GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REVIEW 2018–19

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

Geological Survey of Western Australia

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Cover
Outcrop of the Duck Creek Dolomite that consists of thin- to very thick-bedded, buff or grey-weathering dolomite. It is commonly stromatolitic or brecciated, and silicification is locally intense. The formation is only weakly resistant to weathering and erosion and generally outcrops as low mounds and hills, and low strike ridges (photo by Olga Blay)

Frontispiece
Complexly refolded banded iron-formation at Mount Klemptz, about 13 km south of Sandstone in the central Yilgarn Craton (photo by Michael Wingate)

Contents

Year in review

In 2018–19, the Geological Survey of Western Australia (GSWA) is separating the future-focused Work Program and the retrospective Annual Review. This is a new approach for GSWA, the purpose of which is to enable these documents to be published in a timely fashion to retain their relevance. Thus the Geological Survey Work Program for 2019–20 was completed in May and published in September 2019; however, in future it will be published shortly after the beginning of the new financial year.

The past year has seen a period of stabilization after the Machinery of Government changes and departmental restructure. At the same time, there was a pause in the regular meetings of the Geological Survey Liaison Committee (GSLC) and its minerals and petroleum technical subcommittees (MTSC and PTSC). GSLC meetings recommenced in September 2018, with new Terms of Reference, new committee members, a reinvigorated Geological Survey and Resource Strategy Division (GSRSD) and a commitment to our stakeholders to include the six-monthly reports from the GSLC within the appropriate Geological Survey and Resource Strategy Annual Review (refer to Appendices). Advice presented to the Director General through these reports has the potential to impact the Geological Survey Work Program and future strategic focus.

Throughout this restructure, GSWA has continued to publish manuscripts, maps and digital products as well as maintain its online databases in line with the 2018–19 Work Program.

This resulted in 30 text publications, six geological maps and 18 digital products released during the year. GSWA has also published the 2018–19 edition of the Mineral and Petroleum Statistical Digest along with the downloadable resources data files for 2018 and 2018–19, generated by the Resource Strategy team.

GSWA continued to generate exciting pre-competitive geoscience data, with, for example, over 3500 new whole-rock geochemical analyses for the Greenstone Stratigraphic Geochemical Barcoding study in the Eastern Goldfields and an accompanying Report highlighting the links between gold mineralization and lamprophyre/sanukitoid magmatism in the Black Flag Group.

The 2019 Pilbara airborne gravity survey saw the completion of the second-generation gravity coverage for the State at an equivalent station spacing of <2.5 km. The Geoscience Directorate also released the northern half of a State regolith map at 1:500 000 scale, with the southern half to be released by the end of the 2019 calendar year.

Further, GSWA continued to upload and release statutory data and gazetted new guidelines for mineral exploration reports. A new Mines and Mineral Deposits database (MINEDEX) interface is under development and data entry into the system continues, as well as the update of commodity flyers.

Land Use Planning has been heavily involved in the government initiatives around Plan For Our Parks, the Geraldton Alternative Settlement Agreement and other land use planning programs, and the team has worked well under pressure during the year.

The Abandoned Mines program saw the completion and de-gazetting of the Black Diamond and Pro-Force pilot projects and the start of the main shaft remediation program.

The Exploration Incentive Scheme (EIS) in 2018–19 had many achievements, including the Co-funded Exploration Drilling program, which saw the discovery of the Viago Lode by Bellevue Gold Limited. Round 16 (2018) and Round 17 (2018–19) had completion rates of 70% and 71%, respectively, compared to the historical average of 58–59%. Significant outputs in pre-competitive data were also achieved, including geophysical, geochemical and geochronology projects.

Commodity markets were on a bit of a rollercoaster for much of 2018–19, with the US–China trade tensions entering a third year. Late in 2018, political tensions contributed to weakening prices that mostly recovered in

the first quarter of 2019 as trade negotiations resumed and some commodities experienced a series of supply shocks, including iron ore, nickel, copper, lead, zinc and tin.

The Australian dollar was down almost 8%, averaging 72 US cents in 2018–19, with global commodity prices generally holding up well. The financial-year average price of most commodities increased on the gains made in 2017–18, and iron ore rebounded strongly on the back of the losses it recorded in the previous financial year.

Following these changes, Western Australia remains one of the world's top contributors to the global commodity market. According to United States Geological Survey (USGS) data, Western Australia ranked among the top five jurisdictions for the production of eight major minerals and in the top 10 of a further three.

Western Australia's mineral and petroleum industry reported record sales of $145 billion*, a $30 billion increase on 2017–18. This was driven by improved iron ore prices and increasing liquefied natural gas (LNG) volumes and prices.

The petroleum sector accounted for 26%, or $38.4 billion, of the total value of Western Australia's mineral and petroleum sales in 2018–19. Western Australia's most valuable petroleum product, LNG, accounted for 20% of all mineral and petroleum sales during the year, rising from $18.9 billion in 2017–18 to $29 billion in 2018–19.

The State's resources sector is still dominated by mineral commodities, accounting for 74%, or $107 billion, of total sales value. Iron ore was by far the most valuable commodity, accounting for 73% of mineral sales and 54% of overall sales.

In conclusion, 2018–19 has been a year of consolidation and realignment for the division and upon entering 2019–20, we focus on further refining our direction, strategies and products.

