced for the Tambellup project.

Investment

More than \$24 billion was invested in Western Australia's mining and petroleum sector in 2021–22. This result was largely driven by production-sustaining projects across the iron ore industry, as well as the Iron Bridge magnetite project.

This was its highest level for a single calendar or financial year since 2016, though it was still only half of the level observed during the mining investment boom between 2011 and 2015. The level of mining and petroleum investment in Western Australia has increased for the last 11 quarters after adjusting for seasonal variability.

Western Australia's share of national mining and petroleum investment was 59% due to higher levels of investment growth in Western Australia compared to the rest of the country. The State's share was slightly above its 10-year average of 56%.

The resources sector was a key contributor to growth in total new capital expenditure in Western Australia accounting for 72% of total investment spending, though its share remains well below the more than 80% it was during the mining investment boom.

There is also a strong pipeline of investment projects under development in Western Australia across a diverse range of commodities, including battery and critical minerals, that will help secure the State's position as a globally significant minerals and petroleum producer into the future.

Overview

Major iron ore production-sustaining projects including Gudai–Darri and Queens Valley as well as LNG backfill projects including Greater Western Flank Phase 3 (for the North West Shelf) and Julimar–Brunello Phase 2 (for Wheatstone) all entered production during the year, and will contribute to the State's minerals and petroleum output in the coming years.

Overall, as of September 2022, there were resource projects under development and committed valued at an estimated \$57 billion, up by almost \$5 billion from the March 2022 estimate. These include:

- Pluto LNG expansion and Scarborough gas
- Jansz-lo compression
- Crux gas
- Onslow iron ore
- Western Range iron ore
- Mt Holland lithium
- Eneabba REE refinery
- Mardie salt and potash
- Mt Weld REE mine expansion and Kalgoorlie cracking and leaching plant
- Super pit expansion
- Kathleen Valley lithium.

The estimated capital cost of medium- to longer-term projects at feasibility and prefeasibility stage was \$87 billion, up by \$3 billion from the March 2022 estimate.

Major projects at this stage included Browse gas, Clío-Acme gas, Dorado oil, the Pilbara hub iron ore, Western Ridge iron ore, Mallina gold, Caravel copper, Kalgoorlie nickel, expansion of the Kalgoorlie Consolidated Gold Mines mill, NiWest nickel, West Musgrave nickel–copper, the Australian vanadium project, and Yangibana REE.

Recurrent budget

For the 2021–22 financial year, GSWA continued some internal organizational changes associated with the new directorate, Geoscience Data Management (GDM). The following changes impacted both staffing levels and budget allocations. This is reflected in the appropriation of funds as shown in Table 1.

Table 1. GSWA budget and actual expenditure for the 2021–22 financial year

<i>Directorates and business areas</i>	<i>Salaries budget (\$000)</i>	<i>Non-salaries budget (\$000)</i>	<i>Salaries actual (\$000)</i>	<i>Non-salaries actual (\$000)</i>	<i>Total actual spend (\$000)</i>	<i>FTE (inc EIS)</i>	<i>FTE (ex EIS)</i>
Executive and Administrative Support**	1518	103	1311	125	1436	6.00	4.00
Minerals and Energy Resources	5522	803	5046	670	5716	49.91	47.91
Geoscience	4198	631	4288	746	5034	39.04	35.44
Geoscience Data Management	1324	1132	1240	1173	2413	14.00	13.00
Core Libraries and Field Support	1246	1154	1455	899	2354	19.40	19.40
Geoscience and Titles Information	3554	289	3151	315	3466	36.97	36.97
Resource Strategy	1485	140	1323	158	1481	13.00	13.00
GSWA totals	18847	4252	17814	4086	21900	178.32	169.72

** Excludes state batteries expenses and budget but includes hydraulic fracture stimulation (also known as fracking)

- The Geoscience and Titles Information branch moved all projects associated with data management to the newly established GDM branch, reducing its project load and budget.
- The State Geoscience Project area absorbed both the Geophysics Acquisition and Processing project and the 3D Geoscience project into one budget in 2021–22. David Martin was appointed manager of this project area. The area also includes the new Earth Imaging and Observation team.
- The HyLogger and the National Virtual Core Library (NVCL) project moved from Minerals and Petroleum Resources Directorate to the Geoscience Directorate in early July 2021.
- A new project area, New Energy Systems, was created within the Minerals and Energy Resource Directorate.
- The Geoscience Data Transformation Strategy project commenced in 2021–22 with a small injection of funding from the Digital Capability Fund. The total funding allocated is \$10.6 million over a four-year period. Deavi Purnomo, as general manager of the GDM, will manage this project.
- The final payment of \$1.6 million supported the purchase and installation of the CAMECA Ion Microprobe at Curtin University. This was part of the COVID Recovery additional State funding.

The total budget for GSWA was \$37.556 million (excluding departmentally funded projects). This can be separated into \$12.5 million towards the EIS (inclusive of EIS-funded salaries), \$1.6 million for the CAMECA instrument, with the remaining \$23.456 million going to GSWA overall. The total expenditure against this was \$37.487 million overall (salary and non-salary inclusive).

Figures 1 and 2 illustrate GSWA directorates' salary and non-salary budgets vs actual expenses in 2021–22, respectively.

All reference to the EIS budget and expenses are discussed in a later section (see **Exploration Incentive Scheme – overview**).

Recurrent budget

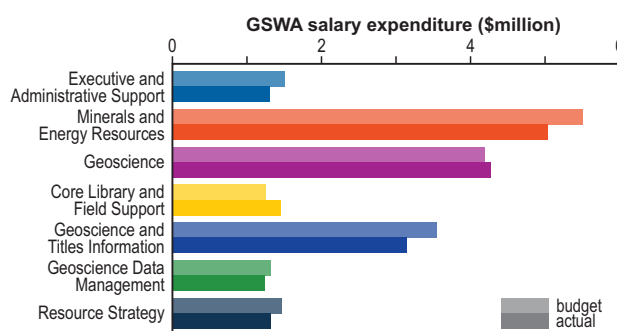


Figure 1. GSWA salary expenditure for the 2021–22 financial year

Staffing

In July 2021, Paul Duncan was appointed general manager, Geoscience and Titles Information branch. There were 20 new appointments for the division in 2021–22.

The total number of public sector staff employed by GSWA at the end of the financial year was 182 people (equivalent to 178.3 full-time equivalents [FTE]) with a revised recurrent salary budget allocation of \$18.847 million. This does not include the four Mining Rehabilitation Funded (MRF) positions, funded through the MRF program. The full FTE breakdown per directorate can be seen in Table 1. As part of the staff and FTE equivalent total, there was an increase in EIS-funded positions from eight FTE to nine FTE with the addition of the new Senior Liaison Officer, Land Access and Aboriginal Engagement. With the inclusion of the nine EIS-funded positions, the total salary budget was \$19.923 million (182 people at 178.3 FTE).

GSWA (excluding EIS) was within the overall budget allocation with a reduction in salary expenses and within the acceptable variance (4%) for non-salary expenses.

At the end of the financial year, GSWA employed a maximum of 17 fee-for-service (FFS) contractors at any one time, for short-term and finite projects.

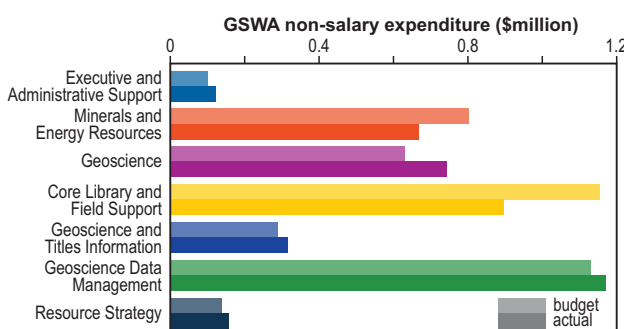


Figure 2. GSWA non-salary expenditure for the 2021–22 financial year

Recurrent budget

Collaborative projects

Forty-four collaborative projects were commenced or ongoing in 2021–22 with a total of six completed in the financial year, inclusive of all data and reports. Further details are provided in Appendix 1.

Products

As reported in the Geological Survey work program 2021–22, GSWA forecast the publication of the following:

- 5 maps
- 3 data packages
- 7 digital layers
- 13 online data releases
- 44 text publications (not including posters/flyers).

The final count for these categories on 30 June 2021 was:

- 5 maps
- 4 data packages
- 11 digital layers
- 4 online data releases
- 35 text publications (not including posters/flyers).

GSWA has moved away from Geological Series maps to digital seamless layers delivered via data packages. This is reflected in the reduced number of maps released, and the addition of the new measure to count digital layers as shown in the Appendices. GSWA published a total of 40 posters in eBookshop and presented 29 at conferences, GSWA Open Day and other events throughout the year. With the COVID restrictions lessening throughout the 2021–22 financial year, there was an increase in attendance for GSWA events, and intrastate conference attendance for staff. International and interstate attendance was still restricted for this financial 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 2021–22.

Program review

GS10 Energy Geoscience and Carbon Strategy

Manager: Deidre Brooks

Objectives

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

Currently, the branch's focus areas are the Canning, Carnarvon and Perth Basins. These basins have proven petroleum systems and are underexplored, particularly the vast Canning and Officer Basins. The branch contributed to geological mapping and new reviews of the Western Australian portion of the Centralian Superbasin, including the Amadeus and Officer Basins, and interpreted results to better understand the energy potential of these older basins (Fig. 3).



Figure 3. Taking soil gas measurements near Harvey 2 wellsite to detect natural hydrogen and other gases

Initially part of the 2020–21 AGP, work continued on developing new data layers and capturing new information for the Energy Systems Atlas within WAPIMS. The focus was twofold:

1. Creating the Energy Systems Atlas map layer under the heading 'Reservoir' to display measured core porosity and permeability
2. Developing new data fields and capture of a variety of temperature and thermal conductivity data, to be added as a map layer in 2022–23.

Program review

Highlights and activities

- Investigated the potential for natural hydrogen and helium in the sedimentary basins of Western Australia. This is a new field of research for the branch. In 2021–22, work on this project included a compilation of all petroleum wells that reported hydrogen and helium shows. Soil gas measurements at selected field sites were undertaken with both a handheld detector and an autonomous monitoring device. Finally, Fluid Inclusion Stratigraphy (FIS) on samples from the vintage petroleum exploration well Meda 1 in the Canning Basin confirmed the presence of significant hydrogen and helium in fluid inclusions in the lower part of the well
- Continued to develop the Report on the petroleum source rocks of Western Australia and associated compilation of petroleum geochemistry data. The Report was not released due to competing project priorities
- Released Report 230 on the hydrocarbon source rock potential of the Permian in the Carnarvon Basin
- Interpreted new geophysical AEM data with results incorporated into a Report covering the Canning and Ord Basins for release next financial year
- Continued geophysical interpretation and mapping of the southern Canning Basin. Seismic interpretation of the Kidson Sub-basin, Ryan Shelf and Crossland Platform will be the final area covered by this project. The latest interpretation uses the results from the Barnicarndy 1 stratigraphic well drilled in 2019, the EIS and Geoscience Australia's (GA) Exploring for the Future (EFTF) co-funded Kidson Sub-basin seismic survey and the reprocessed vintage 2D seismic lines (both were completed in the 2018–19 financial year)
- Released Report 222 – a review of the geology of the Cobb Embayment, on the eastern margin of the Canning Basin
- Work progressed on the WA unearthed book on the Mesozoic of Western Australia (in collaboration with Curtin University).

Products released

- Report 222 The Cobb Embayment: Ordovician syntectonic siliciclastic deposition on the eastern margin of the Canning Basin, Western Australia
- Report 230 Source rock potential of Permian rocks in the Southern and Northern Carnarvon Basins
- New pre-competitive sample analyses released in 2021–22 is listed below:
 - » Samples from the Carnarvon Basin were analysed for organic petrography (31 samples), organic geochemistry of Total Organic Carbon (TOC), Rock-Eval and HAWK pyrolysis (18 samples) and results published in GSWA Report 230
- External publication – see Appendix 4

Program review

GS12 Land Use Planning

Manager: Samantha Carter

Objectives

The Land Use Planning branch helps shape and inform land use planning policy and outcomes by providing advice based on geoscience, resource mapping and prospectivity assessments. The branch collaborates with other government departments such as the Departments of Planning, Lands and Heritage; Premier and Cabinet; Biodiversity, Conservation and Attractions; and Jobs, Tourism, Science and Innovation, as well as Local Government Authorities (LGA) to assist with land use decisions and managing impacts arising from land use/tenure changes.

The branch aims to maintain access for exploration and development of the State's mineral, basic raw material, petroleum and geothermal energy resources while assisting with the delivery of State land use objectives. Input is also provided into strategic and statutory planning matters, including policy advice on resources. Early engagement regarding proposed land use/tenure change ensures informed decision making and provides opportunities to optimize land use planning by identifying mutually beneficial, long-term outcomes for the proponent, the State Government and the Western Australian community.

The branch also provides geoscientific and administrative advice on Mining Act assessments related to mineral resources, mineral prospectivity and reported mineral exploration and mining activities.

Highlights and activities

- Proposals for land subdivisions and other land use changes are routinely received from State and LGA. Each proposal is examined, its implications for access to mineral and energy resources assessed, and recommendations, advice and approvals made accordingly
- A significant volume of assessments, recommendations and approvals was carried out to support the land component for various Native Title Settlement Agreements including the South West Native Title Settlement, the Wiltingin Determination Area Indigenous Land Use Agreement (ILUA) and the Tjiwarl ILUA
- 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 in early 2020. Additional areas have been proposed during the course of the ILUA negotiations with various native title holders. The branch has played a key role in consultation with the resources industry, prospectivity assessment and input into this whole-of-government project
- High-level advice was provided to the State Government on the Land and Public Works Legislation Amendment Bill 2022, which allows for more flexible use of Crown land. This will include opportunities for pastoralists, native title parties and others to be involved in the growing renewables market, which includes carbon farming, hydrogen and wind/solar power. Advice is being provided on competing interests in land use to ensure informed decision making by Government, and involves balancing conflicting land tenure/uses and managing potential unintended consequences.

Product released

- Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia – 2022 (map)

Program review

GS14 Mines and Mineral Deposit Information

Manager: Nicole Wyche

Objectives

The Mines and Mineral Deposit Information 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 the Department of Mines, Industry Regulation and Safety (DMIRS) to provide specialist technical advice on commodities to internal and external stakeholders via the Mines and Mineral Deposits business system (MINEDEX), and to produce industry-focused publications. The MINEDEX application also provides data services critical to the function of other DMIRS business systems including the Environmental Assessment and Regulatory System (EARS), Safety Regulation System (SRS) and Royalties Management System (RMS).

Highlights and activities

- Each month, MINEDEX is visited by around 1200 individual users. Usage is spread over 3000 sessions and 65 000 individual page views. Over 50% of users are new users
- MINEDEX downloads, including Major Resource Projects and Operating Mines maps, are among the top 10 products downloaded from GSWA annually
- This year, three reports for working with Mineral Resource and Ore Reserve data were released, accompanied by two spatial layers. These products provide estimate data totalled by estimate category (Mineral Resource or Ore Reserve) and status (Proven, Probable, Measured, Indicated or Inferred) and reporting code compliance. They are updated daily (Figures 4 and 5).

Products released

- Mines – operating and under development, Western Australia – 2022 (map)
- Atlas of mineral deposits and major petroleum projects 2021 (poster)
- Atlas of mineral deposits and major petroleum projects 2021 (book)
- Major resource projects, Western Australia 2021 (map)
- Exploration and mining highlights (Hotspots) September 2021 and February 2022 (poster)
- Kimberley mineral resources and petroleum projects – 2022 (map)
- Flyers in the Commodity Summary series (which provide a summary of resource amounts and distribution, and project development highlights): gold, titanium–zircon, aluminium, nickel–cobalt, lithium, vanadium, manganese, rare earth elements, graphite, copper, zinc, lead, potash, antimony, tungsten, chromium, phosphate, diamond, garnet
- Spatial layer Resource Estimates by Project
- Spatial layer Resource Estimates by Project (Gold)

Program review

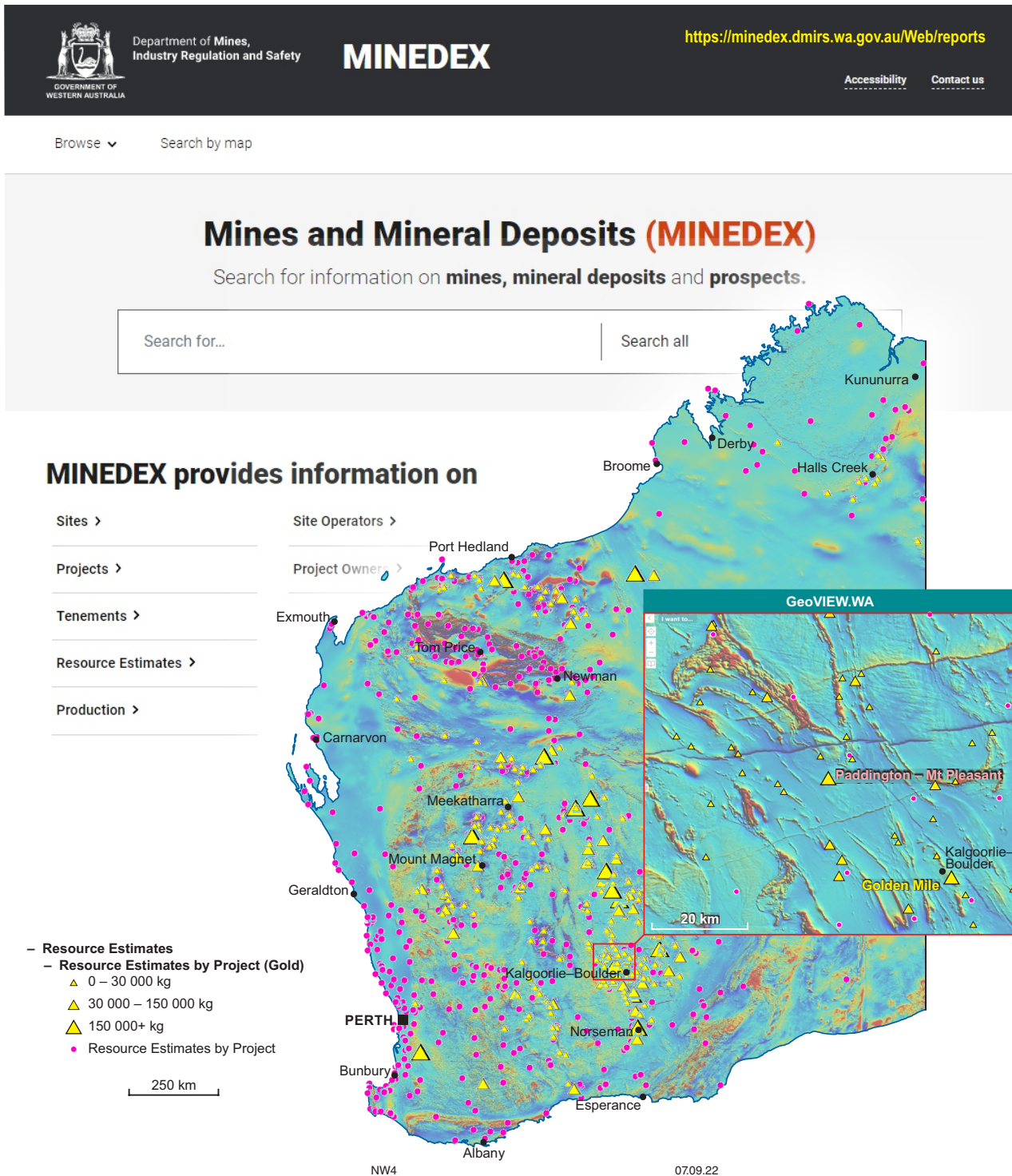



Figure 4. MINEDEX spatial layers for resource estimates: Resource Estimates by Project and Resource Estimates by Project – Gold are updated daily and show the distribution of Mineral Resource and Ore Reserve data throughout Western Australia

Program review



Government of Western Australia

Department of Mines, Industry Regulation and Safety

WESTERN AUSTRALIAN MINERAL RESOURCE AND ORE RESERVE ESTIMATE TOTALS BY PROJECT

MINEDEX

MINEDEX - REP01


Table 1 – Total Mineral Resources and Ore Reserves for Western Australia by Commodity and Project

This table shows the total mineral resources and ore reserves for each MINEDEX Project.

Totals may include estimates that are not compliant with industry standard reporting codes.

Total mineral resources and total ore reserves must not be combined.