Jeffrey Haworth
EXECUTIVE DIRECTOR

* Monetary amounts stated are in Australian dollars, unless otherwise specified.

Overview

Overview of mineral exploration and development trends

The mineral and petroleum industry is crucial to Western Australians, with the materials mined here used in our buildings, cosmetics and medicines as well as in the technology and infrastructure we need for our future. The industry's opportunities, challenges, investments and needs are inseparable from Western Australia's future and so its performance and contributions to our economy are highly valued.

Western Australia remains one of the world's top contributors to the global commodity market, ranking among the top five countries for production of eight major minerals and in the top 10 of a further three (USGS, 2019).

Overall in 2018–19, Western Australia's mineral and petroleum industry reported record sales of $145 billion*. The bulk of the $30 billion increase in 2017–18 was the result of improved iron ore prices and increasing LNG volumes and prices.

According to the Department of Mines, Industry Regulation and Safety (DMIRS) mineral and petroleum investment database, Western Australia has resource projects in the pipeline valued at an estimated $108 billion (Table 1).

Recently announced new projects include:

- Australian Vanadium Limited's $500 million vanadium project near Meekatharra
- stage one of Caravel Minerals Limited's $481 million namesake copper mine
- EcoMag Limited's $130 million hydrated magnesium carbonate processing plant
- Red 5 Limited's $218 million expansion of the King of the Hills gold mine
- Atlantic Pty Ltd's $127 million Windimurra vanadium pentoxide plant rebuild
- stage one of Kibaran Resources Limited's $32.5 million Kwinana graphite plant
- Metals X Limited's $27 million restructure of the Nifty copper mine, which aims to improve performance and reduce costs at the mine.

Table 1. Forecast investment in mineral and petroleum resource projects in Western Australia as of September 2019

Sector	Commodity	Capital expenditure ($ million)	
		Committed/ under construction	Planned/ possible
Minerals	Gold	264	959
	Iron ore	15 820	1509
	Nickel, copper and zinc	356	3349
	Lithium	2558	4247
	Infrastructure	0	70
	Other minerals	733	8321
	Subtotal minerals	**19 731**	**18 455**
Petroleum	Crude oil and condensate	0	0
	Gas	0	5000
	LNG	5714	58 951
	Pipelines and infrastructure	0	0
	Subtotal petroleum	**5714**	**63 951**
Total forecast investment		**25 445**	**82 406**

Consistent investment over time and access to land for exploration are important. Exploration and subsequent mine development is needed to sustain Western Australia's position as a leading mineral producer.

As reported by the Australian Bureau of Statistics (ABS), Australia's mineral exploration expenditure was $2.3 billion in 2018–19, up from $2 billion in 2017–18. Western Australia contributed $1.4 billion (61%) of this spend with the gold, iron ore and base metal sectors attracting the largest shares. Gold exploration expenditure in Western Australia increased 8% from

* Information provided in this overview, unless otherwise specified, was derived from sources that include DMIRS data and Australian Securities Exchange (ASX) reports. Data sources are detailed in the Resources data files, which can be accessed on the DMIRS website (www.dmirs.wa.gov.au/lateststatisticsrelease).

$591.5 million in 2017–18 to $672.8 million in 2018–19. Iron ore exploration increased 13% from $274 million in 2017–18 to $310 million in 2018–19.

The ABS also reports on onshore and offshore petroleum exploration expenditure. Nationally, petroleum exploration expenditure has fallen every year since 2013–14. The 2018–19 financial year marks the first increase in petroleum exploration expenditure, with almost $1.3 billion spent across Australia. High oil prices in Australian dollar terms are thought to be behind the modest return of confidence in the oil and gas industry.

Western Australia's petroleum exploration expenditure also increased year-on-year, up from $562 million in 2017–18 to $734 million in 2018–19 (a 3% increase). Western Australia's share of national petroleum exploration spend also increased to 58% in 2018–19, the highest it's been since 2015–16.

Data regarding the split of exploration across onshore and offshore activities is only available at a national level. In 2018–19, Australia's total onshore petroleum exploration expenditure was $436 million vs $812 million for offshore exploration.

Some notable company exploration announcements during the year included:

- Independence Group NL uncovered a nickel system much larger than previously apparent through near-mine exploration work at Nova.
- Royal Nickel Corporation Minerals delivered an almost 390% increase in Measured and Indicated Resources within its Beta Hunt gold mine to 710 000 oz and a three-fold increase in Inferred Resources to 250 000 oz.
- Liontown Resources Limited boosted the Resource at the Kathleen Valley project by 353% to 75 Mt for 2.5 Mt of lithium carbonate equivalent and 23 million lb of tantalum pentoxide. Liontown Resources raised $18 million to fund further exploration and development studies at its Kathleen Valley and Buldania lithium prospects.
- Cobre Pty Ltd announced the discovery of a volcanic-associated massive sulfide deposit containing copper, gold, silver and zinc at its Perrinvale project.
- In February, Rio Tinto Limited revealed a copper–gold–silver discovery at the Winu project in Western Australia's Paterson Province. The results from the discovery came from 24 holes as part of its US$250 million global exploration program. The largest intersection came in at 741 m at 0.45% copper, 0.52 g/t gold and 2.94 g/t silver, with four intersections returning copper grades of greater than 1%, one of which also had gold grades above 1 g/t. The highest-grade intersection indicated was 60 m at 1.03% copper, 1.22 g/t gold and 4.3 g/t silver, with narrower, higher-grade intersections also cited including 6 m at 4.7% copper, 2.5 g/t gold and 26 g/t silver.
- Northern Minerals Limited announced a high-grade maiden Resource estimate of 144 000 t grading 2.23% total rare earth oxides for the Dazzler prospect, 15 km north of the Browns Range deposit near Halls Creek. This grade is more than three times the average of the Browns Range deposit. Northern Minerals also commenced an infill and drilling program at the Dazzler and Iceman prospects for mineral resource extension and definition.
- Salt Lake Potash Limited defined a 73 Mt sulfate of potash, a high-grade Resource for its Lake Way project in the Northern Goldfields region.
- Mincor Resources NL increased the size of the Mineral Resource at its Cassini nickel project, raising the total to 780 000 tonnes of 3.7% nickel, a total of 28 500 t of nickel, a 52% increase over the previous estimate in August 2018. Mincor is continuing with extension drilling, aiming to further expand the Resource.
- Venus Metals announced a 'world-scale' vanadium Resource at its Youanmi project of 134.7 Mt grading 0.34% vanadium pentoxide for a contained 458 900 t. This result is supporting additional metallurgical test work and scoping studies to advance the project.
- Shell Energy Australia Pty Ltd is planning a 3D seismic survey to be conducted between July and December 2019 across three permits held by the company in the offshore Browse and Bonaparte Basins.
- Following the landmark Dorado discovery in July 2018, the successful appraisal result has given Carnarvon Petroleum Ltd and its Joint Venture partner, Santos Limited, confidence to progress plans for field development. Exploration and appraisal wells are planned for the Dorado and Roc South fields, with Carnarvon Petroleum having raised $50 million in February to fund the program. The Dorado discovery is one of the largest oil discoveries ever on the North West Shelf.

Budget

Recurrent budget 2018–19

The Annual Review will report on the areas only (with some exceptions) associated with the Geological Survey Work Program for 2018–19 (GSWA, 2018) and will not include branches such as Resource Strategy.

The branches and directorates within GSWA are shown in Table 2. Figure 1 illustrates the GSWA budget vs actual expenses in 2018–19. All reference to the EIS budget and expenses are presented in the EIS overview and achievements section of this Annual Review.

In the 2018–19 financial year, GSWA had 159 public sector employees (equivalent to 145 full-time equivalents [FTE]) with a revised recurrent salary budget allocation of $16.9 million. The salary budget is inclusive of the previous GSWA directorates and branches with the addition of Strategic Policy and Carbon Strategy. Eight EIS-funded positions are now included in the salary budget due to the transition of long-term public sector contracts to permanent positions.

The first noticeable feature of both Figure 1 and Table 2 is that the GSWA (and the GSRSD overall) were within the budget allocation with no overspend in either salaries or operational. The variance was a $668 000 underspend, which is well within the over-budget allowance of 5%, as per cash management reporting. The forecast estimate of the GSWA's overall budget was reported as $29.78 million in the Geological Survey Work Program for 2018–19. This is inclusive of $10 million from the EIS and was estimated prior to confirmation of the final allocation. The estimate is close to the overall final allocated budget and actual expenses.

Staffing

Movement of staff throughout the year left areas with funded vacant positions that were not filled for the entire financial year, leading to some underspend in salaries. GSWA employed 132 FTE and approximately 65 fee-for-service (FFS) contractors, which is slightly over the initial estimate in the Work Program of 126 FTE and 55 FFS, respectively. Some of the FFS contractors were employed in an information and communication technologies (ICT) capacity and were 'shared' among DMIRS business areas.

New for 2018–19

Relevant to the distribution of funding in 2018–19, and differing from previous years, is the cessation of the previous branch 'Geoscientific and Exploration Information (3106)' and reallocation of projects to the Minerals and Petroleum Resources branch. This included the following project areas:

- Mineral Exploration Information Management
- Petroleum Exploration Information Management
- Perth Core Library
- Joe Lord Core Library (Kalgoorlie)
- Virtual Core Library (HyLogger).

The primary reason for the reallocation was budget management and does not reflect any changes in tasks or output for these areas.

Table 2. Comparison of allocated recurrent budget and expenditure for GSWA directorates and branches. Abbreviation: FTE, full-time equivalents

	Budget		Actual expenses			
Directorates and business areas	Salaries ($,000)	Non-salaries ($,000)	Salaries ($,000)	Non-salaries ($,000)	Total ($,000)	FTE
Executive and Administrative Support	1044	49	1124	100	1224	8.0
Minerals and Petroleum Resources	5203	1558	4696	1867	6563	44.3
Geoscience	3526	908	3273	792	4065	27.1
Logistics and Field Support	284	801	345	696	1041	4.0
Geoscience and Titles Information	4592	1381	4460	1325	5785	48.3
Totals	**14 649**	**4697**	**13 898**	**4780**	**18 678**	**132**