Project		Mineral Resources				Ore Reserves			
Project Code	Project Name	Ore Quantity (million tonnes)	Average Grade (gram/tonne)	Contained Commodity (kilogram)	Commodity	Ore Quantity (million tonnes)	Average Grade (gram/tonne)	Contained Commodity (kilogram)	Commodity
J00102	Golden Mile	545.97	1.56	850,453.80	Gold	280.85	1.28	359,820.70	Gold
J02786	Mallina Gold	225.05	1.24	279,148.20	Gold	0.00	0.00	0.00	Gold
J04673	Gruyere								
J00134	Granny Smith								



Government of Western Australia

Department of Mines, Industry Regulation and Safety

WESTERN AUSTRALIAN MINERAL RESOURCE AND ORE RESERVE ESTIMATE TOTALS BY PROJECT

MINEDEX

MINEDEX - REP01

J02419Thunderbox

J00186Tarmoola - K

J02241Carosue Dam

J00292Paddington

J00226Marvel Loch

J01703Sunrise Dam

J00156Mt Magnet

Table 1 – Total Mineral Resources and Ore Reserves for Western Australia by Commodity and Project

This table shows the total mineral resources and ore reserves for each MINEDEX Project.

Totals may include estimates that are not compliant with industry standard reporting codes.

Total mineral resources and total ore reserves must not be combined.

Project		Mineral Resources				Ore Reserves			
Project Code	Project Name	Ore Quantity (million tonnes)	Average Grade (gram/tonne)	Contained Commodity (kilogram)	Commodity	Ore Quantity (million tonnes)	Average Grade (gram/tonne)	Contained Commodity (kilogram)	Commodity
J00102	Golden Mile	545.97	1.56	850,453.80	Gold	280.85	1.28	359,820.70	Gold

This table comprises 1 row(s).

Table 2 – Total Mineral Resources and Ore Reserves for Western Australia by Commodity, Project and Estimation Category

Project Code	Project Name	Commodity							
J00102	Golden Mile / KCGM	Gold							

(C) Total Compliant and Unclassified

	Ore Quantity (million tonnes)	Average Grade (gram/tonne)	Contained Commodity (kilogram)	Estimate Date	Reporting Code(s)
Measured mineral resources (Compliant + Unclassified) ¹	122.98	0.70	86,083.20	31/03/2022	JORC2012
Indicated mineral resources (Compliant + Unclassified) ²	268.95	1.87	503,877.00	Multiple	JORC2012
Inferred mineral resources (Compliant + Unclassified) ³	154.05	1.69	260,493.60	Multiple	JORC2012
Proven ore reserves exclusive of mineral resources (Compliant + Unclassified) ⁴	0.00	0.00	0.00		
Probable ore reserves exclusive of mineral resources (Compliant + Unclassified) ⁵	0.00	0.00	0.00		
Proven ore reserves as inclusive subset of mineral resources (Compliant + Unclassified) ⁶	122.98	0.70	86,083.20	31/03/2022	JORC2012
Probable ore reserves as inclusive subset of mineral resources (Compliant + Unclassified) ⁷	157.87	1.73	273,737.50	Multiple	JORC2012
Are there Supplementary estimates for this Project?	No				

This table comprises 1 Project(s).

Figure 5. MINEDEX reports for resource estimate data show estimates for each mining project in summary and provide detailed data by estimate category, estimate status, and reporting code compliance. Example tables from MINEDEX report Western Australian Resource Estimates by Project

Program review

GS20 Mineral Systems Studies

Manager: Warren Ormsby

Objectives

The Minerals Exploration Geoscience branch focuses on providing information to assist and encourage mineral exploration in Western Australia. A major part of this role involves studying mineral systems on both an empirical and genetic basis and providing timely relevant information to the mineral exploration industry. The work in this area is complemented by projects funded by the EIS (see ES43 Mineral Systems).

Information is disseminated via the online Mineral Systems Atlas and associated Guide, the Data and Software Centre, Geological Information Series packages, internal and external publications, and presentations to the minerals industry. The Atlas currently contains GIS-based map layers of significant geological 'proxies' for critical metallogenic processes, for the komatiite-hosted nickel, banded iron-formation (BIF)-hosted iron, rare-element pegmatite and mafic intrusion-hosted vanadium mineral systems.

The branch underwent some staffing and structural changes during the year, with the branch management transferred to Warren Ormsby. A new position for a Mineral Investment Specialist to assist with the resource investment role (see GS85 Resources Investment Information) was filled in January 2022. In turn, staff and responsibilities associated with the HyLogger and gold fingerprinting functions were transferred to the Geochronology and Geochemistry branch. Another staff member transferred to the Land Use Planning branch and a new staff member commenced in November 2021.

Highlights and activities

Work advanced on two new mineral systems (potash and manganese) with associated documentation for inclusion in the Mineral Systems Atlas. This included the publication of seven primary GIS layers in the Mineral Systems Atlas. These primary data layers provide the source data for many of the derived hydrology and geochemistry layers that will be added in 2022–23. All new primary data and associated documentation were also published and made available for downloading from the Data and Software Centre. Documentation for both new mineral systems will be published as Records and Guides in 2022–23.

Documentation for the existing iron-formations mineral system was completed and published. In addition, documentation for the komatiite-hosted nickel mineral system was well advanced and will be published in 2022–23. Work commenced on the mafic intrusion-hosted nickel–copper–platinum group element system. Upgrades were also made to the content, structure and functionality of the Mineral Systems Atlas as part of ongoing improvements. This included the addition of the mining tenements layer to further help users with locating areas of interest.

The laboratory work was completed for the study of fluid inclusions from the John Galt hydrothermal vein- and breccia-hosted REE deposit. A Report is pending.

Reports were published on the nickel prospectivity in the Collurabbie region of the northeastern Yilgarn Craton and the Obelisk Cu–Au mineralization in the Paterson Orogen.

A new EIS-funded project (see ES43) commenced in December: MRIWA project M10433 – Detection of distal footprints in the Southwest Yilgarn: Linking basement and cover (partners: MRIWA, CSIRO, resource companies). This study is re-evaluating the gold prospectivity of the South West Yilgarn through the application of recent advances in geochemical technologies, targeting chemical and isotopic anomalies in cover rocks that have been proven to provide vectors to mineralization in the more thoroughly explored central and eastern terranes of the Yilgarn. This project involved close collaboration with staff from the CSIRO and other branches of GSWA. Significant work associated with M10433 took place throughout 2021–22 (see ES43 for details).

Program review

Building upon work from the AGP, further GIS-based studies on mapping mineralization trends from industry drillhole and soil geochemical data for selected critical minerals were carried out. This included the further development and testing of novel software created through Curtin University for plotting of mineralization trends from gridded geochemical data. This ongoing work is aimed at helping to identify craton-scale controls on mineralization.

Completion of work for the AGP included contributing to the Western Australian State geoscientific imagery and data, 2021 data package that was released in November 2021. This included the release of bedrock and alluvial gold working data and imagery derived from the inventory of abandoned mine features.

Products released

- Report 223 Alteration and Cu–Au mineralization at the Obelisk prospect, Paterson Orogen, Western Australia
- Record 2021/10 Iron-formations: a minerals systems analysis
- Record 2022/2 Geology and mineralization potential of the Gerry Well greenstone belt (Collurabbie region), northeastern Yilgarn Craton

Program review

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Jyotindra Sapkota

Objectives

The Eastern Goldfields Superterrane (EGST) occupies the eastern third of the Archean Yilgarn Craton and is widely considered a typical upper crustal granite–greenstone terrane. This highly mineralized region contains world-class gold and nickel deposits, and significant deposits of other commodities including base metals, REE, uranium, gemstones and industrial minerals. The present terrane configuration of the EGST is traditionally interpreted to reflect accretion of a number of pre-existing ‘continents’ in a series of collisional events between c. 2800 and 2650 Ma.

However, local abundance of komatiites and associated thick basaltic successions, and the identification of a basement succession broadly similar in age to regions of the western Yilgarn Craton suggests that subsequent closure following the c. 2.7 Ga mantle plume-fed rifting of an autochthonous basement may represent an alternative geodynamic model. An understanding of the tectonic evolution of the Eastern Goldfields, including the structure and stratigraphy, is essential to the understanding of the controls on formation and distribution of mineralization in the region (Fig. 6).

Highlights and activities

- Geological reinterpretation of the volume imaged by the 2019 Ora Banda – Kambalda high-resolution seismic survey
- Field traverses and geochemical, geochronological and isotopic sampling of the granite–greenstone belt across the Kalgoorlie Terrane
- Geochemical sampling of diamond drillholes (GSWA and company core libraries) from well-established stratigraphies in support of the Greenstone Stratigraphic Geochemical Barcoding project
- Petrophysical analysis of diamond drillcore samples was undertaken for Induced Polarization Galvanic Resistivity, Inductive Conductivity, Magnetic Susceptibility, Remnant Magnetization, Dry Bulk Density, Apparent Porosity and P-wave Sonic Velocity. Terra Petrophysics Pty Ltd has submitted the petrophysical data and Report to GSWA
- Explanatory notes drafted for stratigraphic units covering the Broad Arrow, Vettors and Higginsville Subgroups of the Kalgoorlie Group.

Product released

- East Yilgarn, 2022 GIS data package

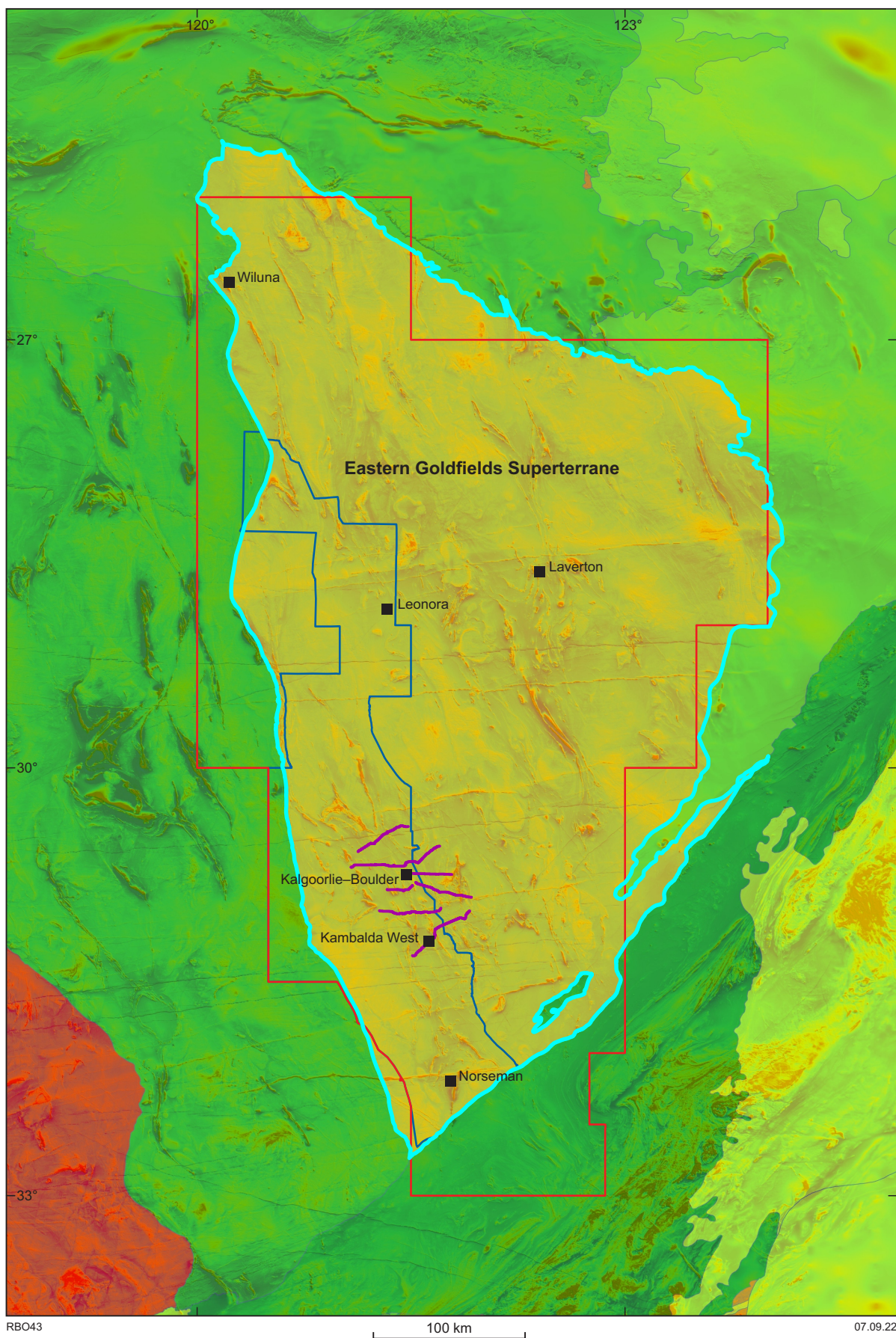


Figure 6. Eastern Goldfields Superterrane highlighted in light blue. The red and blue polygons outline the GS52 project area and the 1:100 000 IBG coverage. The purple lines represent the GSWA 2019 high-resolution seismic survey lines

Program review

GS53 State Geoscience

Manager: David Martin

Objectives

The State Geoscience branch is responsible for maintaining and communicating a coherent geoscience framework for Western Australia via GSWA databases, the GSWA website and social media, statewide layers on GeoVIEW.WA, published Reports, the State geological map, and the collection of statewide geophysical datasets. The branch incorporates four sections:

- ENS and State Maps – responsible for statewide databases, geological content on the GSWA intranet and internet sites, and the compilation of statewide layers on GeoVIEW.WA
- Paleontology and Geoheritage – provides and coordinates paleontology services across GSWA and manages all aspects of the State's geoheritage
- Geophysics Acquisition and Processing – plans and manages regional geophysical data acquisition projects, prepares datasets for delivery to the public and internal users, and provides internal processing and interpretation services, and advice as required. The section also manages the geophysical survey index and data repository (MAGIX), and the submission, archiving and release of airborne and some ground survey datasets submitted by the exploration industry. Activities related to reflection seismic data acquisition are listed under ES71
- Earth Imaging and Observation – geophysical imaging of the crust and lithosphere using various geophysical methods such as seismology, potential field geophysics and integration with geology. Activities and products are listed under ES31, ES39 and ES42.

Highlights and activities

- Population of WAGIMS, the **W**estern **A**ustralia **G**eochronology, **I**sotope, **M**etamorphic history and mineral chemistry **S**ystem), commenced. WAGIMS centralizes storage of all data files related to these subjects and offers the ability to interrogate data at a granular level
- The branch has been actively involved in many working groups related to the Data Transformation Program and will continue to make a significant ongoing contribution to this work for the duration of the program
- The GIMENS (**G**eochronology, **I**sotope, **M**etamorphic history and mineral chemistry **E**xplanatory **N**otes **S**ystem, module for the digital compilation and online delivery of Geochronology Records from data held in WAGIMS is now in the testing phase of development, and work has continued on the population of ENS entries
- Continued to work on search and functionality issues in GSWA product delivery systems
- WAROX text data was released as searchable layers on GeoVIEW.WA to assist text-mining of this rich data source
- Release of a revised 1:100 000 interpreted bedrock geology layer on GeoVIEW.WA
- Publication of a GSWA Record detailing the geological significance of the State's major crustal boundaries, and background to the compilation methods used for the associated map and 3D model (Fig. 7)
- GSWA webinar on detrital zircon constraints on the timing of assembly of Proterozoic Australia
- Biostratigraphic studies continued on Barnicarndy 1, with the external publication of conodont systematics, continued work on trilobite systematic studies, and contributions to the upcoming interpreted well completion report and digital core atlas

Program review

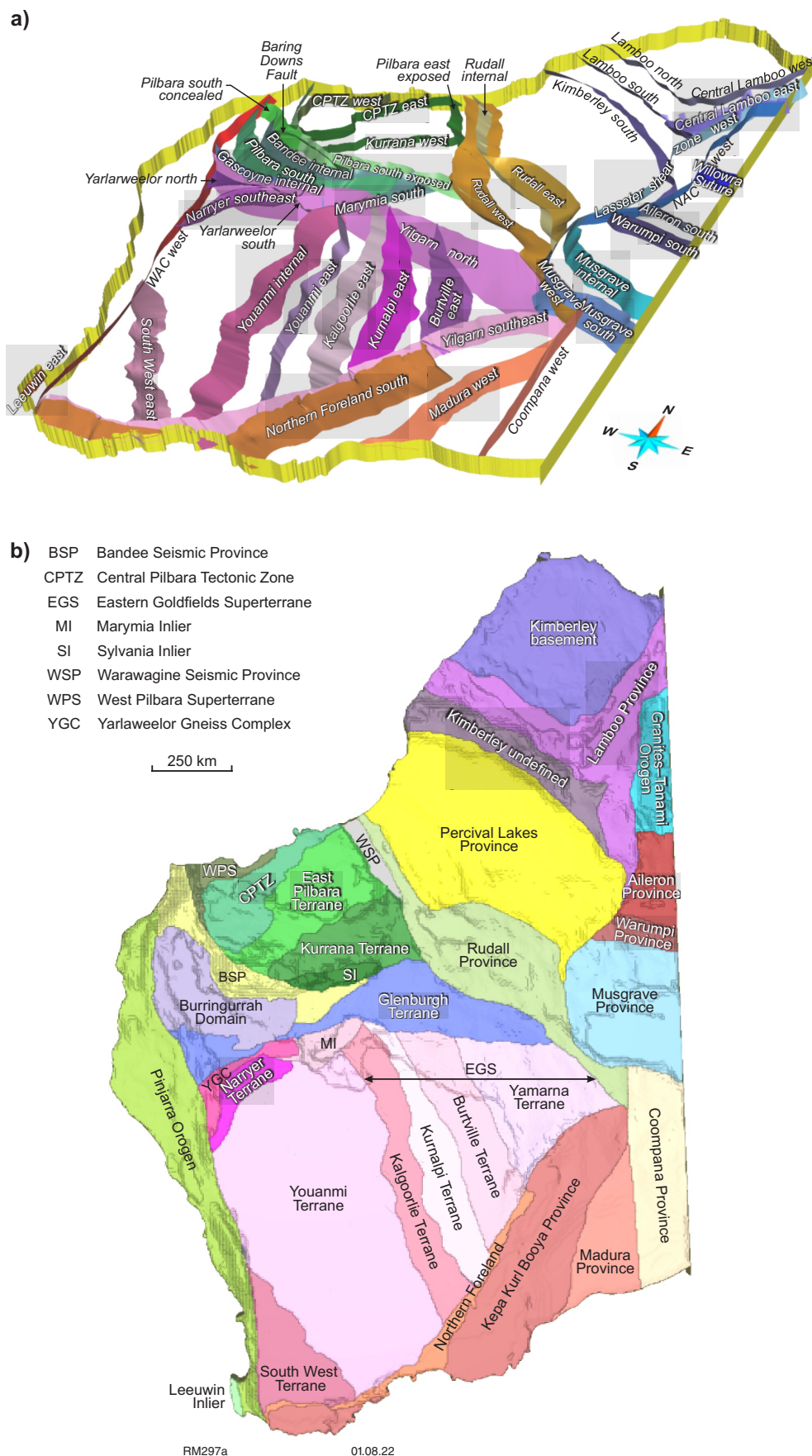


Figure 7. Major crustal architecture of Western Australia; a) 3D model of major crustal boundaries; b) map of major upper-crustal blocks

Program review

- Extensive Geoheritage and Geotourism advocacy, including provision of advice and assessments of mining proposals, assessments of Geoheritage Reserve access applications, Geoheritage Site and Reserve condition check visits, support of Murchison GeoRegion development, and continued work on a GSWA Record detailing the nomination process for new Geoheritage sites
- Public and educational outreach, including public talks to natural history interest groups, presentations at paleontology conferences, a number of curriculum-linked primary and high school talks. GSWA's booth at the inaugural Perth Gem and Mineral show was a great success
- Regional survey data acquisition activities are reported under the EIS programs ES30 Airborne and Ground Geophysical Surveys
- In the first full year of the availability of the new online platform for direct survey registration and data submission by external users into the MAGIX geophysical data repository (<https://magix.dmirns.wa.gov.au>), 143 new company airborne survey datasets containing 534 000 line-km of data were received for inclusion in the repository. At 30 June 2022, the repository contained some 14.7 million line-km of company data from 2990 surveys. Open-file datasets are available for download via the MAGIX platform and the GeoVIEW.WA online system.

Products released

- About 150 completed ENS units published, mainly from the Pilbara and Yilgarn Cratons
- Record 2022/7 Compilation and geological implications of the major crustal boundaries map and 3D model of Western Australia
- 1:100 000 digital geology layers on GeoVIEW.WA
- WAROX Site Notes layer on GeoVIEW.WA
- WAROX Lithology Notes layer on GeoVIEW.WA
- Radiometric anomaly grids (80 m) of Western Australia (2021 – version 1) and associated products
- 32 Paleontology Reports publishing historical and recent biostratigraphic consultancy work commissioned by GSWA
- External publications – see Appendix 4

Program review

GS54 Geochronology and Geochemistry

Manager: Michael Wingate

Objectives

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

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

The new CAMECA 1300 HR³ ion microprobe (Fig. 8), funded by AuScope and by the Western Australian Government through DMIRS, has been installed and is undergoing set-up and testing at the John de Laeter Centre. This state-of-the-art instrument is the replacement for the recently decommissioned SHRIMP A ion probe, which provided a huge amount of data over more than 25 years. The new CAMECA will work alongside SHRIMP B, and will provide a huge range of complementary techniques.