Budget

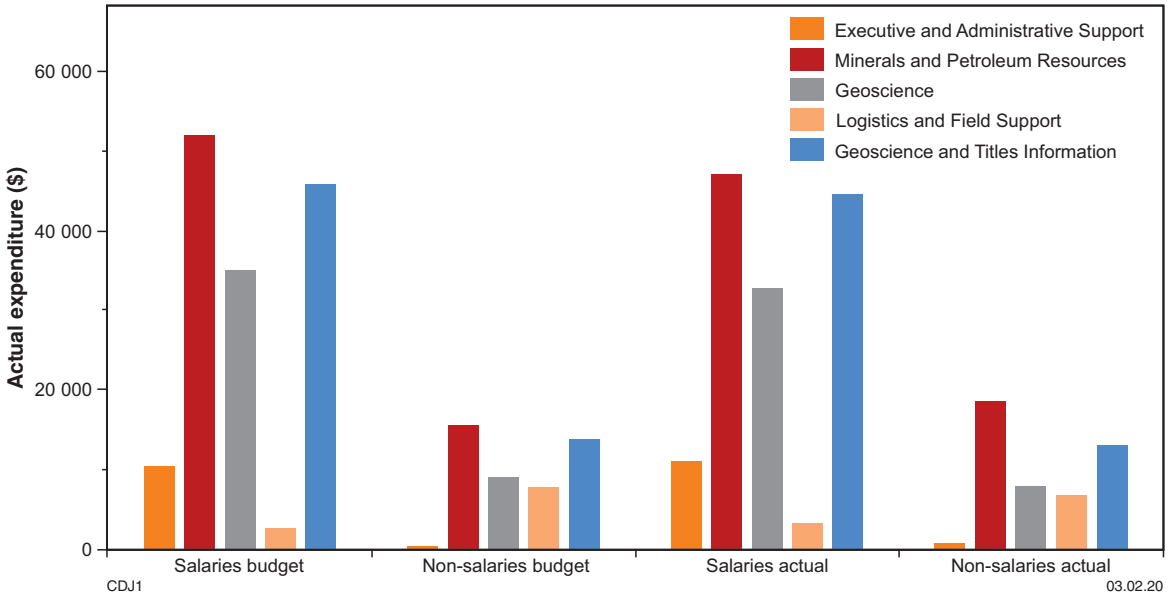


Figure 1. GSWA recurrent expenditure for the 2018–19 financial year compared to budget allocation

With the merger of Department of Mines and Petroleum and Department of Commerce in July 2017, and organizational changes throughout the Department, GSWA has acquired four areas previously aligned with Mineral Titles. These areas are incorporated into the final budget review and form part of the 'Geosciences and Titles Information Branch (3105)'. These areas were Data Capture (GS87), Data Integrity (GS88), Spatial Projects (GS89) and the Native Title Team (GS90).

Although the Geochemistry and Regolith project (GS43) was originally assigned a budget in 2018–19, many of the requirements were incurred against the Geoscience Mapping Through Cover project (GS64), and the main draw on the GS43 budget was geochemical analyses for the new Greenstone Stratigraphic Geochemical Barcoding project. As GS43 concluded in 2017–18, there was no Geochemistry and Regolith project summary in the Work Program for 2018–19 and thus the Annual Review. The expenses aligned with GS43 were primarily a result of panel arrangements for analysis and other services historically assigned to GS43. This has changed in the 2019–20 financial year.

The Pilbara Craton project (GS45) concluded in 2018–19 and the West Musgrave Province (GS57) concluded in 2018–19, with the release of the digital maps and explanatory notes in the West Musgrave Geological Information Series data package update for the latter. Resources from both these projects moved to Tectonic Evolution of the Fortescue and Hamersley Groups (GS63) for 2019–20.

Publications

As reported in the Work Program for 2018–19, GSWA forecasted the publication of 16 maps, 35 text publications and 20 data packages. The final count for these categories on 30 June 2019 were six maps, 30 text publications and 18 data packages. The map delivery was significantly reduced from the number forecast, with the outstanding items due for release in early 2019–20. In addition, GSWA also published a total of 73 posters that were presented at conferences, the GSWA Open Day and other events throughout the year.

GSWA provides a diverse array of data and services funded through recurrent and EIS funding, many of which have not been previously acknowledged in the Work Program or Annual Review. A range, but not all, of GSWA's published data, products, advice and services for 2018–19 are highlighted in the Appendices.

Program review

GS10 Energy Geoscience and Carbon Strategy

Manager: Deidre Brooks

Objectives

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

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

During late 2018, Geoscience Australia (GA) confirmed 'Exploring for the Future' funding for a GSWA-operated stratigraphic well to be drilled in the southern Canning Basin during the dry season of 2019. This new project resulted in a change of work priorities for several Canning, Moora and Amadeus Basin projects as staff were redirected to plan for the drilling campaign. The well will be the first deep hole to intersect the sedimentary succession and basement in the Waukarlycarly Embayment, Canning Basin.

Highlights and activities

- Work continued on a palynological review of the southern Perth Basin, south of Bunbury, that will lead to a future reassessment of the stratigraphy, which is currently closely tied to the northern Perth Basin stratigraphy despite large differences in depositional history.
- Compilation of petroleum geochemistry data continued for inclusion into a future Report and digital data package on the petroleum source rocks of Western Australia.
- Seismic interpretation and mapping of the southern Canning Basin continued, with a second report covering the Willara Sub-basin and Broome Platform to be published early in the 2019–20 financial year. Work commenced on interpretation of the Kidson Sub-basin, Ryan Shelf and Crossland Platform, which will be the final area covered by this project. The latest interpretation utilizes the EIS-funded recently acquired Kidson Sub-basin seismic survey and the new reprocessed vintage 2D seismic lines.
- Building 3D depth models of significant geological surfaces in the southern Perth Basin and western Canning Basin continued.
- Results of dating of basement rocks from beneath the western Canning Basin suggests that the basin is underlain by metamorphosed Neoproterozoic Centralian Superbasin in the south, and Kimberley Basin in the north. Work is continuing on this project through 2019–20.
- A manuscript on the stratigraphy and biostratigraphy of the Grant and Reeves Formations of the Canning Basin is waiting on final input from the external palynologist prior to publication, which is anticipated to be in the 2019–20 financial year.
- In collaboration with Curtin University, work progressed on the Western Australia unearthed book on the Mesozoic of Western Australia.

- GS10 projects placed on hold due to planning for the drilling of Waukarlycarly 1 include:
  - compilation of a Digital Core Atlas for Sally May 2 and Nicolay 1
  - a review of the Cobb Embayment of the Canning Basin
  - geological studies on the Ordovician, Canning Basin
  - a Report on the structure and stratigraphy of the western Amadeus Basin
  - a Record on the bitumen recovered in Goonderoo 1 and 1A.

Products released

- Report 184 Regional seismic interpretation and structure of the southern Perth Basin, Western Australia
- Report 188 Petroleum geochemistry and petroleum systems modelling of the Perth Basin, Western Australia
- Record 2018/11 The Cryogenian Aralka Formation, Amadeus Basin: a basinwide biostratigraphic correlation
- GSWA Harvey 1, Perth Basin: Digital Core Atlas (interactive digital product)
- Paleontology report 2019/1 F52644–F52652: Tonian stromatolite *Tungussia erecta* in the Pollock Hills, Amadeus Basin, Western Australia
- Paleontology report 2018/1 A stromatolite assemblage, including *Eleonora boondawarica* Grey and Walter, 1994 and *Acaciella savoryensis* Grey and Walter, 1994, from mineral drillhole AusQuest Table Hill 07THD003
- 29 Explanatory Notes System (ENS) entries related to the Amadeus Basin
- 10 ENS entries related to the Cobb Embayment (Canning Basin) and the Musgrave area
- New pre-competitive sample analyses:
  - U–Pb detrital zircon geochronology:
    - Frankenstein 1, Canning Basin, 2728.0 – 2728.6 m, released 31 May 2019 *in* Wingate, MTD, Lu, Y and Haines, PW 2019, 199496: metasandstone, Frankenstein 1; Geochronology Record 1562: Geological Survey of Western Australia, 7p.
    - Frankenstein 1, Canning Basin, 2801.0 – 2801.2 m, released 31 May 2019 *in* Wingate, MTD, Lu, Y and Haines, PW 2019, 199495: metagabbro vein, Frankenstein 1; Geochronology Record 1561: Geological Survey of Western Australia, 4p.
    - Wilson Cliffs 1, Canning Basin, 3537.79 – 3542.08 m, released 31 May 2019 *in* Wingate, MTD, Lu, Y and Haines, PW 2019, 199497: metasandstone, Wilson Cliffs 1; Geochronology Record 1563: Geological Survey of Western Australia, 5p.
  - Palynology:
    - Palynostratigraphy of Samples from Ungani Far West-1 and Ungani North-1, Canning Basin, released in Western Australian Petroleum and Geothermal Information Management System (WAPIMS).
- External publication — see Appendices.

Table 3. Pre-competitive sample analyses released by GS10 Energy Geoscience and Carbon Strategy in 2018–19

Analysis type	Well	Depth (m)	Sample type
U–Pb detrital zircon geochronology	Frankenstein 1	2728.0 – 2728.6	Core
U–Pb detrital zircon geochronology	Frankenstein 1	2801.0 – 2801.2	Core
U–Pb detrital zircon geochronology	Wilson Cliffs 1	3537.79 – 3542.08	Core
Palynology	Ungani Far West 1	1810–1815	Cuttings
Palynology	Ungani North 1	1820–1825	Cuttings
Palynology	Ungani North 1	1890–1895	Cuttings
Palynology	Ungani North 1	1935–1940	Cuttings

GS12 Land Use Planning

Manager: Warren Ormsby

Objectives

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

Highlights and activities

- Proposals for land subdivisions and other land use changes are routinely received from State and local government authorities. Each proposal is examined, its implications for access to mineral and energy resources assessed, recommendations, advice and where necessary, approvals made accordingly.
- A large volume of assessments, recommendations and approvals were carried out to support the land component of the Geraldton Alternative Settlement Agreement. To assist with this process, external funding was obtained for a geologist for one year.
- Work commenced 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 ha of conservation estate over five years. The branch is playing a key role in consultation with the resources industry, prospectivity assessment and input into this whole-of-government project.
- Work continued on the assessment of potential land tenure changes associated with the South West Native Title Settlement project. Additional external funding continued for a geologist to facilitate the branch's role in this project.

Products released

- Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2019 (map).