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

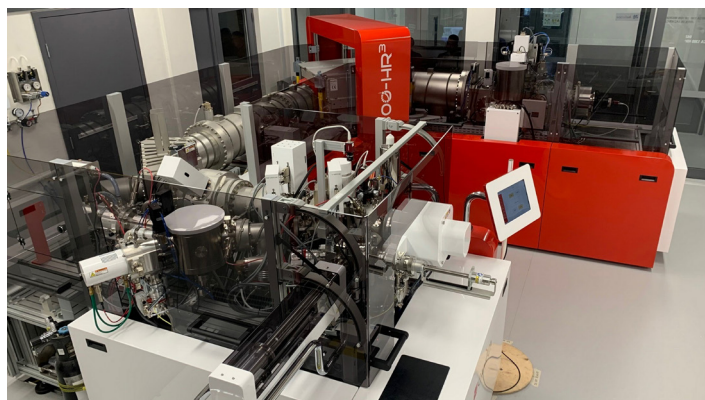


Figure 8. Installation of the CAMECA 1300 HR³ in the John de Laeter Centre at Curtin University commenced in 2022. This next-generation ion microprobe replaces the SHRIMP-A ion microprobe, which was decommissioned early in 2022. The SHRIMP revolutionized geochronology in Western Australia during its 25-year operational life. NCRIS AuScope and the Western Australian government, through DMIRS, jointly funded the new state-of-the-art CAMECA instrument. This instrument will enable significant advances in our understanding of Western Australian geology

Program review

GS58 West Yilgarn

Manager: Raphael Quentin de Gromard

Objectives

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

This project formerly incorporated only the Youanmi Terrane but was expanded to include the South West Terrane and the Narryer Terrane, primarily as a result of work and interpretations that emerged from the 2020–21 southwest Yilgarn Accelerated Geoscience Program (AGP) (Fig. 9).

Highlights and activities

- Substantial data collation and new data collection, interpretation and compilation in the southwest Yilgarn as a result of the southwest Yilgarn AGP has been merged into GIS layers covering the entire west Yilgarn
- Digital interpreted bedrock geology (IBG) maps were released on the West Yilgarn GIS 2022 data package, which included updated stratigraphy, suites and structures at 1:100 000 and 1:500 000 scale
- Mapping and sampling in the Youanmi, South West and Narryer Terranes continued. This included a two-week program in the Narryer Terrane that resulted in 35 new samples for geochronology and 140 new samples for geochemistry
- Ongoing, targeted geochemical sampling of stratigraphic intervals through greenstones across the west Yilgarn established that the rationale of the Eastern Goldfields Geochemical Barcoding Project can be applied here
- Sampling for geochronology and geochemistry of greenstone belts in the western Youanmi Terrane investigated the extent and nature of exposed c. 2950 Ma crust
- Cooperative projects continued involving geochemistry, metamorphic and structural studies in the South West, Youanmi and Narryer Terranes.

Products released

- West Yilgarn 2022 Geological Information Series (GIS) data package including the pre-Mesozoic IBG of the southwest Yilgarn
- Murchison Supergroup and granitic suites update in ENS

Program review

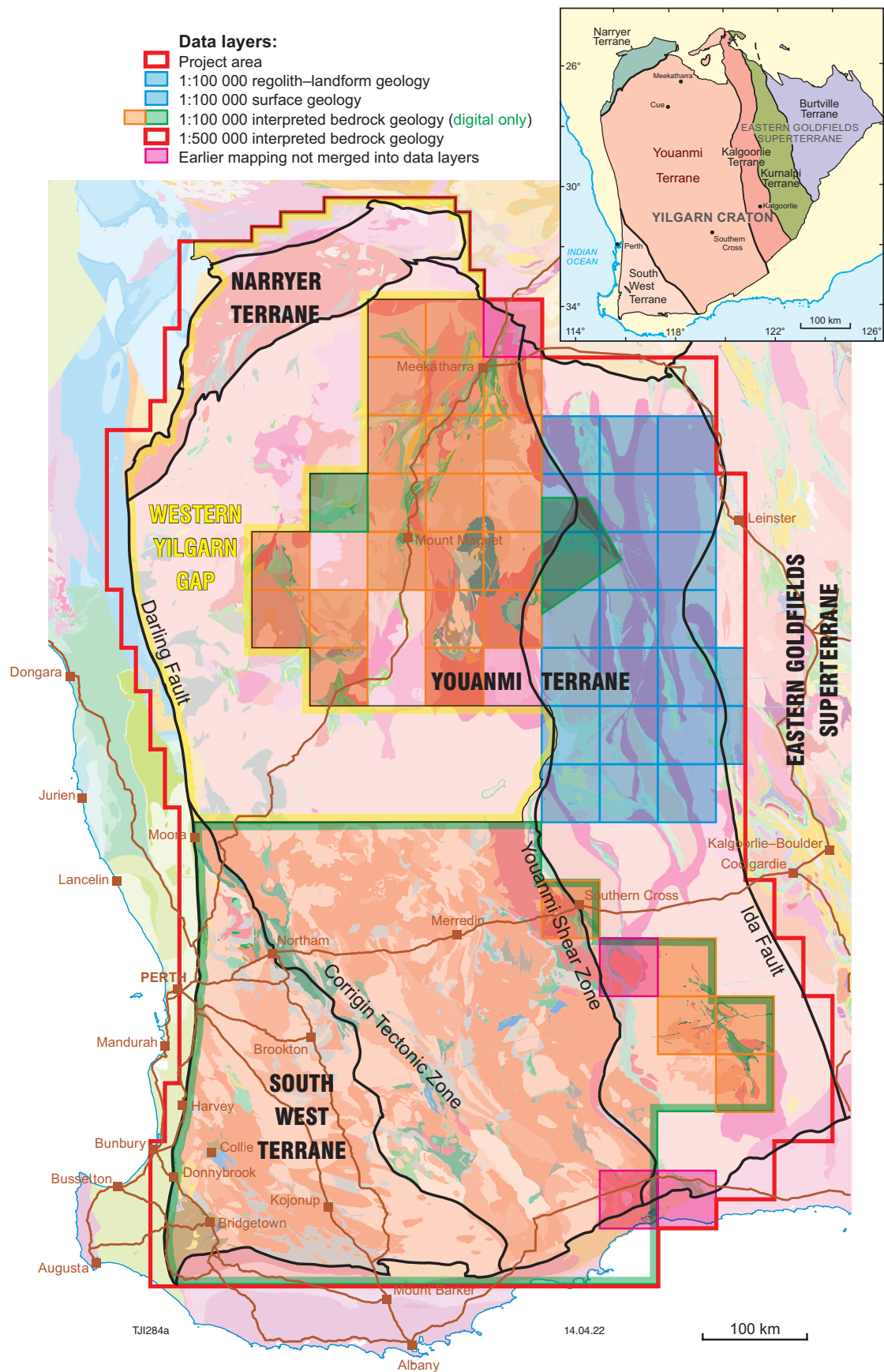


Figure 9. Simplified interpreted bedrock geology map highlighting the extent and mapping progress of the GS58 West Yilgarn project area

Program review

GS63 Pilbara and Hamersley

Manager: Heather Howard

Objectives

The 2775–2630 Ma volcano-sedimentary Fortescue Group and the conformably overlying 2630–2445 Ma Hamersley Group belong to the Mount Bruce Supergroup, which unconformably overlies the granite–greenstones of the Pilbara Craton in Western Australia. Not only does this supergroup incorporate the world's best-preserved sequence of Archean ultramafic to felsic volcanic deposits and, arguably, the world's most continuous transect across the Archean–Proterozoic boundary, it remains the most economically important stratigraphic unit on the Australian continent (Fig. 10).

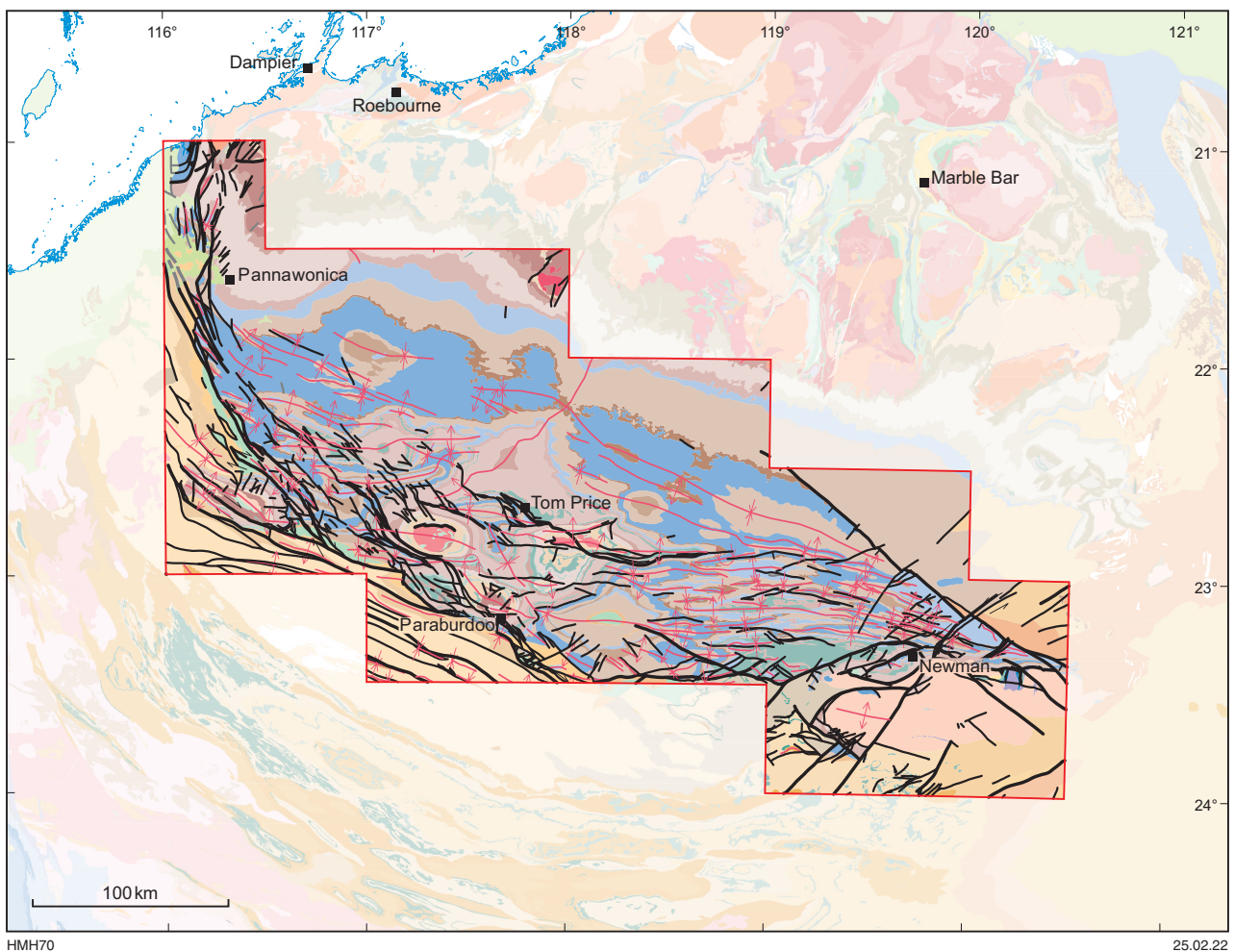


Figure 10. Area covered within the Fortescue and Hamersley Basins project

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.

Program review

Highlights and activities

- Acquisition of new geochemical data from outcrop and drillcore sampling in the Fortescue Group
- Further ENS lithostratigraphic unit reports completed for the Pilbara Craton
- 1:100 000 scale IBG compiled for COOYA POOYA and MOUNT WOHLER map sheets for release on GeoVIEW.WA in 2023–24.

Products released

- Fortescue–Hamersley, 2022 Geological Information Series
- YULE, SATIRIST and HOOLEY map sheets released on State 1:100 000 IBG layer via GeoVIEW.WA
- 100 ENS lithostratigraphic unit reports for the Pilbara Craton
- External publications — see Appendix 4

Program review

GS64 Geoscience Mapping Through Cover

Manager: Richard Chopping

Objectives

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

The primary focus for GS64 for 2021–22 was the improvement and update of regolith maps and to test geophysical techniques in order to find methods that best map through and within the regolith cover. GS64 is closely linked to ES36, which is the EIS project area for the Mineral Exploration Cooperative Research Centre (MinEx CRC).

Highlights and activities

- Expansion of the geophysical methods used for 3D paleochannel imaging in the Gascoyne Province pilot study to other parts of the State
- Acquisition of borehole material from the Department of Primary Industries and Regional Development (DPIRD) for HyLogger spectral mineralogy analysis of regolith from the central southwest Yilgarn
- Analysis of UltraFine+ results by a CSIRO collaborative project presented to sponsors; final report on these results to be released in 2022
- Acquisition of horizontal to vertical spectral ratio (HVSr) passive seismic data for paleovalley mapping within MRIWA project M10433 (SOWETO)
- HyLogger spectral mineralogy analysis of regolith material from 56 DPIRD boreholes from the central southwest Yilgarn
- Continuing research on geophysical techniques for regolith 3D mapping
- Continuing framing for upcoming MinEx CRC Phase 2 research activities
- Continuing research in preparation for drilling campaigns under the MinEx CRC National Drilling Initiative (NDI) (see ES36).

Products released

- Report 231 Regolith–landform mapping of the west Kimberley Craton: application of geophysics and spectral remote sensing
- 1:100 000 regolith geology regimes of Western Australia, 2022, GIS layer and abstract
- HyLogger spectral mineralogy of regolith from the central southwest Yilgarn, GIS layer and abstract

Program review

GS65 Proterozoic Margins

Manager: Fawna Korhonen

Objectives

Proterozoic Margins resides within the GS64 Geoscience Mapping Through Cover branch, with the primary objective being to investigate and map the geology of the remote greenfields regions. Current project areas are focused on the margins of the Officer and Canning Basins, to which the basement is informally known as 'The Gap', and to provide essential data and knowledge towards GSWA's commitment to the NDI of the MinEx CRC (see GS64 and ES36) (Fig. 11). The project work is primarily funded through ES38.

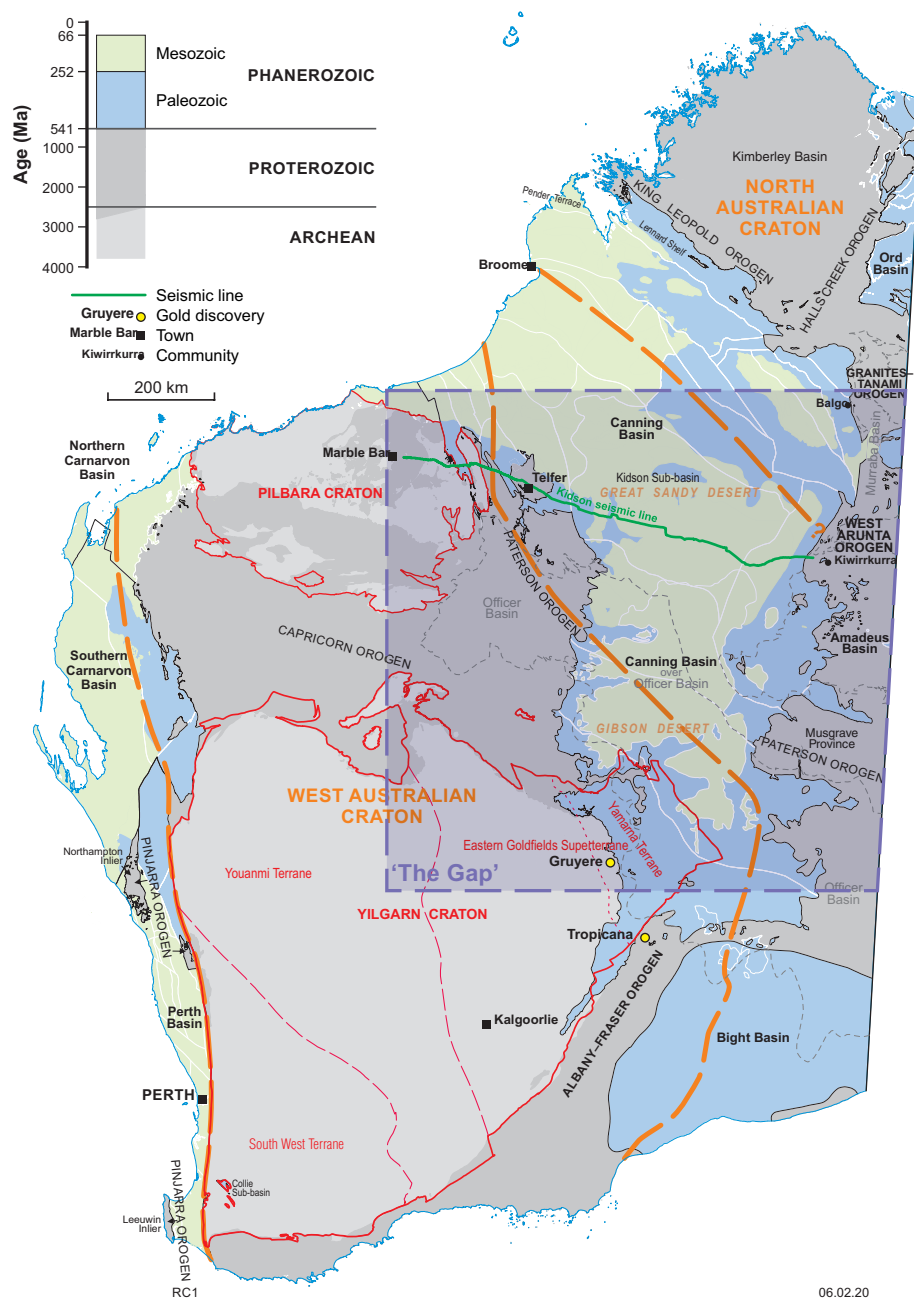


Figure 11. Tectonic units of the State showing the project areas covered by ES38 within dashed outline. The region is informally defined as 'The Gap', reflecting the basement regions between the North, West and South Australian Cratons

Program review

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

- Analysis of the age, character and correlations of Paleoproterozoic–Neoproterozoic sedimentary basin outliers in the Kimberley region
- Continued collection of isotopic and geochronological data from the Aileron and Warumpi Provinces, and the Lasseter Shear Zone. Some of this was done with the MinEx CRC embedded researcher placed at GSWA
- Initial data processing for two National Argon Map (NAM) projects (Lasseter Shear Zone [‘The Gap’] and Albany–Fraser), and submission of sample sets for two additionally funded argon projects (Paterson and Far East Yilgarn, both ‘The Gap’) under the Opportunity Fund of MinEx and Auscope. Data processing for these latter two projects will occur within a GSWA/MinEx-co-funded Masters project (Australian National University)
- Detailed metamorphic analysis of samples across the State, with a particular focus on drillcore in the eastern Canning Basin and samples in the Kimberley region
- Continued application of non-traditional geochronological techniques, including in situ Rb–Sr dating of biotite and muscovite from 10 samples, and novel in situ Lu–Hf dating of garnet from four samples across the State
- Completion of a dataset for heavy mineral concentrates from 42 regolith samples in the West Arunta; these data will be incorporated into the Heavy Mineral Map of Australia, in collaboration with Curtin University and GA
- Supporting petrophysical data acquisition in the Paterson region
- Continuing framing for upcoming MinEx CRC Phase 2 research activities
- Continuing research in preparation for drilling campaigns under the MinEx CRC NDI (see ES36).

Products released

- Record 2022/6 In situ biotite and apatite Rb–Sr geochronology of metasedimentary and meta-igneous rocks in Western Australia
- Record 2022/7 Compilation and geological implications of the major crustal boundaries map and 3D model of Western Australia (collaboration with GS53 State Geoscience)
- Report 215 Geochronology of metasedimentary and igneous rocks in the Lamboo Province, Kimberley region: reassessing collisional geodynamic models
- Report 223 Alteration and Cu–Au mineralization at the Obelisk prospect, Paterson Orogen, Western Australia (collaboration with GS20 Mineral Systems Studies)
- Update to Metamorphic History State layer on GeoVIEW.WA
- Metamorphic History Records 11–20
- External publications – see Appendix 4

Program review

GEOSCIENCE AND TITLES INFORMATION

Incorporates Geoscience Publishing, Titles Information and the Western Australian Core Libraries

General manager: Paul Duncan

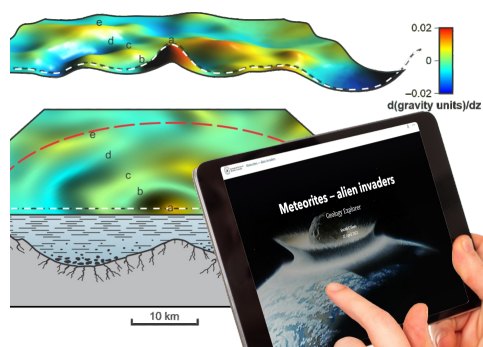


Figure 12. An example of one of the many projects published by the section

Geoscience Publishing

Incorporates GS80 Editing and Publishing, GS81 Mapping and Events, GS82 Graphics, GS97 Discover Geology

Manager: Robin Bower

Objectives

Professional geoscience products including graphics and promotional information products are critical to support the effective delivery of geoscience information for Western Australia. The section has delivered this capability with qualified and experienced geoscience editors, cartographers, geoscience content creators, graphics professionals, desktop publishers, online coordinators and geospatial professionals.

Highlights and activities

The team has focused on its key objectives this year and has achieved the following:

- produced technical Reports, Records and data packages (Fig. 12)
- delivered innovative geoscience products (including StoryMaps, apps and flipbooks)
- repurposed data for diverse platforms
- provided editorial assistance to other sections
- been involved in production and process improvement
- assisted with the development and delivery of promotional materials including posters and flyers
- been involved in the Geotourism working group and production of Geotourism products
- assisted with the update of GSWA web pages and other content
- assisted with the Geoscience Data Strategy.

Products released

- 5 geological maps
- 4 online data releases
- 35 text publications
- 40 posters
- 25 commodity flyers

Program review

Titles Information

Incorporates G587 Title Certification, G588 Title Support, G590 Title Services (Native Title)

Manager: Craig Wainwright

Objectives

The main objectives of this branch are:

- Committing to the vital role of supporting the grant of title process and maintenance of all relevant spatial data layers in TENGGRAPH Web
- Ensuring that all lease and licence holders' tenements are reliably maintained as they pass through the various dealings and compliances identified under the *Mining Act 1978*
- Managing a vast array of special category land and DMIRS Administrative and native title layers required to accurately appraise and assess grant conditions on tenements and support Land Use planning
- Supporting the native title determination process delivering historical and live tenement and petroleum data to the State Solicitor's Office (SSO) as part of the process of determining native title claims across Western Australia through the Federal Court
- Delivering data packages that relate to emerging native title compensation claims (Fig. 13).



Figure 13. The survey lease backlog has been eliminated with issue of survey instructions

Program review

Highlights and activities

The following tasks have been achieved this year:

- Reduced Survey Lease Backlog to operational levels, with reduction of 287 leases this year totalling 1100 outstanding unsurveyed leases since January 2018
- Managed survey projects with lease holders and authorized surveyors – Surveying of Mining Leases in accordance with Sec80 of the *Mining Act 1978*
- Continued timely certification of new unsurveyed applications
- Implemented 60 identified enhancements to new TENGRAPH Pro system
- Progress towards planned introduction of electronic signatures for survey documents and digital certified survey documents, further streamlining the survey process
- Introduced survey document production in ArcGIS Pro
- Continued contributions on planning and progress towards implementation of GDA2020 within DMIRS – envisaged for early 2023
- Roads added as a polygon layer in TENGRAPH Web
- Added Carbon Sequestration Farming Layer to TENGRAPH Web
- Continued Support for Plans for our Parks initiative
- Captured over 5800 historical tenements in TENGRAPH Web further enhancing the digital representation of historical mining records
- Audited spatial and textual historical tenement data with over 2000 tenement files, title registers and survey documents scanned
- Produced 370 Right to Negotiate and Notification Plans
- Delivered 175 Native Title Determination and Compensation Claims to date – 29 for 2021–22.

Program review

DATA MANAGEMENT

Incorporates GS83 Geoscience Data Services, GS84 Geoscience Data Delivery, GS86 Geoscience Data Governance

General manager: Deavi Purnomo

Objectives

The branch consists of experienced well-qualified staff who are critical to the quality and delivery of geoscience data and systems. These staff members include geoscience database managers, geospatial officers, web mapping specialists, data analysts, business analysts, application developers and GIS specialists. The outcomes of this branch form part of the **Geoscience Data Transformation Strategy**'s direct actions.

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

The branch incorporates three sections:

- Geoscience Data Services
- Geoscience Data Delivery
- Geoscience Data Governance.

Highlights and activities

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

The following online Geoscience Information Systems were released:

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

The team has:

- Delivered geoscientific digital datasets and data layers
- Provided online applications and database training
- Maintained geoscience data delivery platforms.

Products released

- 4 data packages
- 11 digital layers

Program review

GS85 Resources Investment Information

Manager: Warren Ormsby

Objectives

Our ongoing objective is to facilitate the provision of resource-related information to industry, researchers, and the wider public. This contributes to the stimulation of mineral and petroleum investment in Western Australia, the acceleration of exploration, the development of new resources, and a greater understanding of the relevance of geoscience in the community. This facilitation occurs by provision of geoscientific, policy, and regulatory information to assist with attracting new resource investment.

Highlights and activities

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

Engagement examples include:

- Establishing a booth presence with high-impact information displays at major investment conferences and seminars
- Conducting investment workshops, seminars, and updates for small groups
- Publishing high-quality maps, posters and flyers in hardcopy and online
- Responding to investor requests for information and advice relating to geoscience, policies, and regulations
- Providing a steady stream of engaging content via social media on LinkedIn and Facebook
- Producing the GSWA Webinar Series
- Engaging with young geoscientific professionals at university and networking events
- Supporting earth sciences education in Western Australian schools
- Sponsoring geoscientific-centred events financially, in kind, or by providing expert staff.

Industry engagement

- Asia Pacific Energy Capital Assembly (APAC), Singapore

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

- Prospectors & Developers Association of Canada Annual Convention (PDAC)
- North American Prospect Expo (NAPE) Summit
- Australia Japan Mineral Resources Investment Seminar

Program review

National engagement

GSWA was represented in person at these State-based and interstate events:

- NewGenGold Conference
- Diggers & Dealers Mining Forum
- Paydirt Battery Minerals Conference
- Perth Gem and Mineral Show
- RIU Explorers Conference
- RIU Good Oil & Gas Energy Conference
- Australian Petroleum Production and Exploration Association (APPEA) Conference

The GSWA Open Day, held on 12 November 2021, was also a key event for resource and investment information where staff were able to engage directly with industry and research. It was a sold-out and very successful event.

Program review

GS91 Statutory Mineral Exploration Information

Manager: Julia Thom

Objectives

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

Highlights and activities

- Data received and reviewed:
 - » 4057 mineral exploration reports and data were reviewed
 - » 2647 reports were released to open file
 - » More than 96% of reports were received via the online submission wizard
 - » 1362 drill collar files and related data files uploaded into the drillholes database comprising 222 452 individual drillholes and associated downhole data
 - » 1587 surface geochemistry files uploaded into the drillholes database comprising 579 033 individual samples and associated geochemistry data
- In the previous financial year, all open-file mineral exploration reports (WAMEX) that were not available in a non-optical recognition format were converted and an external Amazon Web Services (AWS) website launched. This allowed for text searching of all WAMEX reports available on the biannually released hard drive. The website was updated with two further sets of reports released on the hard drive.
- An AWS external website facility was launched to search for and download harmonized open-file surface and downhole geochemistry data from exploration company datasets in the mineral drillholes database. The website was updated with further releases of this data and a number of improvements and enhancements were made.
- Data requests:
 - » 1148 core library (mineral core) viewing and sampling requests were approved
 - » 655 Combined Reporting Groups were granted or amended
- Sunset Clause
 - » Under the provisions of Regulation 96(4) of the Mining Act the 'sunset clause', 1252 reports received in 2016 which were still confidential and advertised for release. A total of 1150 of these reports did not receive objections and were released
 - » In addition, a list of 185 reports submitted between 2002 and 2011 (the lapsed objections) were advertised on the website for release. A total of 98 reports were released without objection and 87 received renewed objections. These are currently under review.

Program review

Performance measures

This section 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
- 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.

Program review

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

Objectives

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

The section adds quality-assured geoscience information to the Western Australian Petroleum and Geothermal Information Management System (WAPIMS) database, undertakes transcription and scanning programs related to State activities, and ensures data submitted are complete and in a format easily used by explorers. As part of the AGP, the WAPIMS team is working on the Energy Systems Atlas in collaboration with the Energy Geoscience branch.

Highlights and activities

- WAPIMS main enhancements
 - » Added new group of layers in WAPIMS map under Energy System Atlas as part of the AGP
 - » Added new columns in Data by Depth – Composite Well Log displays and Mud log displays
 - » Added Hydrocarbon Distribution/Petroleum Composition including plot/graph for the internal Analysis grid and external Petroleum Composition grid
 - » Injection well additions – new columns for Water Injection by Well and new grids for CO₂ Data wells and Surveillance wells
 - » Finalize and release a new redesigned seismic reprocessing projects workflow
- Data remastering – transcribed petroleum data to a modern stable media for industry and government
 - » 2257 tapes transcribed to a new media and data loaded into WAPIMS
 - » 19 well logs scanned and digitized from acreage release area
- WAPIMS data management
 - » 79 947 new records created
 - » 42 354 records updated
- Data received and reviewed
 - » 257 reports, 14 logs, 139 survey data, 5051 slides and residues
 - » 310 reports reviewed and information captured (new and legacy)
 - » Other WAPIMS entries: monthly production (11 462), underground storage daily data (3134), underground storage monthly data (112), CO₂ injection by well (6299), water injection by well (1519), water production by well (2920)
- Data released – reports, well logs, survey data published in WAPIMS: 263 documents, 10 041 slides and residues
- Sampling approval requests processed: 88 from 401 wells

Program review

- Statistics and metrics 2020–21
 - » 74 823 documents downloaded from WAPIMS
 - » 87.3% of reports received and accessioned within 14 days
 - » 98.1% of the sampling approvals processed within five days, from 337 wells
 - » 91.3% of the slides and residues received, accessioned and archived within 14 days
- Achievements
 - » Audit and moved petroleum slides relinquishment collection from Mineral House to Carlisle
 - » Assisted with the Geoscience Data Transformation Program – provided documentation, planned future projects, etc.
 - » Provided assistance to other sections
 - » Created more layers in Energy Atlas map.

Program review

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Objectives

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

Highlights and activities

- From July 2021 to June 2022, over 49 000 m of core and about 9000 m of chips and cuttings from 171 drillholes were scanned (Fig. 14). These comprised 112 EIS co-funded holes (Rounds 18–22), 38 historical and donated mineral holes, and 21 petroleum wells. AuScope, as part of an NCRIS grant scheme, funded data processing of up to 2100 m of core from five EIS co-funded drillholes from the Joe Lord Core Library in Kalgoorlie

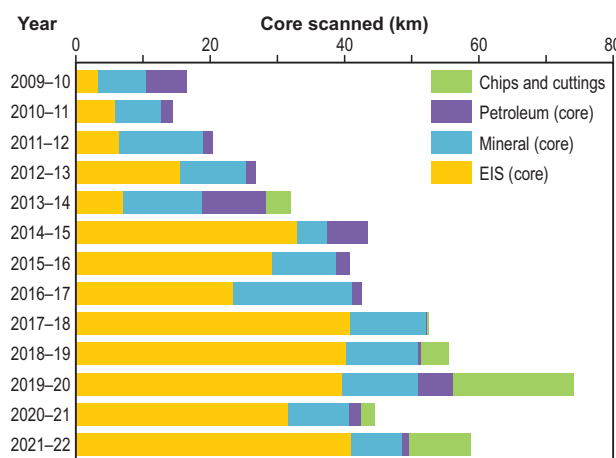


Figure 14. HyLogger data production

- Overall, new and reprocessed high-resolution core images and hyperspectral data for 373 000 m of drillcore and 36 600 m of chips and cuttings from 1400 drillholes were delivered to the AuScope national portal and GeoVIEW.WA using the HyLogger database, which includes 131 datasets processed to level 1 or level 2 in the year
- All datasets reprocessed for the AGP were publicly released through the GeoVIEW.WA and NVCL Discovery portals. All open-file HyLogger datasets are now standardized to the latest spectral unmixing algorithms and spectral reference library, and improved tray images are available
- HyLogger staff created and released over 1400 summary downhole mineralogy histograms for all open-file processed HyLogger datasets, accessible through the GeoVIEW.WA portal

Program review

- HyLogger staff were actively involved in several GSWA, UWA and CSIRO research projects, including scanning core for the EIS petrophysics project, assisting with application of machine learning to petroleum cuttings, mapping salt and carbonates through stratigraphic wells from the Canning Basin, and assisting a PhD project reconstructing submerged paleoshorelines of the North West Shelf. HyLogger staff also contributed to the EIS drilling program delivering hyperspectral data and high-resolution images of 63 drillholes to 12 exploration companies
- The HyLogger team is actively collaborating with internal technical teams to promote HyLogger data to the cloud, update current HyLogger database architecture and workflows, and assist with Geoscience Data Transformation Strategy projects
- The HyLogger team provided four educational tours for State delegations and company geologists visiting the Perth Core Library, presented four TSG trainings/consultancies for industry and students, and manually delivered 141 datasets, excluding external portals
- The HyLogger workshop, in collaboration with CSIRO, was delivered in June to academia and industry to promote the use of hyperspectral technology
- The HyLogger team took possession of a new handheld Laser-Induced Breakdown Spectroscopy (LIBS) analyser, enabling measurement of light elements (e.g. H, Li, C, Na) and complexes complementary to portable X-ray fluorescence (pXRF).

Products released

- Statewide Spatial Datasets package HyLogger drillholes
- 1400+ Summary Histograms of HyLogger downhole spectral mineralogy

Program review

GS94 Perth Core Library

GS96 Joe Lord Core Library

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

Objectives

DMIRS core libraries at Carlisle (Perth) and Kalgoorlie house important collections of samples of representative geology and mineral endowment of Western Australia. These collections have been sourced over many decades from government stratigraphic drilling, mineral industry donations, 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 exhibits the mineral and energy prospectivity of the State and encourages innovative resources exploration.

The core libraries at Carlisle and Kalgoorlie also house the extensive core generated since 2009 from the EIS Co-funded Exploration Drilling Program. After a short six-month confidentiality period, this core is a great boost to explorers and academia, providing new core from greenfields areas and allowing testing of new ideas and concepts.

Kalgoorlie also has a large collection of paleochannel core drilled by GSWA during the mid-1980s (Fig. 15).

Highlights and activities

- With the expansion of the Joe Lord Core Library (Kalgoorlie) now complete, the tripled site storage capacity and extended outdoor viewing area have already seen an increase in utilization from industry and academia. The expansion was opened in November 2021 by the Minister for Mines and Petroleum, Bill Johnston
- WAPIMS and CIMS are updated weekly
- Carlisle outdoor processing area expanded with new layout racking.



Figure 15. Viewing core in the Perth Core Library

Program review

GS98 New Energy Systems

Manager: Trevor Beardsmore

Objectives

The Western Australian Government is committed to diversifying and growing the State's economy while reducing net greenhouse gas (GHG) emissions to zero by 2050. These aspirations are to be realized via a raft of initiatives that include the Energy Transformation and Future Battery Industry Strategies. These strategies will capitalize on the State's impressive natural resource endowment, technical know-how and premier geographic location to build a fully integrated 'green' energy industry that exports products and expertise to a demanding world (Fig. 16).

The role of GSWA's New Energy Systems branch is to support the State's New Energy Transition (NET) by coordinating the provision of geoscientific information and advice that informs the:

- Discovery and recovery of mineral and energy resources required for the generation and storage of renewable energy (including bedrock, groundwaters, mine residues and disused mine infrastructure)
- Mitigation of solid and gaseous mine waste streams
- Development of government policies and regulations to stimulate and govern the impact of activities to bring about the NET.

Highlights and activities

In 2021–22, New Energy Systems commenced foundational work on a suite of projects, commonly in collaboration with other groups:

- Estimating the capacity of Western Australia's prospective mafic–ultramafic bedrock geology to permanently geosequester waste greenhouse gases. A GSWA Report is being prepared
- Mapping the distribution and characteristics of mine residues (tailings and rock waste), as potential resources for battery and other critical minerals, and feedstocks for greenhouse gas sequestration by mineral carbonation (collaborating with GSWA's Land Use Planning branch, DMIRS' Environment and Mine Safety groups, and the MRIWA – Curtin University 'Mineral Carbonation Roadmap' initiative). Early work has included cataloguing of mine residue features, identifying data gaps, and developing a proposal for a pilot-scale investigation of pertinent characteristics of several representative tailings storage facilities, to be undertaken subject to approval and funding
- Compiling 'formation water' geochemistry from statutory petroleum industry reports, to evaluate prospectivity for critical minerals in deep groundwaters (collaborating with GSWA's Statutory Information [WAPIMS] and Energy Geoscience and Carbon Strategy branches). New products will include a GSWA Report and a feature layer in GSWA's Energy Systems Atlas.

Products released

All projects are at the early stages of development. No publications or other products were completed in 2021–22.

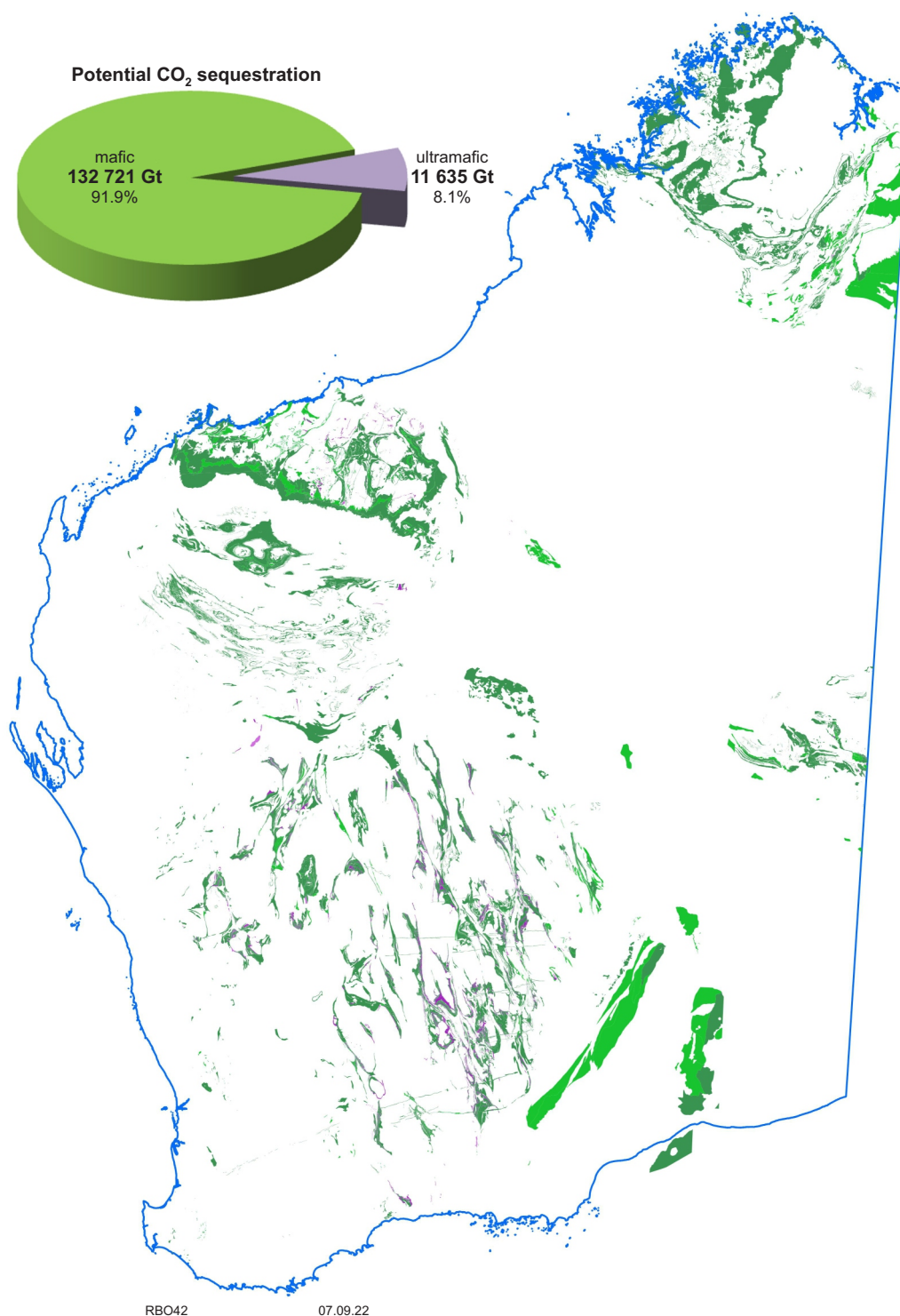


Figure 16. Western Australia's geology contains abundant Ca- and Mg-rich rocks theoretically able to sequester all of the State's greenhouse gas emissions for millennia

EIS overview

Overview of the Exploration Incentive Scheme

The Western Australian Government's EIS began in 2009, and has remained active throughout new governments to the present day. The objective of the EIS is to promote exploration in Western Australia to increase the discovery rate of economic deposits, emphasizing greenfields areas underexplored for mineral deposits and frontier energy basins.