GS14 Statutory and Resource Information

Manager: Nicole Wyche (acting)

Objectives

The Statutory and Resource Information (SRI) branch tracks mineral exploration and mining activities in Western Australia. We collate data on mineralized sites, exploration and mining projects, mineral resources and mineral production. This data allows DMIRS to provide specialist technical advice on commodities to our stakeholders via MINEDEX and other publications. The SRI branch also has a regulatory role, performing compliance assessments relating to the *Mining Act 1978* and other legislation. The SRI branch includes the Statutory Mineral Exploration Information section (GS91) and Statutory Petroleum Exploration Information section (GS92). The results for these sections are reported elsewhere in this document.

Highlights and activities

- Each month, MINEDEX is visited by around 1200 individual users. Usage is spread over 3000 sessions and 65 000 individual page views. Just over 50% of users are new users.
- The redevelopment project converting the current MINEDEX user interface from a Java to .NET platform is on track for release in the final quarter of 2019. This project will modernize the MINEDEX user experience, be compatible with tablet and mobile devices, and will be the first DMIRS online database to conform to the standards of the Office of Digital Government.
- Approximately 1430 compliance assessments, providing geological advice on mining lease and other tenure applications were completed.
- Over 4500 data sources were consulted to update MINEDEX.
- Responses were provided to over 850 queries from internal stakeholders.
- Responses were provided to over 330 queries from external stakeholders.
- Release of Significant exploration activity in Western Australia (‘hotspots’ poster; released twice yearly).
- Release of Investment Opportunities flyers released for Lithium and Rare Earth Elements.

Products released

- Western Australia Atlas of mineral deposits and major petroleum projects 2019 (book and map)
- Mines — operating and under development, Western Australia (map)
- Major resource projects 2019 (map)
- Mineral deposits and major petroleum projects — 2019 (map)
- Record 2018/8 Geology, resources and exploration potential of the Ellendale diamond project, west Kimberley, Western Australia.

Performance metrics

This section is responsible for one Resource and Environmental Regulation performance metric. This metric requires that 80% of all applications for mining leases by Mineralization Report or Resource Report be processed within 21 business days. Following improvements to staffing levels in this section, the target was met for February–April 2019 (available results at time of this publication).

GS20 Mineral Systems Studies

Manager: Trevor Beardsmore

Objectives

The Minerals Geoscience branch focuses on mineral systems in Western Australia, with the objectives of building metallogenic models and improving our understanding of the geodynamic environment of ore formation, thereby assisting with making exploration targeting in greenfields areas more predictive. Such work typically involves both fieldwork (mapping, core logging, sampling) and laboratory studies (petrology, geochronology, isotope chemistry), and is supported by and supplements existing databases. The branch makes extensive use of the GSWA HyLogger (Project GS95) to assist with detailed studies of alteration assemblages in diamond drillcore and other specimens from mineral deposits. The work in this area has been complemented by projects funded by the EIS (reported herein under ES43 Mineral Systems Atlas). All mineral systems knowledge is ultimately made available for the benefit of resource companies, research groups, other government agencies and the wider community. This knowledge is disseminated via geographical information system (GIS) packages, and internal and external publications.

Highlights and activities

The Mineral Systems Studies project continued its studies of volcanogenic massive sulfide (VMS), rare earth element (REE), gold, nickel and iron ore deposits. These studies focus on determining characteristics of the geological setting, mineralization and associated alteration that inform metallogenic interpretations, and also provide useful tools for targeting mineral deposits at all scales, thereby reducing the technical risk of discovery for resource companies.

Volcanogenic massive sulfide systems

Representative diamond drillcore was acquired from one of the more significant deposits in the Manindi VMS camp, for logging, sampling and hyperspectral scanning using GSWA's HyLogger-3, to test mineral vectors developed in studies of VMS mineralization at Golden Grove and Weld Range (described in GSWA Report 141).

Rare earth element systems

Geological and metallogenic studies continued on several Western Australian REE systems. The group is investigating the poorly understood hydrothermal, vein-and-breccia-hosted heavy REE mineralization in the East Kimberley and north Tanami regions. The age of the mineralization event at John Galt deposit has been determined, and other physical and chemical constraints are being obtained from fluid inclusions and alteration studies.

Gold systems

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

Josh Guilliamse completed his systematic study of the Mount Clement gold deposit in the Ashburton Basin, reviewing historical exploration data, field reconnaissance mapping and sampling of the local geology, logging and sampling of drillcore archived by GSWA, and petrographic and geochemical analysis of samples. This and subsequent work contributes to a much larger, ongoing collaborative investigation of the architecture and metallogeny of the Capricorn Orogen being done under the banner of the National 'UNCOVER' initiative.

Nickel systems

Lauren Burley continued preparing her Master of Economic Geology dissertation on the

Fisher East komatiite-hosted nickel mineralization for publication as a GSWA Report. In 2018–19, Lauren began pursuing a program of systematic, regional-scale sampling of lithostratigraphy and selected komatiite-hosted nickel sulfide systems adjacent to the boundaries between the Kurnalpi, Burtville and Yamarna Terranes, as part of a larger collaborative project between GSWA, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and The University of Western Australia (UWA), to understand the tectonostratigraphic and metallogenic evolution of the far eastern Yilgarn Craton. Lauren also began a study of the geochemical fertility of mafic volcano–plutonic rocks of the Warakurna Large Igneous Province for nickel – copper – platinum group element [PGE] mineralization, using targeted mapping and sampling of mafic intrusive rocks in the Edmund and Collier Basins, and petrological and lithogeochemical analyses.