At the end of the 2021–22 financial year, the EIS had received \$188.03 million from variable funding sources (Table 2) since the EIS started in 2009. EIS 5 funding is from Mining Tenement Rent (MTR), which increased in 2019.

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

Table 2. Funding sources for the EIS since 2008–09

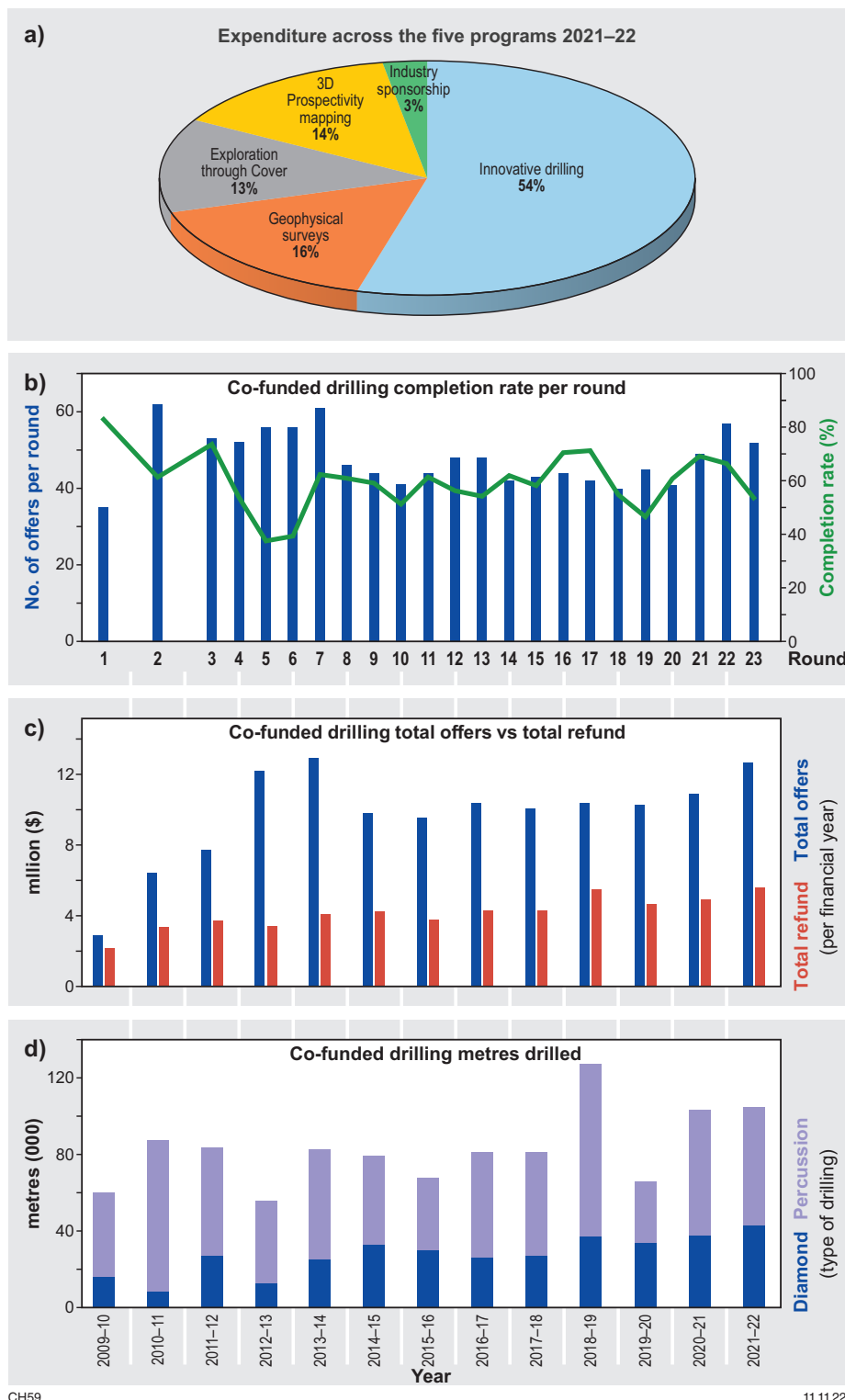
<i>EIS phase</i>	<i>Year</i>	<i>Royalties for Regions</i>	<i>Consolidated revenue</i>	<i>Mining tenement Rent (MTR)</i>
EIS 1	2008–09 to 2012–13	\$76 340 000		
EIS 1A	2013–14	\$24 200 000		
EIS 2	2013–14 to 2016–17		\$30 000 000	
EIS 3	2017–18 to 2018–19	\$15 000 000		\$5 000 000
EIS 4	2019–21			\$25 000 000
EIS 5	2021–22			\$12 500 000

Major programs

Five overarching comprehensive programs provide the framework to stimulate an increase in private sector resource exploration, to bring about new mineral and energy discoveries and maintain Western Australia's ranking as one of the most attractive minerals investment destinations. Expenditure across the five programs is shown in Fig. 17 (a–d). The five programs are:

1. **Government–Industry co-funding**
 - 1.1 Co-funded Government–Industry drilling
 - 1.2 Co-funded Government–Industry Energy Analysis
2. **Geophysical surveys**
 - 2.1 Airborne gravity surveys
 - 2.2 Passive seismic and magnetotelluric surveys
 - 2.3 2D and 3D active seismic surveys
3. **Encouraging exploration through cover**
 - 3.1 Depth of Cover and its interfaces
 - 3.2 Basement geology and evolution
 - 3.3 Proterozoic margins
 - 3.4 Petrophysics
 - 3.5 MinEx CRC participation

EIS overview



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Figure 17. Dashboard view of the EIS: a) pie chart showing the expenditure across the five EIS programs for 2021–22; 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 who withdraw, fewer holes drilled than estimated, and actual direct drilling costs being less than estimated; d) total number of metres drilled by diamond and percussion (e.g. RC, rotary air blast, aircore, auger)

EIS overview

4. 3D prospectivity mapping

- 4.1 Mineral systems
- 4.2 Energy systems
- 4.3 3D lithospheric visualization
- 4.4 Geochemical barcoding
- 4.5 Yilgarn granite project
- 4.6 Mapping geodynamic setting
- 4.7 Enhanced geochronology and isotopic mapping
- 4.8 Novel geochronology and isotopic analysis

4. Promoting strategic research with industry

- 5.1 MRIWA support

EIS overview

Dashboard view of the EIS

Major highlights and activities

- ES20 Co-funded Exploration Drilling – Rounds 22 (2021) and 23 (2021–22) had completion rates of 67% and 54%, respectively
- ES20 Co-funded Exploration Drilling – Rounds 24 and 25 opened for applications in 2021–24 (Table 3)

Table 3. Application statistics for EIS Co-funded Exploration Drilling Rounds 24 and 25

Round	No. of applications	No. of successful applications
24	84	50 general, 1 prospector
25	107	41 general, 6 prospectors

- ES20 Co-funded Exploration Drilling – 104.8 km of drilling by 70 projects completed in the 2021–22 financial year (Table 4)

Table 4. Co-funded Exploration Drilling completed in 2021–22

Diamond drilling (m)	Percussion drilling (m)	Total (m)	Co-funded offers	Projects completed
42 893	61 932	104 825	98	70

- ES30 Airborne and Ground Geophysical Surveys – under a National Collaborative Agreement with GA, an airborne electromagnetic (AEM) project completed acquisition across Murchison and parts of the southwest. A total of 30 200 line km was released by March 2022
- Three companies announced basement electromagnetic targets were identified on their tenements based on the released AEM data across the southern half of Western Australia
- ES31 New seismic monitoring stations installed in the Canning Basin (12) and the Goldfields region (5) are live streaming data to GA and were incorporated into the National Alerts Centre
- Over 4000 petrophysical results of diamond core from the Paterson Orogen, Eastern Goldfields, West Arunta and Eucla were released
- Report 226 Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag Groups – Ora Banda to Kambalda region was released. The Report has a new dataset of ~2800 high-quality whole-rock geochemical analyses of subvolcanic, volcanic, and volcanoclastic rocks from the Kalgoorlie Group. The Report is used to construct chemostratigraphic barcodes within the broader Ora Banda – Kambalda region of the Eastern Goldfields
- Report 233 Critical metals in laterite related to pegmatite mineral systems of the western Yilgarn Craton (Li, W, Sn, Ta, REE) was released
- A new project, ES55 Novel Geochronology and Isotope Analysis, was initiated to facilitate the addition of 'novel' isotope techniques to date a wider range of rocks and minerals and to isotopically characterize and trace a wider range of geological processes (e.g. using apatite, biotite).

EIS program review

ES20 Government-Industry Co-funded Exploration Drilling

Manager: Charlotte Hall

Objectives

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

Highlights and activities

- Round 22 – 12-month drilling period ended on 31 December 2021 with a 68% completion rate (historical average completion rate is 59%)
- Round 23 – 12-month drilling period ended on 31 May 2022 with a 54% completion rate
- Round 23 was the first round whereby the 12-month drilling period was moved forward by a month to start on 1 June 2021, and end on 31 May 2022. This allowed for interim invoices to be submitted to DMIRS one month before the end of the financial year. Going forward, all rounds will either start on 1 June, or 1 December, ending 12 months later
- Musgrave Minerals Limited (Round 22) – Moyagee Project had significant gold intersections and visible gold at Target Zone 2, which was renamed White Heat
- Encounter Resources (Round 22) EIS program of two holes, including ETG0226 that had intersections with pyrite and chalcopyrite, prompted the drilling of an additional five holes and expansion of ideas on the target
- Maximus Resources (Round 23) – diamond drilling to test down dip plunge of the Redback deposit identified a new target, the 'Western Contact', with encouraging gold grades
- Strike Energy (Round 23) – discovered commercial gas in the EIS co-funded hole, extending the gas field in the North Perth Basin across the Early Permian Kinga Formation
- Tempest Minerals Limited (Round 24) – Meleya project intersected visible copper and semimassive sulfides in the first 709 m hole, in the Yalgoo region.

Products released

- A total of 70 EIS Co-funded Exploration Drilling reports was released to open file, including 18 with battery elements listed in the target commodity (nickel, cobalt, lithium, manganese, aluminium, REE and graphite).

EIS program review

ES23 Government–Industry Co-funded Energy Analysis Program

Manager: Charlotte Hall

Objectives

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

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

Highlights and activities

Table 5 outlines the highlights for the year.

Table 5. Energy Analysis Program highlights for 2021–22

<i>Series/Year</i>	<i>No. of applicants</i>	<i>No. of grants</i>	<i>Petroleum grants</i>	<i>Geothermal grants</i>	<i>Date reports released to open file</i>
Series 2 / 2022	8	6	6	0	1 March 2023
Series 3 / 2022–23	1	1	1	0	1 September 2023

EIS program review

ES30 Airborne and Ground Geophysical Surveys

Manager: David Howard

Objectives

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

Highlights and activities

- The AusAEM20-WA program to extend the AusAEM 20 km line spacing survey program across the remainder of Western Australia continued during 2021–22 with SkyTEM surveys in the southwest and the Murchison. Data from the 30 200 km of survey over both areas were released by March 2022. Coverage of the remaining areas of the State in the east and in the Kimberley, funded by the EIS, were incorporated into GA's Exploring For the Future (EFTF) Western Corridor program (see Fig. 18). Work in the Western Australian areas commenced in June 2022, and it is anticipated that these data will be released during the 2022–23 financial year.

Products released

- SkyTEM survey areas datasets and inversions (MAGIX numbers 71588 and 72050)

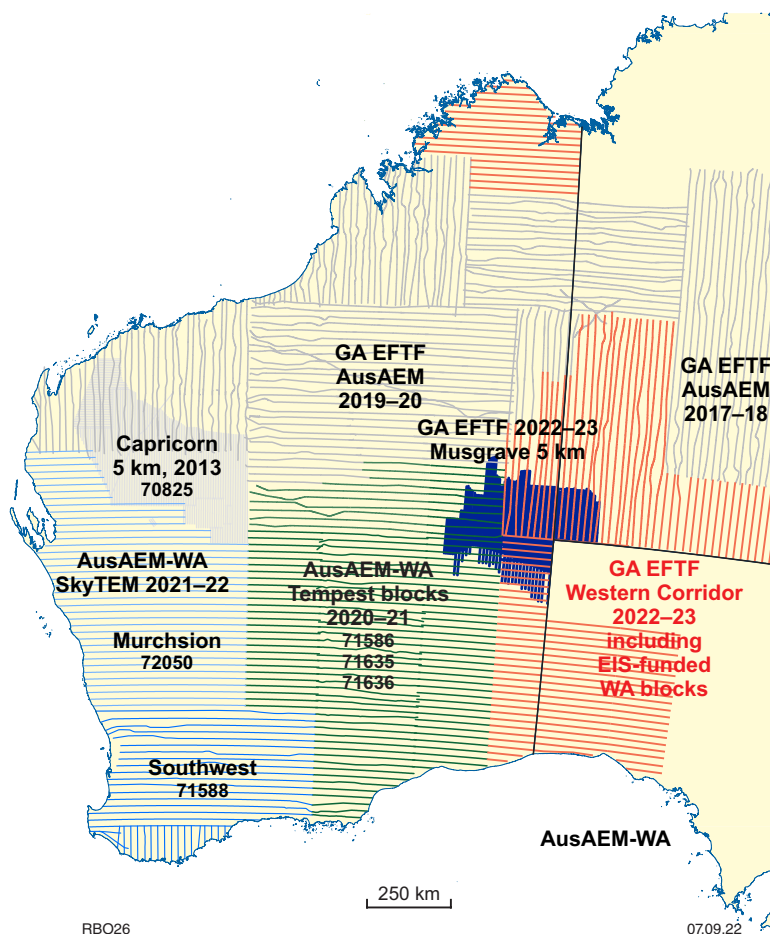


Figure 18. Location of AusAEM survey areas in Western Australia. Numbers refer to dataset registration numbers in MAGIX data repository

EIS program review

ES31 Deep Seismic Survey Program

Manager: Klaus Gessner

Objectives

Integrated geophysical and geological transects across the West Australian, North Australian and South Australian Cratons and their margins in Western Australia, and the intervening Neoproterozoic and Phanerozoic basins, are critical for understanding the geological evolution of the Australian lithosphere over some four billion years of the Earth's history. These transects also provide an understanding of the localization of mineral systems within the upper crust. In addition to collaborating with GA on the active source seismic acquisition, GSWA is collaborating with Macquarie University and UWA on passive source and magnetotelluric (MT) surveys.

Highlights and activities

- Seismic monitoring of an earthquake swarm in Arthur River in collaboration with Australian National University, GA, and Macquarie University
- Addition of satellite communications to the Canning Basin Baseline monitoring project and installation of two new stations. There is now a total of 12 stations in the Canning Basin live streaming data to GA and being incorporated into the National Alerts Centre
- First testing of automatic AI algorithms for earthquake detection run using live streamed data from the six GSWA stations telemetering data from the Canning Basin
- Five new seismic monitoring stations installed in the Goldfields region and are live streaming data to GA and being incorporated into the National Alerts Centre
- A passive seismic array of 39 temporary stations is running in the Pilbara in collaboration with Macquarie University.

Products released

- 16 stations streaming real-time data to GA

EIS program review

ES36 Participation in MinEx CRC

Manager: Richard Chopping

Objectives

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

The GSWA embedded researcher position was initially placed from the University of South Australia for two years from January 2020 to December 2021, although staff movements required backfilling the position and the position has subsequently been extended to December 2024. The research focus of this position is to understand the chemistry and source of fluids within key regions of Western Australia to allow for predictive studies of likely mineralization within these greenfields areas. The expression of mineral chemistry and associated alteration of mineralizing systems within petrophysical and geophysical datasets will be investigated in order to integrate these exploration methods.

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

Highlights and activities

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

EIS program review

ES38 Proterozoic Margins

Manager: Fawna Korhonen

Objectives

The Proterozoic Margins section operates predominantly under ES38, but with links to GS65. The primary objective is to investigate and map the geology of the remote greenfields regions on the margins of the Officer and Canning Basins, where the basement is informally known as 'The Gap', much of which resides under regolith and younger basin cover (see Fig. 11). 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

- Participation in MRIWA project M470a, A multi-scale approach to controls on mineralization in the Fraser Zone, Western Australia
- Collaborative work on the Paterson Orogen, as part of the MRIWA M521 project
- Supporting petrophysical data acquisition in the Paterson region
- Continuing research and preparation for drilling campaigns under the MinEx CRC NDI.

Products released

- Listed under GS65

EIS program review

ES39 Petrophysics

Manager: Charlotte Hall

Objectives

During 2021–22, GSWA sampled diamond core from the Mt Weld carbonatite deposit, Paterson Orogen, Kalgoorlie Terrane, Albany–Fraser Orogen and the South West Yilgarn for petrophysics.

The analytical work was done by a Perth-based company, Terra Petrophysics. Seven physical properties were acquired and include:

- Induced polarization (chargeability) and galvanic resistivity
- Inductive conductivity
- Magnetic susceptibility
- Remanent magnetization
- Ratio of induced- to remanent-magnetization intensity of the sample (known as the Koenigsberger Ratio (Q), as well as an estimate of the total remanent vector (relative to drillhole)
- Dry bulk density
- Apparent porosity
- P-wave sonic velocity.

For all projects, a datasheet has been produced by Terra Petrophysics and many are accompanied by a report. The report contains a description of the methods, a first-pass analysis of the data, a summary of the petrophysical measurements and a photo of each sample (Fig. 19). The written reports are available from the DMIRS eBookshop, and the online MAGIX geophysical data repository.

A tender for an additional five years of petrophysical data acquisition was awarded to Terra Petrophysics. Initially, core will be chosen from greenfields areas and adjacent to potential 2D active reflective seismic lines in the south west and Perth Basin – western Yilgarn Craton.

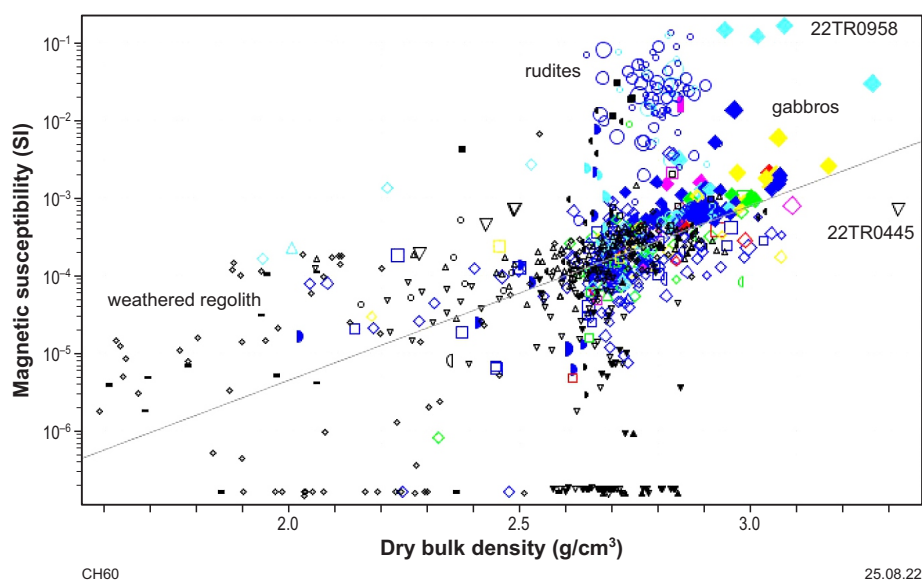


Figure 19. Representation of petrophysical data

EIS program review

Products released

- Report 217 Regional petrophysics: Paterson Orogen 2020–21: 5 holes, 274 samples, MAGIX Registration No. 72014
- Report 218 Regional petrophysics: Eucla basement: 2 holes, 93 samples, MAGIX Registration No. 72014
- Report 219 Regional petrophysics: West Arunta: 10 holes, 975 samples, MAGIX Registration No. 72014
- Report 224 Regional petrophysics: Kalgoorlie Terrane: 9 holes, 1976 samples, MAGIX Registration No. 72029 – holes near Kalgoorlie–Boulder
- Report 225 Regional petrophysics: Yamarna Terrane: 6 holes, 346 samples, MAGIX Registration No. 72201
- Kalgoorlie Terrane: diamond core from and around Norseman, 337 samples, MAGIX Registration No. 72201. No report to date
- Mt Weld: EIS co-funded drillhole 86 samples, MAGIX Registration No. 72201

EIS program review

ES42 3D Lithosphere Visualization Project

Manager: Ruth Murdie

Objectives

The aim of the 3D Lithosphere Visualization Project is to visualize and model relevant portions of the solid Earth in Western Australia. The objective is to extend knowledge from exposed and well-understood areas of the Earth's crust and lithosphere to inaccessible or data-poor parts using 3D structural analysis, modelling and numerical simulation techniques. These techniques also test the validity of conceptual models and interpretations. An important aspect of ES42 is the cooperation with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling. In addition to collaborating with GA, GSWA also engages with Macquarie University, the Institute of Geology and Geophysics at the Chinese Academy of Sciences (IGG-CAS), Monash University and UWA on passive source seismology, MT surveys and next-generation 3D modelling techniques (Fig. 20).

Highlights and activities

- Australian Research Council (ARC) project LP170100890 'Enhanced 3-D seismic structure of Southwest Australia' – a collaboration with the ANU, GA and the Department of Fire and Emergency Services – continues with the data collection and initial processing from 27 seismometers, which have since collected around 18 months of data
- LOOP2 had a start-up meeting with all participants. The fault interpretation of the Eastern Goldfields was provided for a test dataset for a 3D model.

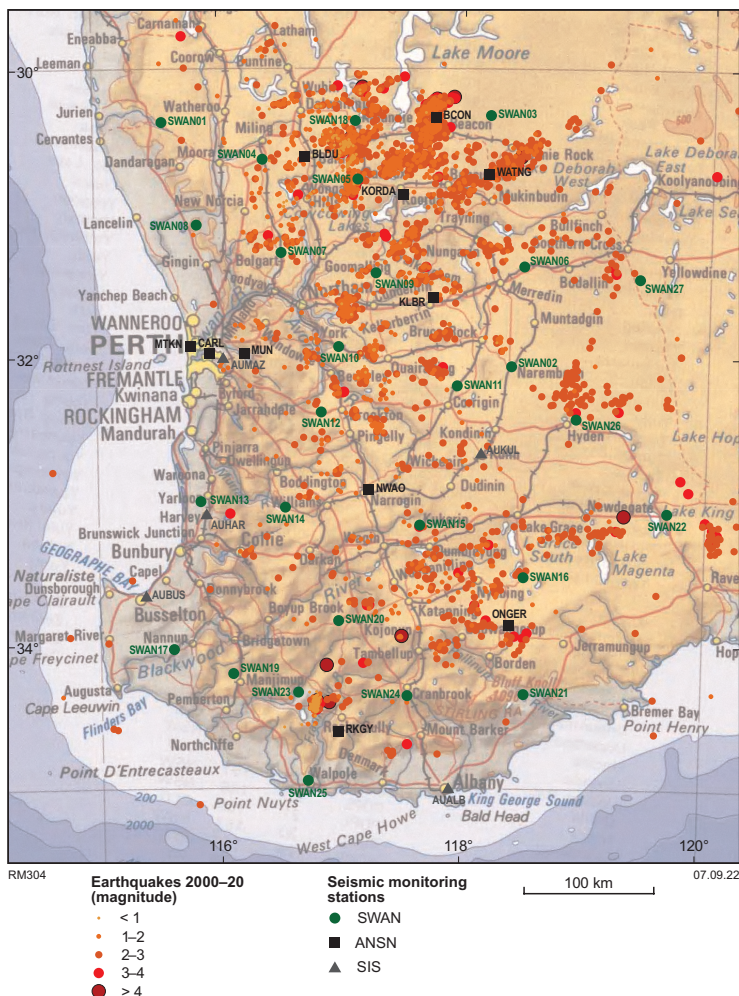


Figure 20. Plot of seismic events recorded during the first 18 months of recording on the SWAN seismic network. Abbreviations: SWAN = South West Australia passive seismic Network, ANSN = Australian National Seismograph Network, SIS = Seismometers in Schools

EIS program review

ES43 Mineral Systems

Manager: Warren Ormsby

Objectives

Under this program, GSWA collaborates with other government, university and industry partners to study specific aspects of Western Australian mineral systems. These projects are partly to fully funded by the EIS, with the Minerals Geoscience branch managing in-house participation.

Projects underway in 2021–22 include:

- MRIWA M10433 – Detection of distal footprints in the Southwest Yilgarn: Linking basement and cover (\$750 000 over three years)
- ARC Linkage LP190100635 – Realising Australia's rare earth resource potential (\$20 000 per annum over three years)
- MRIWA M532 – Geology, mineralogy and metallurgy of eMaterial resources in Western Australia (\$50 000 per annum over two years)
- Critical Metals (Li, Sn, W, Ta, REE) in the western Yilgarn Craton (\$100 000 for one year)
- Isotopic fingerprinting of native gold from Western Australia (\$31 500 for a six-month pilot study).

Highlights and activities

GSWA is a partner in the MRIWA M10433 project 'Detection of distal footprints in the Southwest Yilgarn: linking basement and cover', along with MRIWA, CSIRO and resource companies. This three-year project commenced in December 2021. This study is re-evaluating the gold prospectivity of the Southwest Yilgarn through the application of recent advances in geochemical technologies, targeting chemical and isotopic anomalies in cover rocks that are proven to provide vectors to mineralization in the more thoroughly explored central and eastern terranes of the Yilgarn. This project involves close collaboration with staff from CSIRO and other branches of GSWA.

Significant work associated with M10433 took place throughout 2021–22, including logging and sampling of drillcore from gold prospects and deposits in the region, focusing initially on Tampia and Donnybrook. Analytical work included whole-rock geochemistry, polished thin-section preparation and TIMA scans. Opencut pit mapping was completed at the Tampia gold mine, including a drone survey of the pits and detailed photogrammetry of the pit walls. Fieldwork included regional reconnaissance and participation in a passive seismic survey over paleochannels in the Southwest Yilgarn.

The 'Rare earth resources of northern Australia' project commenced in 2020–21 after being awarded an ARC Linkage grant. Principal investigators at Adelaide University and ANU have been working with sponsors GSWA, GA, the Geological Surveys of New South Wales and Queensland, and REE-focused resource companies. The project aims to investigate the potential for undiscovered economic deposits of rare earth elements within the Australian continent focusing on unconformity-related REE and peralkaline igneous rare metal deposits. Case studies of relevance to Western Australia include the Browns Range and John Galt REE deposits in the East Kimberley – West Tanami region of northern Western Australia. Field visits to these locations took place in July–August 2022 following the lifting of COVID-19 pandemic-related border travel restrictions. In the interim, GSWA organized and provided sample material obtained from the region.

EIS program review

MRIWA project M532 aimed to provide an understanding of the geology and mineralogy of Western Australian spodumene-bearing lithium–caesium–tantalum (LCT) pegmatite-hosted lithium deposits, in order to develop practical geometallurgical models to optimize the sustainable development of these deposits, and verify the suitability of field portable analytical devices for determining lithium abundance and distribution during exploration. The researchers at the John de Laeter Centre at Curtin University produced a first draft report in the 2021–22 financial year. This included development of a petrological and geochemical classification for LCT pegmatites, characterizing the mineralogy and deportment of economic and deleterious elements, and testing the effects of calcination on spodumene concentrates. The final cobranded GSWA–MRIWA Report will be published in the 2022–23 financial year.

CSIRO reanalysed 2438 laterite samples from the western Yilgarn Craton using modern analytical techniques, to determine Li and several other critical metals, including Sn, W, Ta and REE, that could not be reliably measured in previous analytical campaigns using older technologies. The study also collected near-infrared, short-wave infrared and thermal spectral data using the HyLogger-3 system and included mineralogy derived from X-ray diffraction analyses from selected samples. The final Report and all data were published in 2021–22 as provided by CSIRO. Further work is continuing on compiling the new geochemical data into GSWA format for release in 2022–23.

In April 2021, GSWA commissioned the John de Laeter Centre for Isotope Research at Curtin University to undertake a six-month pilot study to determine whether the timing and the source(s) of gold mineralization can be constrained using Pb–Pb and Re–Os radiogenic isotope systematics and other trace element compositions. GSWA provided a selection of native gold specimens from Western Australia that represented a range of geological settings, ages and types of gold deposits, and for which mineralogy and trace element chemistry have already been determined. All analyses have been completed, and John de Laeter Centre researchers are now evaluating the data. A final Report will be released in the 2022–23 financial year.

The Pilbara gold ‘fingerprinting’ project continued in 2021–22, characterizing the provenance and metallogenesis of gold mineralization across the Pilbara Craton. All gold-bearing specimens provided by industry partners have been visually inspected, mounted in resin, cut and polished, and analysed quantitatively for a suite of trace elements using energy dispersive X-ray spectroscopy (SEM-EDX). About half of the samples have also been analysed using LA-ICP-MS, with the assistance of John Watling (TSW Analytical), and subjected to acid etching and crystallographic examination. The outstanding geochemical and crystallographic analyses have been delayed by difficulties in accessing third-party polishing and analytical services. Available data have been evaluated and are being progressively compiled into a series of Mineralogical Records. The first group of these Records will be published in the 2022–23 financial year.

Product released

- Report 233 Critical metals in laterite related to pegmatite mineral systems of the western Yilgarn Craton (Li, W, Sn, Ta, REE)

EIS program review

ES46 Enhanced Geochronology and Isotopic Mapping

Manager: Michael Wingate

Objectives

Project ES46 includes operational geochronology and geochemistry activities previously conducted as part of GS54 Geochronology and Geochemistry. In addition to the activities described above under GS54, ES46 enhances GSWA's core geochronology program with a range of studies conducted in collaboration with university research groups, including Lu–Hf and oxygen isotope and trace element analysis of zircons, and Sm–Nd isotope analysis of whole-rock samples. These analyses underpin construction of a range of isotope maps, which are powerful for imaging lithospheric and crustal architecture, identifying metallogenic terranes and geodynamic environments favourable for mineralization, and constraining the 4D evolution of the lithosphere. Other isotope techniques, some of which are now included under separate project ES55 Novel Geochronology, include Re–Os geochronology, whole-rock Lu–Hf and Pb isotopes, and in situ laser Rb–Sr geochronology. Whole-rock geochemistry remains critically important to GSWA's geoscience programs, and a large proportion of geochemistry analyses is related to samples submitted under ES49 Greenstone Geochemical Barcoding Project and ES51 Yilgarn Granite Project.

Highlights and activities

- GSWA's statewide samarium–neodymium (Sm–Nd) and lutetium–hafnium (Lu–Hf) isotope maps were updated with new data acquired during 2021–22. Previously released Sm–Nd data have been augmented with analyses of 230 new samples, for a total of 2224 analyses, and previously released Lu–Hf data have been augmented with 1311 new analyses from 55 samples, for a total of 14 059 analyses from 778 samples. The maps depict two-stage depleted mantle model ages (T_{DM}^2), which are proxies for the ages of the crustal sources of igneous rocks, and crustal residence times (T_{CR}), which show the difference between model and corresponding crystallization ages, and indicate how long the sources resided in the crust. Significant gradients in model ages are typically associated with major crustal structures that reflect lithospheric architecture and are potentially important for localizing mineral systems
- GSWA's statewide zircon oxygen isotope map, compiled in collaboration with UWA and GA, was also updated in 2021–22, with the addition of 880 new analyses from 49 samples, for a total of 3909 analyses from 231 samples. Zircon oxygen isotope ($\delta^{18}O$) values identify reworking and recycling of supracrustal rocks that have interacted with Earth's hydrosphere, and can be related to geodynamic processes. The map shows that the Pilbara and Yilgarn Cratons are dominated by mantle-like $\delta^{18}O$ values (4.7 – 5.9‰), suggesting that Archean granitic rocks were mainly formed through reworking of igneous material that had not been exposed at the surface. In contrast, Proterozoic rocks in the Capricorn, Paterson and Albany–Fraser Orogens and the Madura and Coompana Provinces indicate mainly elevated $\delta^{18}O$ values (6.6 – 10.4‰), suggesting significant reworking of upper crustal material subjected to weathering or low-temperature hydrothermal alteration
- SHRIMP (75) and LA-ICP-MS (16) U–Pb geochronology of 91 zircon, monazite and baddeleyite samples, from the Youanmi, Narryer and South West Terranes and the Eastern Goldfields Superterrane of the Yilgarn Craton, the Pilbara Craton, the West Arunta Province, and the Capricorn, Albany–Fraser, Pinjarra and Wunaamin Miliwundi Orogens
- Combined with U–Pb and oxygen isotope analyses and seismic reflection data, GSWA's Lu–Hf isotope data elucidate the origin and evolution of the Percival Lakes Province (PLP), an area of Proterozoic lithosphere hidden beneath Neoproterozoic to Cenozoic basins. The results, published in the journal *Geology*, indicate that the PLP consists mainly of reworked remnants of Mesoproterozoic oceanic crust, and that Proterozoic Australia was amalgamated during the earliest phases of Rodinia supercontinent assembly at c. 1.3 Ga (Fig. 21)

EIS program review

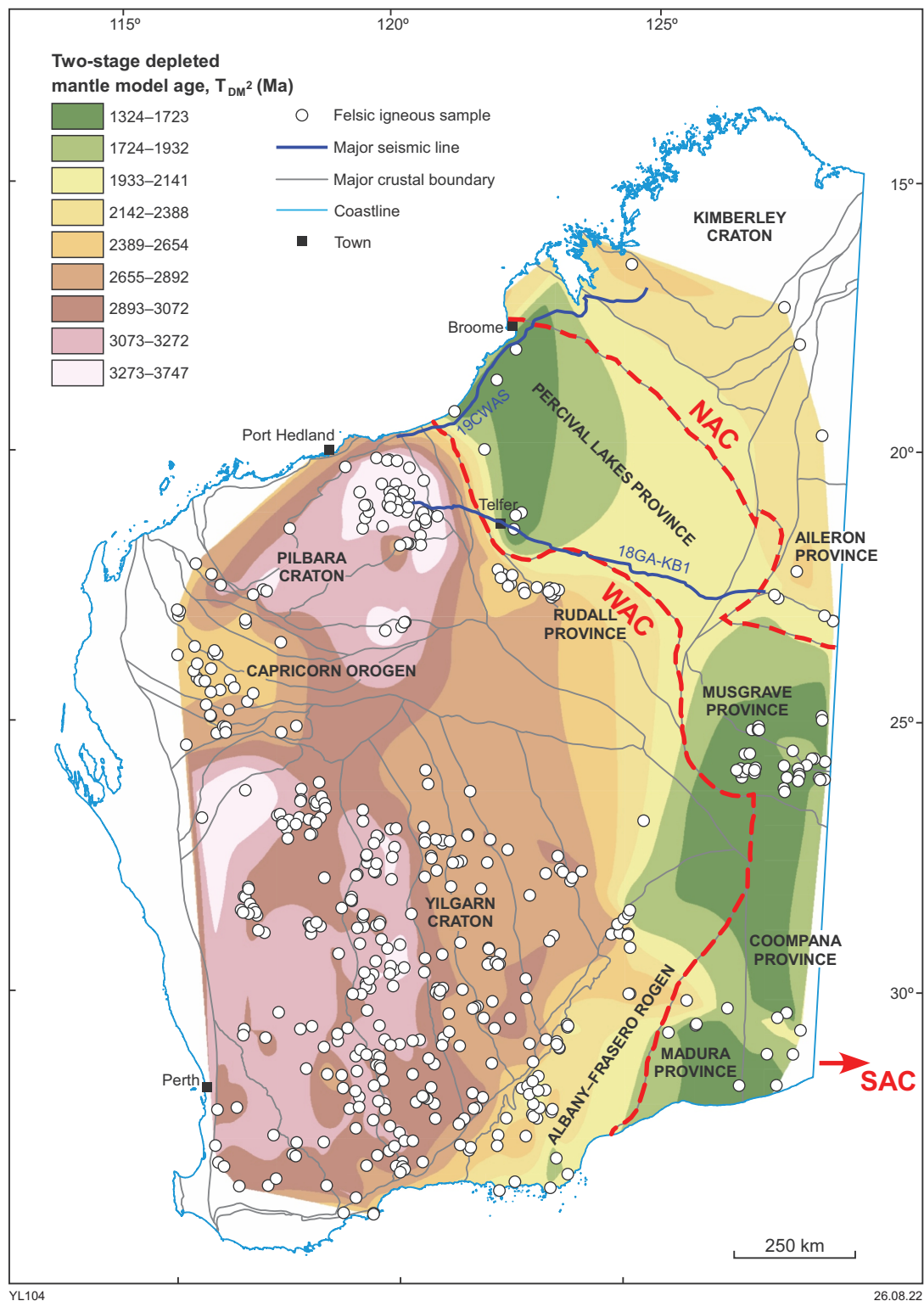


Figure 21. Zircon Lu-Hf isotope map for felsic igneous rocks in Western Australia, based on the median two-stage depleted mantle model age (T_{DM^2}). It highlights the existence of a ~1700 × 400 km Proterozoic lithospheric domain consisting of the Percival Lakes, Musgrave, Coompana and Madura provinces between the West Australian (WAC), North Australian (NAC), and South Australian Cratons (SAC). The apparent absence of Archean lithosphere between the three cratons implies they never directly collided or that complete collision was prevented by impingement of 3D promontories in the converging lithospheric blocks

EIS program review

- SHRIMP U–Pb zircon geochronology of drillcore samples from western Arunta Province rocks beneath the eastern margin of the Canning Basin (see GS65) continue to yield exciting results. Granitic gneisses indicate protolith crystallization ages of c. 1875 Ma, and detrital zircons in paragneiss samples are dominated by c. 1870 Ma age components and yield maximum depositional ages of 1870–1850 Ma. Zircon rims in all samples indicate high-grade metamorphism at 1620–1610 Ma. Zircons from altered granitic rock in the western Aileron Province, a region currently being explored for iron oxide–copper–gold (IOCG) mineralization, yielded a protolith age of c. 1608 Ma and indicate metamorphic or hydrothermal alteration at c. 1580 Ma. Zircons from a nearby detrital sample contain metamorphic rims dated at c. 1586 Ma. These dates are only slightly younger than c. 1590 Ma ages for IOCG deposits in South Australia, such as the giant Olympic Dam deposit
- GSWA has committed to cash and in-kind support, together with several university and industry partners, for an ARC LIEF grant put forward by UWA, to secure a high-sensitivity isotope dilution thermal ionization mass spectrometry (IDTIMS) instrument for U–Pb geochronology. A facility of this type is critically needed in Western Australia, and will complement existing ion microprobe and laser-ICP-MS capabilities
- The WAGIMS database is essentially complete and is being populated with metadata, files and data related to geochronology, isotope studies, and mineral chemistry. The new database will enable complex, statewide data queries and form the basis of a new system for publishing reports that provides access to additional sample-related materials and consistently incorporates the most up-to-date geological and analytical information
- Contributions to GSWA publications and data packages:
 - » Report 223 Alteration and Cu-Au mineralization at the Obelisk prospect, Paterson Orogen, Western Australia
 - » Report 222 The Cobb Embayment: Ordovician syntectonic siliciclastic deposition on the eastern margin of the Canning Basin, Western Australia
 - » Record 2022/6 In situ biotite and apatite Rb–Sr geochronology of metasedimentary and meta-igneous rocks in Western Australia
 - » Record 2022/2 Geology and mineralization potential of the Gerry Well greenstone belt (Collurabbie region), northeastern Yilgarn Craton
 - » Record 2021/8 GSWA 2021 extended abstracts: advancing the prospectivity of Western Australia
 - » Record 2021/4 Accelerated Geoscience Program extended abstracts, 2021
 - » Southwest Yilgarn Geological Exploration Package
 - » Geological Information Series: Northwest Pilbara 2020, East Yilgarn 2020, East Albany–Fraser Orogen 2020, Youanmi 2020
 - » Barnicarndy 1 deep stratigraphic drillhole (poster)
 - » GSWA Fieldnotes and social media pages.

EIS program review

Products released

- 102 new Geochronology Records and U–Pb datasets released to online applications, published maps and digital products (GeoVIEW.WA, DASC and eBookshop)
- 4046 new whole-rock geochemistry analyses released via GEOVIEW.WA and eBookshop
- New digital data layers released or updated in GeoVIEW.WA, DASC and/or digital data packages:
 - » GSWA Geochronology, featuring 1899 Geochronology Records, together with corresponding digital isotope datasets
 - » Whole-rock Sm–Nd isotope maps and extended abstract, including 2224 samples in total (new data for 230 samples)
 - » Zircon Lu–Hf isotope maps and extended abstract, including 14 059 spot analyses from 778 samples (new data from 55 samples)
 - » Zircon oxygen isotope maps and extended abstract, including 3909 spot analyses from 231 samples (new data from 49 samples)
- Report 226 Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag Groups – Ora Banda to Kambalda region
- Report 215 Geochronology of metasedimentary and igneous rocks in the Lamboo Province, Kimberley region: reassessing collisional geodynamic models
- Record 2022/9 Yilgarn Granite Project – notes to accompany 2022 data release
- Record 2022/8 Eastern Goldfields greenstone geochemical barcoding project – notes to accompany 2022 data release
- Record 2022/3 Extreme rare earth element enrichment in altered basaltic rocks of the Eastern Goldfields

EIS program review

ES47 Energy Systems

Manager: Deidre Brooks

Objectives

The objective of this program area is to collect pre-competitive data to assist in determining the State's potential for energy sources such as petroleum, geothermal, carbon capture and storage, helium and natural hydrogen that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms.