Iron systems

The study of Yilgarn iron ore systems is being extended with a program to obtain ages for hydrothermal iron mineralization, beginning with selected iron deposits in the Weld Range, Koolyanobbing and Windarling regions. Sensitive high-resolution ion microprobe (SHRIMP) U–Pb dating of cogenetic phosphates has been performed using the facilities at the John de Laeter Centre, Curtin University. The results of this work has been submitted to Mineralium Deposita and developed as a GSWA Record. A summary of the physical–chemical characteristics and source of mineralizing fluids responsible for the Yilgarn Craton iron deposits has been submitted to Ore Geology Reviews. An overall synthesis is to be published as a GSWA Report and series of external publications.

Mineral Systems Atlas

Much of the branch's effort during 2018–19 was spent on developing a significant new initiative — the online, interactive, GIS-based Mineral Systems Atlas. This delivers 'mappable geological proxies' for critical metallogenic processes that are derived from systematic 'mineral systems analyses' of known or probable mineral systems in Western Australia. The mappable geological proxies are being created from existing and enhanced or newly created public domain datasets, for use in GIS-based mineral prospectivity studies by mineral explorers. The Atlas is engineered so that constituent 'proxy layers' are automatically updated whenever the underpinning databases are modified.

To date, suites of mappable proxies have been developed for komatiite-hosted nickel and hydrothermal iron ore systems. Additional systems are being developed and are at draft stage for rare element pegmatite, vanadium-bearing layered intrusions and lateritic nickel systems.

The Mineral Systems Atlas was presented at the GSWA 2019 Open Day, and an extended abstract is included in Record 2019/2 GSWA 2019 extended abstracts (p. 9–12).

Nickel collaborative study with the Xi'an Centre, China Geological Survey

GSWA continued a collaborative research project with the China Geological Survey and hosted a visit from Chinese geologists, which included examining drillholes sourced from the eastern parts of the Yilgarn Craton that are prospective for ultramafic-hosted nickel sulfide mineralization. Members of the Minerals Geoscience branch also participated in a reciprocal visit to China where they engaged in discussions with geologists from the China Geological Survey and visited notable world-class nickel deposits, including Jinchuan, Xiarihamu and Shitoukengde.

Products released

- Compilation of HyLogger records, 2019 (26 records)
- External publications — see Appendices.

GS52 East Yilgarn (Kalgoorlie Office)

Manager: Jyotindra Sapkota

Objectives

The Eastern Goldfields Superterrane (EGST) occupies the eastern third of the Archean Yilgarn Craton and is widely considered a typical upper-crustal granite–greenstone terrane. This highly mineralized region contains world-class gold and nickel deposits, and significant deposits of other commodities including base metals, REE, uranium, gemstones and industrial minerals. The present terrane configuration of the EGST is traditionally interpreted to reflect accretion of a number of pre-existing 'continents' in a series of collisional events between c. 2800 and 2650 Ma. The effects that mantle plumes have had on the magmatic stratigraphy of the greenstones is reflected by the local abundance of komatiites and associated basalts. However, systematic geological mapping and the acquisition of a substantial body of geochronological and geochemical data, indicate that evolutionary models involving rifting of an autochthonous basement also need to be (re)evaluated. These different models can lead to different interpretations on the nature of magma source regions and the evolution of translithospheric structures that form pathways for mineralizing magmas and fluids. An understanding of the tectonic evolution of the Eastern Goldfields, including the structure and stratigraphy, is essential to the understanding of the controls on formation and distribution of mineralization in the region.

Highlights and activities

- Mapping of the greenstone belt in the western part of the Eastern Goldfields Superterrane between Ora Banda and Mount Ida
- Field traverses and geochemical, geochronological and isotopic sampling of the granite–greenstone belt across the Kalgoorlie Terrane between Mount Ida and Norseman
- Geochemical sampling of diamond drillholes (GSWA and company core libraries) from well-established stratigraphies in support of the Greenstone Stratigraphic Geochemical Barcoding project
- Study to determine pressure–temperature–time (*P*–*T*–*t*) evolution of a suite of layered metamorphosed mafic and sedimentary rocks in the Copperfield area along the Ballard Shear Zone
- Interpretation of bedrock geology across the entire Eastern Goldfields Superterrane at 1:500 000 scale
- Acquisition of high-resolution seismic data between Ora Banda and Kambalda
- Work commenced on creating a virtual field guide of important geological localities in the East Yilgarn.

Products released

- Record 2018/15 A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity
- External publications — see Appendices.

GS53 Chief Geoscientist and Terrane Custodians

Manager: Simon Johnson

Objectives

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

Highlights and activities

- Rebuilt and updated the GSWA field observation and rock database (WAROX)
- Streamlined the process for producing a State metamorphic map with accompanying golden spikes that precisely define the timing and conditions of peak and retrograde metamorphism
- Completed the design for a geochronology, isotope and mineral chemistry database (WAGIM)
- Continued editing, approval and publication of over 420 lithostratigraphic, tectonic and orogenic events explanatory notes
- Completed the data entry module for regolith units in ENS and entered 556 regolith units from across the State
- Release of the 1:500 000 State regolith map for the northern half of Western Australia.