Highlights and activities

- The Barnicarndy 1 stratigraphic well was drilled during 2019–20. The drilling was funded by the Commonwealth Government EFTF program, administered by GA. The post-well analysis performed by GSWA is funded by the EIS. Post-well analysis completed in 2021–22 includes thermochronology, sequence stratigraphy, ichnology and carbon and oxygen isotope analysis. These new results will be incorporated into the Interpretive Well Completion Report which was originally slated to be released in 2021–22. Due to delays in staff availability this report will be released in 2023–24. Work on the Barnicarndy 1 Digital Core Atlas continued
- The geophysical analysis and seismic correlation of the Barnicarndy 1 well to the 2018 Kidson Seismic Survey was completed and a Record released in 2021–22
- During 2021–22, two SEEBASE projects were funded by the EIS: the Officer Basin SEEBASE and the Perth Basin SEEBASE (Fig. 22). The draft results were completed in June 2022 and the final products for both of these studies will be released through the DMIRS eBookshop and WAPIMS in 2022–23
- An EIS-funded Canning Basin collaborative core analysis project in 2015–16 for the well Olympic 1 is still yielding new information. A Record on the petrophysical and petrographic assessment of the reservoir and seal quality, including commentary on the CO₂ storage potential, was written and is planned for release in 2022–23
- In January 2022, a three-year collaborative project between the Energy Geoscience and Carbon Strategy branch, the HyLogger section and CSIRO was initiated to develop machine learning-based automated lithology classification of petroleum cuttings. The project is using HyLogger high-resolution digital images of selected cuttings of representative lithologies and wells.

Product released

- Record 2021/9 Geophysical analysis of Barnicarndy 1: data quality control, velocity anomalies, out-of-plane reflections, and correlation uncertainties

EIS program review

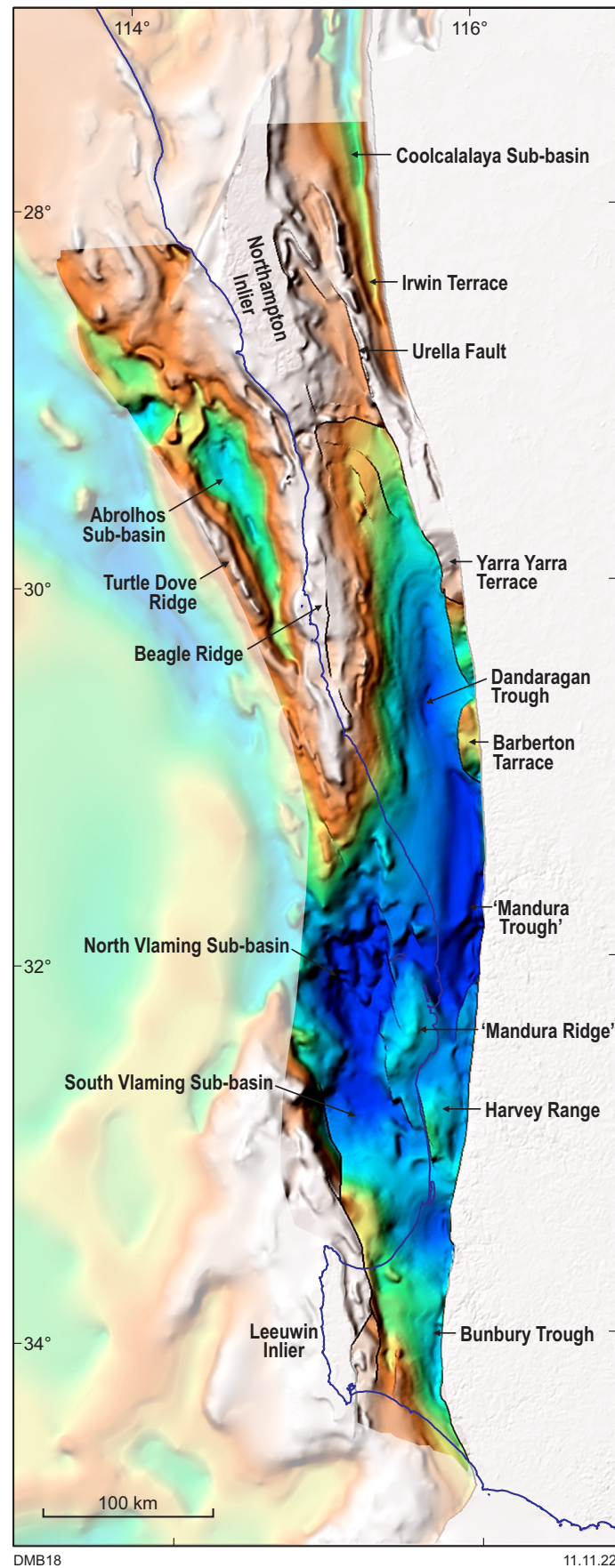


Figure 22. New Perth Basin 2022 SEEBASE image showing interpreted Depth to Basement (dark blue = deep, grey = shallow or basement at surface)

EIS program review

ES49 Greenstone Geochemical Barcoding Project

Manager: Hugh Smithies

Objectives

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

Highlights and activities

- 723 new samples were submitted for whole-rock major and trace element geochemistry
- Continued sampling of outcrop and drillcore samples from the central southern Kalgoorlie Terrane to support chemostratigraphic interpretations in that area
- Analytical data from a drillcore sampling campaign (~400 samples) in the Norseman region was returned and will form a focus of future interpretation
- Further sampling in support of regional chemostratigraphic interpretations in the northern Kalgoorlie Terrane through the Yilgarn 2020 Project conducted through the Centre for Exploration Targeting (CET) and UWA
- Sampling in support of regional chemostratigraphic interpretations in the southern, central and western Kurnalpi Terrane has begun.

Products released

- Greenstone Geochemical Barcoding Project – 2022 data release (Record 2022/8 Eastern Goldfields Geochemical Barcoding dataset, Appendix 1)
- Record 2022/8 Eastern Goldfields greenstone geochemical barcoding project – notes to accompany 2022 data release
- Record 2022/3 Extreme rare earth element enrichment in altered basaltic rocks of the Eastern Goldfields
- Report 226 Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag Groups – Ora Banda to Kambalda region

EIS program review

ES51 Yilgarn Granite Project

Manager: Hugh Smithies

Objectives

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

Highlights and activities

- A total of 1999 samples, including 1934 samples from the GA collection, was reanalysed and 65 samples from the GSWA archive collection were submitted for whole-rock major and trace element geochemical analysis.

Products released

- Yilgarn Granite Project – 2022 data release (Record 2022/9 Yilgarn Granite Project dataset, Appendix 1)
- Record 2022/9 Yilgarn Granite Project – notes to accompany 2022 data release

EIS program review

ES55 Novel Geochronology and Isotope Analysis

Manager: Fawna Kornhonen

Objectives

The Novel Geochronology and Isotope Analysis project complements the work done by Geochronology and Geochemistry (GS54) and Enhanced Geochronology and Isotopic Mapping (ES46). 'Novel' isotope techniques were added to date a wider range of rocks and minerals and to isotopically characterize and trace a wider range of geological processes. This work relies on the increasing range of available isotopic methods that are now available (due to technological advances in, for example spectrometer detection limits, in situ techniques, simultaneous acquisition of trace element chemistry), which provide innovative opportunities to expand isotope studies to a wider range of rocks and minerals. These advances include several novel techniques that can be applied to date geological events that may not otherwise be possible with traditional U–Pb techniques, including mineralization, alteration, hydrothermal fluid flow, low- to medium-temperature metamorphism, deformation, exhumation, and diagenesis. In many cases, these analyses can be done in situ, preserving the mineralogical relationships in a sample, together with simultaneous measurement of trace elements to assess, for example, fertility, mineral systems footprints, pressure–temperature conditions and paragenesis.

Highlights and activities

- This was the inaugural year of the project, which has been set up in a different way from other projects (i.e. committee consensus to select successful projects). As such, the management of the project required a Terms of Reference document, and other administrative tasks that were finalized at the beginning of the project approval
- In situ Rb–Sr dating of biotite, muscovite, and apatite was completed from 16 samples across the State, and in situ Lu–Hf garnet dating from four samples
- Support for a multi-year project focused on developing a new radiogenic dating method based on apatite to provide age constraints on salt stratigraphy
- Support for a multi-year project to conduct apatite fission track dating in MinEx CRC project areas.

Products released

- Rb–Sr Geochronology Records for 10 samples across the State
- Record 2022/6 In situ biotite and apatite Rb–Sr geochronology of metasedimentary and meta-igneous rocks in Western Australia

EIS program review

ES71 2D and 3D Active Seismic Surveys

Manager: David Howard

Objectives

Deep crustal, active seismic surveys were previously included as part of the program of deep earth imaging together with passive seismic and magnetotelluric surveys. In 2021–22, with the completion of the AusAEM program in reach, GSWA decided to increase funding to both active as well as passive seismic acquisition. Active seismic acquisition was separated administratively, under its own cost centre, from the expanded passive seismic (WA-Array) and magnetotelluric (AusLAMP-WA) programs designed to investigate the deeper lithospheric architecture, and which have remained as the Passive Seismic and Magnetotelluric Surveys work programs.

Currently, Western Australia has an aggregate coverage of 7326 line-km of deep active seismic transects as shown in Figure 23, which also illustrates the impact of EIS funding on the rate of acquisition. In the 17 years between 1988 and 2005, a total of 2483 km of lines was acquired, mostly funded by GA (and its antecedents). With the contribution of EIS funding, in the nine years between 2010 and 2019, GSWA and GA acquired a total of 4843 km of data – twice the number of kilometres in half the time.

GSWA is now looking to expand the number of transects in key lithostructural areas to improve understanding of the major crustal structures in the State.

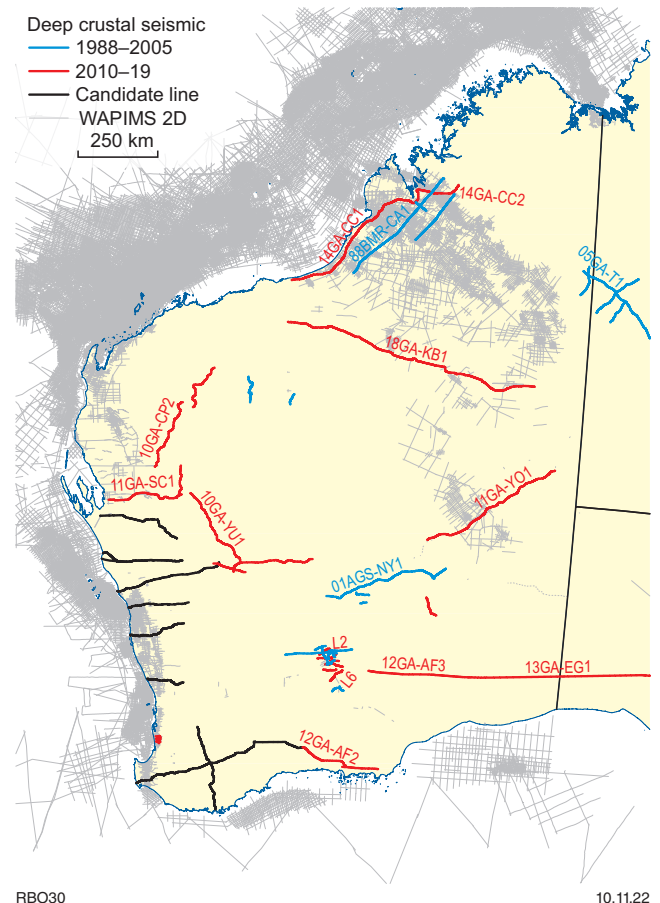


Figure 23. Location of deep crustal and other seismic lines

Highlights and activities

- Planning began for deep crustal surveys in the South West Terrane and in the area of the North Perth Basin, in the State's Midwest region. A Request for Tender will be issued in the early part of 2022–23. The total number of lines and kilometres of data will depend on tendered prices and available budget, but it is anticipated that an aggregate of up to 700 km should be possible. Candidate lines are shown in Figure 23.

Products released

- No products were released during 2021–22.

Special projects

TF70 Hydrogen Storage Potential of Depleted Oil and Gas Fields

Managers: Deidre Brooks and Sunil Varma

Objectives

The Western Australian Renewable Hydrogen Strategy defines the areas of focus for the development of the hydrogen industry, including exports, remote applications, hydrogen blending in natural gas networks and transport. The Western Australian Government has established a dedicated Renewable Hydrogen Unit to coordinate the State's work on growing the industry, both domestically and for export. The Unit will be a central point of contact for industry and will coordinate activities across relevant Western Australian Government agencies to embed the Strategy's vision. The global market for renewable hydrogen is expected to grow significantly over the coming decades. Western Australia is well placed to capture a significant share of this market due to its excellent renewable energy resources, skilled oil and gas workforce, proximity to Asia, and export infrastructure.

This project was one of these initiatives that will identify subsurface locations suitable for hydrogen storage. The objective of the program was to assess the potential for hydrogen storage in depleted oil and gas fields in the northern Perth Basin and onshore Carnarvon Basin especially with respect to containment, injectivity and extraction, and a high-level review of alternative options for underground storage of hydrogen across Western Australia.

The original proposal was to take a two-stage approach. Stage 1 is a literature review and scoping study. Stage 2 was to consist of 3D static and dynamic compositional modelling of selected depleted oil and gas fields for storage capacity estimation, containment and contamination risks. The Renewable Hydrogen Unit decided to cancel the funding for Stage 2.

The literature review was released in January 2022 and included a high-level assessment of the geological underground storage of hydrogen in depleted oil and gas fields and saline aquifers, and other examples of underground geological storage of hydrogen. The scoping study focused on depleted fields in the northern Perth Basin and onshore Carnarvon Basin within Western Australia to identify the most prospective fields.

Product released

- GSWA Report 221 Hydrogen Storage Potential of Depleted Oil and Gas Fields in Western Australia – Literature Review and Scoping Study

Appendix 1

Collaborative research projects

Completed projects for 1 July 2021 to 30 June 2022

ARC Linkage project LP130100722 – Earth’s best-preserved Archean boninites: do they finally resolve the Archean mantle plume–plate controversy?

Project manager: Derek Wyman (University of Sydney)

Partner researchers/institutions: Jack Lowrey (PhD candidate, University of Sydney / GSWA)

GSWA contact: Tim Ivanic

Duration of project: 2014–18 (extended to 2022)

Project description

This study looked at the geochemistry of mafic rocks in the Murchison Domain of the Yilgarn Craton. Subduction typically starts in the modern Earth with the eruption of chemically distinctive rocks known as boninites. This project studied remarkably well-preserved 2.8 billion-year-old boninites from Western Australia that may finally establish whether modern-style plate tectonics operated in the first half of Earth’s history.

Outputs – planned or actual

- Peer-reviewed journal papers, conference proceedings, GSWA Open Day posters, PhD thesis; GSWA Report
- Lowrey, JR, Ivanic, TJ, Wyman, DA and Roberts, MP 2017, Platy pyroxene: new insights into spinifex texture: *Journal of Petrology*, v. 58, no. 9, p. 1671–1700.
- Lowrey, JR, Wyman, DA, Ivanic, TJ, Smithies, RH and Maas, R 2020, Archean Boninite-like Rocks of the Northwestern Youanmi Terrane, Yilgarn Craton: *Geochemistry and Genesis: Journal of Petrology*, doi:org/10.1093/petrology/egaa002.



Critical minerals (Li, Ta, Nb, W, REE) in the western Yilgarn Craton

Project manager: Trevor Beardsmore

Partner researchers/institutions: CSIRO

GSWA contacts: Trevor Beardsmore, Paul Duuring

Duration of project: 2020–21 (extended to 2021–22)

Project description

CSIRO reanalysed about 2438 laterite samples from the western Yilgarn Craton using modern analytical techniques, to determine lithium and several other critical metals (i.e. tin, tungsten, tantalum and REE) that could not be reliably measured in previous analytical campaigns using older technologies. The study also collected near-infrared, short-wave infrared and thermal spectral data using the HyLogger-3 system and included mineralogy derived from X-ray diffraction analyses from selected samples.

Outputs – planned or actual

- Report 233 Critical minerals in laterite related to pegmatite mineral systems of the western Yilgarn Craton (Li, W, Sn, Ta, REE)
- Laterite geochemistry and mineralogy datasets

In situ biotite Rb–Sr geochronology for multiple ‘t’ in ‘P-T-t’

Project partner: Chris Kirkland (Curtin University)

GSWA contact: Fawna Korhonen

Duration of project: February 2021 to July 2021 (extended to end of 2022)

Project description

Rb–Sr biotite analysis via in situ laser ablation analysis for targeted samples in Western Australia, case study. This technique offered the ability to provide potentially high-precision ages of major fabric-forming mica grains. Rb–Sr biotite ages typically reflect the time through a specific closure temperature that may be close to the crystallization age, dependent on the P – T pathway the rock has taken and rate at which the rock evolves thermally. This technique offered the potential of a powerful new tool to determine the age at which a mineral grows in a deformation–metamorphic fabric, which has previously been difficult to do. When coupled with P – T information from a sample, this provided a rare opportunity to directly date the age of metamorphism from part of the major mineral assemblage.

Outputs – actual

- Biotite Rb–Sr geochronology records on 10 samples compiled into a single GSWA Record, including data tables (raw + processed data; data for standards), figures, images of analytical spot locations, stage file of analysis spots, and interpretation. Sample thin sections returned

Interferometric processing

Project partner: Juerg Hauser (CSIRO)

GSWA contact: Klaus Gessner

Duration of project: March 2021 to August 2021

Project description

Develop and apply a methodology to:

- Reconstruct long offset (<100 km) data from short offset (<10 km) batches of seismic reflection survey data
- Potentially enhance the signal-to-noise ratio
- Establish the feasibility of direct inference of the interfaces and velocity (V_p) from the data reprocessed by CSIRO.

Outputs — actual

- Reports, white paper, seismic interferometric reconstruction method
- A ‘white paper’ progress Report and a presentation of results were delivered to GSWA in November 2021

Appendix 1



Deep learning identification of anomalous data in geochemical datasets

This project is completed and a Report will be published in 2022–23.

Project manager: Trevor Beardsmore

Partner researchers/institutions: Vladimir Puzyrev (Curtin University)

GSWA contact: Paul Duuring

Duration of project: Completed in 2021

Project description

The study applied deep learning models to identify spurious geochemical data within the five WAMEX geochemical datasets. Spurious geochemical data are defined as those samples that have predicted analyte values that are very different from their measured values.

Outputs – actual

- Report



CSIRO Ultrafine+ soils Phase 2 (EIS)

Project manager: Richard Chopping

Partner researchers/institutions: Ryan Noble (CSIRO)

GSWA contact: Nadir de Souza Kovacs

Duration of project: 2019–21 (extended to 2022 for output delivery)

Project description

Supporting the MinEx NDI Western Australian focus area, undertaking UltraFine+ reanalysis of west Arunta regolith geochemistry samples, and other samples collected during geophysical deployments.

Outputs – actual

- Geochemical analyses in WACHEM, Records and Reports
- GSWA received the data plus a presentation on the findings at the UltraFine+ sponsors meeting

Appendix 2

Products and services delivered

Category	Product/service type	Total
Maps	ALL	5
Text publications	Reports/Records/miscellaneous books	34
External publications	All external publications	36
Data packages	Data packages (including online data releases)	8
Digital layers	Digital layers	10
Posters/flyers	Posters and flyers	65
Data acquisition	Explanatory Notes System (ENS) online	159
	HyLogger scanning (per metres scanned)	58 966
	Aeromagnetic survey (line km)	0
	EIS Co-funded drilling – diamond drilling (metres released)	42 369
	EIS Co-funded drilling – other (metres released)	79 562
	Gravity (ground; per station)	0
	Gravity (airborne; line km)	0
	Electromagnetic survey (per line km)	30 176
	Active seismic survey (per line km) – acquisition	0
	Active seismic survey (per line km) – reprocessing	0
	Passive seismic survey (stations)	66
	Geochemistry (sample)	4 046
	Geochronology (report per sample)	102
	Hyperspectral scanning summary (drillhole)	1 375
	Paleontology Reports	32
	Isotope analysis (sample)	200
	GSWA stratigraphic drilling (metres drilled)	0
Information and advice services	Core library – core released (pallets)	254
	Core library – cuttings and vials released (pallets)	19
	Core library – pallets laid out for viewing	3 019
	Industry exploration reports – minerals reports released only	2 642
	Industry exploration records – petroleum records released only	6 078
Information and advice services – land use	Mining Act administration – mineralisation reports, resource reports, sterilization report assessment	71
	Mining Act referrals – expenditure exemptions, extensions of term, retention licence, retention status, SPL reports for the Warden	957
	Geological Advice (Mining Act s.16(3)) – Native Title Settlement – full assessments	441
	Geological Advice (Mining Act s.16(3)) – Native Title Settlement – indicative assessments	471
	Geological advice – land use referrals assessed	799
	Land use management – land use / land tenure change referral assessments	1 515
Mining title and native title services – titles information	Native title claims delivered to SSO/NTTT ^(a)	29
	Native title maps: Right to Negotiate/resource access for SSO/NTTT ^(b)	258
	Number of granted leases issued for survey ^(c)	287

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

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

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

Appendix 3

Products released

Maps

Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia – 2022
Ridge, KJ

Kimberley mineral resources and petroleum projects 2022
Pal, T, Wyche, NL, Murray, SI and D'Ercole, C

Major resource projects, Western Australia 2021 October
Sargent, SN, Wyche, NL, D'Ercole, C, Murray, SI and Irimies, F

Major resource projects, Western Australia 2021
Sargent, SN, Wyche, NL, D'Ercole, C, Murray, SI and Irimies, F

Mines – operating and under development, Western Australia 2022
Sargent, SN, Wyche, NL, D'Ercole, C, Murray, SI and Pal, T

Data packages

East Yilgarn Geological Information Series, 2021

Fortescue–Hamersley Geological Information Series, 2022

West Yilgarn Geological Information Series, 2022

Western Australian State geoscientific imagery and data, 2021

Digital layers

1:100 000 State interpreted bedrock geology of Western Australia

1:10 000 000 tectonic units of Western Australia

1:100 000 regolith geology regimes of Western Australia, 2022
De Souza Kovacs, N

Compilation of metamorphic history information, 2021–22

Mineral Systems Atlas, seven primary data layers

Resource estimates by project
Wyche, NL, D'Ercole, C, Murray, SI and Pal, T

Resource estimates by project (gold)
Wyche, NL, D'Ercole, C, Murray, SI and Pal, T

Samarium–neodymium isotope map of Western Australia
Lu, Y, Wingate, MTD, Champion, DC, Smithies, RH, Johnson, SP, Gessner, K, Mole, D, Poujol, M, Maas, R, Zhao, J and Creaser, RA

WAROX Text Extracts Online

Zircon lutetium–hafnium isotope map of Western Australia
Lu, Y, Wingate, MTD, Kemp, AIS, Smithies, RH, Gessner, K, Johnson, SP, Romano, SS, Mole, D, Kirkland, CL and Belousova, EA

Zircon oxygen isotope map of Western Australia
Lu, Y, Wingate, MTD, Smithies, RH, Johnson, SP and Martin, L

Online/3D geomodels

3D geomodel of Western Australia, 2021

Murdie, RE

Deep time in the Murchison region, Western Australia (Geology Explorer)

White, SR

Geochronology Records and U–Pb datasets released to online applications (GeoVIEW.WA)

Meteorites – alien invaders

Goss, SC

Reports

Report 215 Geochronology of metasedimentary and igneous rocks in the Lamboo Province, Kimberley region: reassessing collisional geodynamic models

Maidment, DW, Lu, Y, Phillips, C, Korhonen, FJ and Fielding, IOH

Report 217 Regional petrophysics: Paterson Orogen 2020–21

Markoski, M, Bourne, B and Trunfull, J

Report 218 Regional petrophysics: West Arunta 2020–21

Markoski, M, Bourne, B and Trunfull, J

Report 219 Regional petrophysics: Eucla basement 2020–21

Markoski, M, Bourne, B and Trunfull, J

Report 220 Depth to the basement estimate from seismic data – a comparative study

Yang, A

Report 221 Hydrogen storage potential of depleted oil and gas fields in Western Australia – literature review and scoping study

RISC

Report 222 The Cobb Embayment: Ordovician syntectonic siliciclastic deposition on the eastern margin of the Canning Basin, Western Australia

Haines, PW, Allen, HJ, Wingate, MTD, Zhan, Y and Dent, LM

Report 223 Alteration and Cu–Au mineralization at the Obelisk prospect, Paterson Orogen, Western Australia

Duuring, P, Guilliame, JN, Kelsey, DE, Fielding, IOH and Fonteneau, L

Report 224 Regional petrophysics: Kalgoorlie Terrane 2020–21

Markoski, M, Bourne, B and Trunfull, J

Report 225 Regional petrophysics: Yamarna Terrane 2020–21

Markoski, M, Bourne, B and Trunfull, J

Report 226 Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag

Groups – Ora Banda to Kambalda region

Smithies, RH, Lowrey, JR, Sapkota, J, De Paoli, MC and Hayman, P

Report 230 Source-rock potential of Permian rocks in the Southern and Northern Carnarvon Basins

Thomas, CM

Report 231 Regolith–landform mapping of the west Kimberley Craton: application of geophysics and spectral remote sensing

De Souza Kovacs, N and Cudahy, TJ

Report 232 Formation of the Yilgarn protocraton by rift-related magmatism from 3.01 to 2.92 Ga

Ivanic, TJ, Wingate, MTD, Lowrey, JR and Lu, Y

Report 233 Critical metals in laterite related to pegmatite mineral systems of the western Yilgarn Craton

(Li, W, Sn, Ta, REE)

Otto, A, Lampinen, H, Pinchand, T, Huntington, JF and Noble, RRP

Appendix 3

Records

Record 2021/1 Geological Survey work program 2021–22

Record 2022/1 GSWA work program 2022–23

Record 2021/8 GSWA 2021 extended abstracts: advancing the prospectivity of Western Australia

Record 2021/9 Geophysical analysis of Barnicarndy 1: data quality control, velocity anomalies, out-of-plane reflections, and correlation uncertainties
Zhan, Y

Record 2021/10 Iron-formations: a mineral systems analysis
Duuring, P

Record 2022/2 Geology and mineralization potential of the Gerry Well greenstone belt (Collurabbie region), northeastern Yilgarn Craton
Grech, LL, Lu, Y, Wang, Y, Gao, Y and Qian, B

Record 2022/3 Extreme rare earth element enrichment in altered basaltic rocks of the Eastern Goldfields
Smithies, RH and Lowrey, JR

Record 2022/4 Fortescue-Hamersley, 2022: extended abstracts

Record 2022/6 In situ biotite and apatite Rb–Sr geochronology of metasedimentary and meta-igneous rocks in Western Australia
Liebmann, J, Kirkland, CL, Korhonen, FJ, Kelsey, DE and Rankenburg, K

Record 2022/7 Compilation and geological implications of the major crustal boundaries map and 3D model of Western Australia
Martin, DMcB, Murdie, RE, Kelsey, DE, Quentin de Gromard, R and Thomas, CM

Record 2022/8 Eastern Goldfields greenstone geochemical barcoding project – notes to accompany 2022 data release
Lowrey, JR and Smithies, RH

Record 2022/9 Yilgarn Granite Project – notes to accompany 2022 data release
Lowrey, HR and Smithies, RH

Miscellaneous books

John Forrest National Park Railway Reserve Heritage Geotrail – Geology explorer
Freeman, MJ

GSWA calendar 2022

Geological Survey Annual Review 2020–21

Paleontology Reports

Fieldnotes: GSWA newsletter July 2021 number 99

Fieldnotes: GSWA newsletter October 2021 number 100

Fieldnotes: GSWA newsletter January 2022 number 101

Fieldnotes: GSWA newsletter April 2022 number 102

Posters

40 posters

Flyers

25 commodity flyers

Appendix 4

External publications on Western Australian geoscience 2021–22

GS01 Executive Team

Gessner, K, Calvert, A, Doublier, M, **Brisbourn, L**, Huaiyu, Y and **Murdie, R** 2021, Seismic imaging of layered crust in the Pilbara Craton: A challenge for Paleoproterozoic crustal overturn?, AGU Fall Meeting 2021, Abstract S51E-02, New Orleans, US, 13–17 December 2021.

GS10 Energy Geoscience and Carbon Strategy

Green, T, Slotznick, SP, Jaqueto, P, Raub, TD, Tohver, E, Playton, TE, **Haines, PW**, Kirschvink, JL, Hocking, RM and Montgomery, P 2021, High-resolution Late Devonian magnetostratigraphy from the Canning Basin, Western Australia: A re-evaluation: *Frontiers in Earth Science*, v. 9, article no. 757749, 12p., doi:10.3389/feart.2021.757749.

Normore, LS, **Haines, PW**, Carr, LK, Henson, P, **Zhan, Y**, **Wingate, MTD**, Zhen, YY, **Lu, Y**, **Martin, SK**, **Kelsey, D**, **Allen, H** and **Fielding, IOH** 2021, Barnicarndy Graben, southern Canning Basin: stratigraphy defined by the Barnicarndy 1 stratigraphic well: *The APPEA Journal*, 61, p. 224–235, doi:10.1071/AJ20160.

Playton, TE, Kerans, C, Hocking, RM, **Haines, PW**, Adams, EW, Hurley, NF and Frost, EL 2021, Devonian reefal carbonates of the Lennard Shelf, Canning Basin, Western Australia: Field guide for a classic carbonate outcrop of the world, *in* Field guides to exceptionally exposed carbonate outcrops *edited by* VP Wright, G Della Porta and E Samankassou: International Association of Sedimentologists, p. 1–69.

Zhan, Y and **Haines, PW** 2022, A regional strike-slip movement under the Canning Basin: *The APPEA Journal*, v. 62, doi:10.1071/AJ21169.

GS20 Mineral Systems Studies

Rebagliati, M, **Duuring, P**, Dickinson, JM, McKinley, BSM and Fagan, AJ 2020, Geology and exploration of the Triassic-Jurassic porphyry-style Cu–Au–Ag±Mo mineralization in the Kemess-Pine area, Toodoggone district, British Columbia, Canada, *in* Porphyry Deposits of the Northwestern Cordillera of North America: A 25-Year Update *edited by* ER Sharman, JR Lang and JB Chapman: Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 57.

GS52 East Yilgarn

Hartnady, MIH, Kirkland, CL, **Smithies, RH**, **Johnson, SP** and Johnson, TE 2021, Pb isotope insight into the formation of the Earth's first stable continents: *Earth and Planetary Science Letters*, v. 578, doi:10.1016/j.epsl.2021.117319.

Zameter, A, Kirkland, CL, Hartnady, MIH, Barham, M, Champion, DC, Bodorkos, S, **Smithies, RH** and **Johnson, SP** 2022, Applications of Pb isotopes in granite K-feldspar and Pb evolution in the Yilgarn Craton: *Geochimica et Cosmochimica Acta*, v. 320, p. 279–303, doi:10.1016/j.gca.2021.11.029.

GS53 State Geoscience

Geological Survey of Western Australia 2021, Closing in on AusAEM–WA: Preview, v. 2021, iss. 214, p. 25, doi:10.1080/14432471.2021.1986980.

Geological Survey of Western Australia: WA-Array announced: Preview, 2022, v. 2022, iss. 218, doi:10.1080/14432471.2022.2083385.

Riganti, A and Haworth, JH 2021, 'Or what good has any geologist ever done to Western Australia?', in Book of Abstracts for the 46th International Commission on the History of Geological Sciences (INHIGEO) Symposium, 19–22 July 2021, Poland, p. 50.

Selway, K, Dentith, M and **Gessner, K** 2021, Lithospheric-scale magnetotellurics over the Eastern Goldfields Superterrane, Yilgarn Craton: Geological Society of Australia, Australian Earth Sciences Convention, February 2021.

Zhen, YY, **Allen, HJ** and **Martin, SK** 2022, Early Ordovician conodonts from Barnicarndy 1 stratigraphic well of the Southern Canning Basin, Western Australia: *Alcheringa: An Australasian Journal of Palaeontology*, v. 46, iss. 1, p. 43–58, doi:10.1080/03115518.2021.2017481.

Murdie, RE, Yuan, H, Miller MS, Pickle, R, Salmon, M and Whitney, J 2022, Rapid deployment for earthquake aftershock monitoring in southwest Western Australia – the Arthur River swarm 2022: *Preview*, v. 2022, iss. 217, p. 39–41, doi:10.1080/14432471.2022.2057678.

GS54 Geochronology and Geochemistry

Austin, JM, Hayman, PC, Murphy, D1, **Wingate, MTD, Lowrey, J, Lu, Y** and Rose, K 2022, The voluminous 2.81–2.71 Ga Goldfields Tholeiitic Super-event: Implications for basin architecture in the Yilgarn Craton and global correlations: *Precambrian Research*, v. 369, 106528, doi:10.1016/j.precamres.2021.106528.

Fougerouse, D, Cavosie, AJ, Erickson, T, Reddy, SM, Cox, MA, Saxey, DW, Rickard, WDA and **Wingate, MTD** 2021, A new method for dating impact events – Thermal dependency on nanoscale Pb mobility in monazite shock twins: *Geochimica et Cosmochimica Acta*, v. 314, p. 381–396, doi:10.1016/j.gca.2021.08.025.

Rowe, ML, Kemp, AIS, **Wingate, MTD**, Petersson, A and van der Riet, C 2021, Cratonisation of Archaean crust: insights from U–Pb zircon geochronology and geochemistry of granitic rocks in the Narryer Terrane, northwest Yilgarn Craton: *Precambrian Research*, v. 372, 106609, doi:10.1016/j.precamres.2022.106609.

GS58 West Yilgarn

Mulder, JA, Nebel, O, Gardiner, NJ, Cawood, PA, Wainwright, AN and **Ivanic, TJ** 2021, Crustal rejuvenation stabilised Earth's first cratons: *Nature Communications*, v. 12, no. 3535, doi:10.1038/s41467-021-23805-6.

GS62 3D Geoscience

Molli, G, Brogi, A, Caggianelli, A, Capezzuoli, E, Liotta, D, Spina, A and **Zibra, I** 2020, Late Palaeozoic tectonics in Central Mediterranean: a reappraisal: *Swiss Journal of Geosciences*, v. 113, no. 23, 32p., doi:10.1186/s00015-020-00375-1.

GS63 Pilbara and Hamersley

Lantink, ML, Davies, JHFL, Hennekam, R, Hilgen, FJ, Lenstra, WK, **Martin, DMcB**, Mason, PRD, Reichart, G-J, Ovtcharova, M and Slomp, CP 2021, Milankovitch climate control on redox cyclicity at the onset of the Great Oxidation Event: *Goldschmidt Virtual 2021*, 4–9 July.

Piechocka, A, Jessell, M, **Martin, DMcB**, Lindsay, M and Ramanaidou, E 2021, Preliminary 3D geological model and structural analysis of the Neoproterozoic to Paleoproterozoic Hamersley Basin, Pilbara, Western Australia, in *Iron Ore Conference 2021: Sustainability in a Changing World: Iron Ore 2021*, Perth, Australia, 8–10 November: Australasian Institute of Mining and Metallurgy, Publication Series No 6/2021, p. 128–137.

GS65 Proterozoic Margins

Williams, MA and **Kelsey, DE** 2022 Thorium zoning in monazite: A case study from the Ivrea–Verbano zone, NW Italy: *Journal of Metamorphic Geology*, v. 40, no. 6, p. 1015–1042.

Normore, L, Haines, PW, Carr, LK, Henson, P, **Zhan, Y, Wingate, MTD**, Zhen, YY, **Lu, Y, Martin, SK, Kelsey, D, Allen, H** and **Fielding, IOH** 2021, Barnicarndy Graben, southern Canning Basin: stratigraphy defined by the Barnicarndy 1 stratigraphic well: *The APPEA Journal*, v. 61, no. 1, p. 224–235, doi:10.1071/AJ20160.

Appendix 4

March, SN, Hand, M, Morrissey, LJ and **Kelsey, DE** 2022 Enigmatic ultrahigh-temperature metamorphism in the Warumpi Province: Continental collision or extension?: Goldschmidt Conference Abstract, Hawaii Convention Center.

GS80 Editing and Publishing

White, SR 2021, Government and geoscience editing: Editors WA, Annual Branch Meeting, 12 August 2021, PowerPoint presentation.

ES42 3D Lithosphere Visualization Project

Chen, X, Levin, V and **Yuan, H** 2021, Small Shear Wave Splitting Delays Suggest Weak Anisotropy in Cratonic Mantle Lithosphere: GRL, v. 48, iss. 16, doi:10.1029/2021GL093861.

Chen, X, Levin, V, **Yuan, H**, Klaser, M and Li, Y 2021, Seismic Anisotropic Layering in the Yilgarn and Superior Cratonic Lithosphere: JGR-Solid Earth, v. 126, iss. 8, doi:10.1029/2020JB021575.

Li, T, Jiang, M, Zhao, L, Yao, W, Chen, L, Chu, Y, Sun, B, Ai, Y, Wan, B, **Gessner, K** and **Yuan, H** 2022, Wedge tectonics in south China: constraints from new seismic data: Science Bulletin, doi:10.1016/j.scib.2022.05.007.

Murdie, RE, Brisbourn, L, Glanville, H, Allen, T, Bugden, C and Dent, V 2021, Earthquake monitoring in the Wheatbelt, Western Australia, Australasian Exploration Geoscience Conference extended abstracts, Brisbane, 15–20 September 2021.

Zhao, L, Tyler, IM, Gorczyk, W, **Murdie, RE, Gessner, K, Lu, Y, Smithies, RH**, Li, T, Yang, J, **Zhan, Y**, Wan, B, Sun, B and **Yuan, H** 2022, Seismic evidence of two cryptic sutures in Northwestern Australia: Implications for the style of subduction during the Paleoproterozoic assembly of Columbia: Earth and Planetary Science Letters, v. 579, 117342, doi:10.1016/j.epsl.2021.117342.

ES46 Enhanced Geochronology and Isotopic Mapping

Caruso, S, Fiorentini, ML, Champion, DC, **Lu, Y**, Ueno, Y and **Smithies, RH** 2022, Sulfur isotope systematics of granitoids from the Yilgarn Craton sheds new light on the fluid reservoirs of Neoarchean orogenic gold deposits: Geochimica et Cosmochimica Acta, v. 326, p. 199–213, doi:10.1016/j.gca.2022.03.023.

Li, Q, Sun, X, **Lu, Y**, Wang, F and Hao, J 2021, Apatite and zircon compositions for Miocene mineralizing and barren intrusions in the Gangdese porphyry copper belt of southern Tibet: Implication for ore control: Ore Geology Reviews, v. 139, Part A, 104474, doi:10.1016/j.oregeorev.2021.104474.

Mole, DR, Frieman, BM, Thurston, PC, Marsh, JH, Jorgensen, TRC, Stern, RA, Martin, LAJ, **Lu, Y** and Gibson, HL 2022, Crustal architecture of the south-east Superior Craton and controls on mineral systems: Ore Geology Reviews, v. 148, 105017.

Parra-Avila, LA, Hammerli, J, Kemp, AIS, Rohrlach, B, Loucks, R, **Lu, Y**, Williams, IS, Martin, L, Roberts, MP and Fiorentini, ML 2022, The long-lived fertility signature of Cu–Au porphyry systems: insights from apatite and zircon at Tampakan, Philippines: Contributions to Mineralogy and Petrology, v. 177, no. 18, doi:10.1007/s00410-021-01878-2.

Wu, C, Chen, H and **Lu, Y** 2022, Crustal structure control on porphyry copper systems in accretionary orogens: insights from Nd isotopic mapping in the Central Asian Orogenic Belt: Mineralium Deposita v. 57, p. 631–641, doi:10.1007/s00126-021-01074-z.

Xu, B, Hou, Z, Griffin, WL, Zhou, Y, Zhang, Y, **Lu, Y**, Belousova, E, Xu, J and O'Reilly, SY 2021, Elevated magmatic chlorine and sulfur concentrations in the Eocene–Oligocene Machangqing Cu–Mo porphyry systems: SEG Special Publications, v. 2, no. 24, p. 257–276, doi:10.5382/SP.24.14.

9999 Mining Rehabilitation Fund

Mitchell, I, **Hryczyszyn, K** and **Read, T** 2019, A framework to prioritise high-risk abandoned mine features for rehabilitation in Western Australia, in Mine Closure 2019: Proceedings of the 13th International Conference on Mine Closure *edited by* AB Fourie and M Tibbett: Australian Centre for Geomechanics, Perth, p. 123–132, doi:10.36487/ACG_rep/1915_11_Mitchell.

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