Products released

- Western Capricorn Orogen, 2018 (Geological Information Series digital package)
- Compilation of WAROX data, 2019 (digital data package)
- Update to the online 1:100 000 interpreted bedrock geology State digital layers
- Report 194 In situ U–Pb geochronology of hydrothermal xenotime and monazite to date gold mineralization in the northern Capricorn Orogen, Western Australia
- Record 2018/12 Capricorn Orogen rutile study: a combined electron backscatter diffraction (EBSD) and laser ablation split stream (LASS) approach
- Update to Meteorite impact structures of Western Australia, virtual tour 2019
- Calendar 2018: Geological Survey of Western Australia
- Calendar 2019: Geological Survey of Western Australia
- Understanding the Meckering earthquake, Western Australia (non-series book)
- 10 phosphate geochronology records
- External publications — see Appendices.

GS54 Geochronology and Geochemistry

Manager: Michael Wingate

Objectives

Geochronology, isotope geology and geochemistry are integral components of GSWA's geoscience programs and mineralization studies. The geochronology program determines precise and accurate ages of minerals, rocks and geological events to understand the geological history of Western Australia and contribute to enhancing the prospectivity of the State. Geochronological techniques are used to constrain the timing of magmatism, metamorphism, deformation and mineralization, using a range of isotope systems (mainly U–Pb, Ar/Ar and Re–Os) and a variety of minerals (zircon, baddeleyite, monazite, titanite, hornblende, feldspars and micas). The SHRIMP in the John de Laeter Centre at Curtin University are used extensively by GSWA for U–Pb geochronology. GSWA also uses LA-ICP-MS instruments in the John de Laeter Centre to date detrital zircons, analyse metamorphic phosphate minerals such as monazite and xenotime in thin sections (see GS53 Chief Geoscientist and Terrane Custodians) and measure the trace element compositions of zircons.

Highlights and activities

- Completed SHRIMP and LA-ICP-MS U–Pb dating of 84 zircon samples
- Completed LASS U–Pb in situ monazite geochronology of 12 samples (more in progress, but delayed due to instrument problems)
- Provided support to GS52 for the production of:
  - Record 2018/15 A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity
  - Record 2019/7 A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, Western Australia.

Products released

- 94 geochronology records and U–Pb datasets released to online applications, published maps and digital products (GeoVIEW.WA and eBookshop)
- Compilation of geochronology information, 2019
- 3118 whole-rock geochemistry analyses, including 178 analyses focused on lithium, released to online applications (GeoChem Extract)
- External publications — see Appendices.

GS55 Geophysics Acquisition and Processing

Manager: David Howard

Objectives

The acquisition, processing, synthesis and interpretation of geophysical and remotely sensed spectral information are integral parts of GSWA's regional geoscience activities. The role of the Geophysics Acquisition and Processing section is to plan and manage the various regional geophysical data acquisition projects, to deliver the datasets to the public and internal users, and to provide processing and interpretation services and advice as required.

Highlights and activities

- Regional survey data acquisition activities are reported under the EIS programs ES30 Airborne and Ground Geophysical Surveys and ES37 Eastern Goldfields Seismic Survey
- 141 new company airborne survey datasets containing about 560 000 line-km of data were received for inclusion in the Airborne Geophysics Index (MAGIX) data repository. At 30 June 2019, the repository contained some 10.7 million line-km of company data from 2476 surveys. Open-file datasets are available for download via the department's GeoVIEW.WA online system
- Datasets from GSWA's new regional geophysics surveys and suitable open-file company surveys were incorporated into new versions of the section's statewide compilation of magnetic, radiometric and gravity grids, available online (www.dmirs.wa.gov.au/geophysics).

Products released

- Magnetic anomaly grids (80 m) of Western Australia (2018 – version 1)
- Magnetic anomaly grids (40 m) of Western Australia (2018 – version 1)
- Magnetic anomaly grids (20 m) of Western Australia (2018 – version 1)
- Radiometric grids (80 m) of Western Australia (2018 – version 1)
- Gravity anomaly grid (400 m) of Western Australia (2019 — version 1).

GS56 North Australian Craton

Manager: Catherine Spaggiari

Objectives

The North Australian Craton comprises most of the northern part of the Australian continent and incorporates a complex assemblage of terranes, basins and igneous provinces that range in age from Neoarchean to Phanerozoic. The craton is host to numerous mineral deposits and major mines, including lead–zinc–silver±copper (Mount Isa, McArthur River), uranium (Ranger, Rum Jungle), iron oxide–copper–gold (Tennant Creek), gold (The Granites, Callie), diamonds (Argyle), nickel–copper (Sally Malay) and iron (Koolan Island). In Western Australia, the craton comprises Paleoproterozoic to Mesoproterozoic rocks exposed in the Kimberley, west Tanami, and west Arunta regions, overlain by sedimentary rocks of the Neoproterozoic Centralian Superbasin and the Phanerozoic Canning, Ord and southern Bonaparte Basins. Understanding the geodynamics and prospectivity of these regions and the stratigraphy of the Paleoproterozoic to Mesoproterozoic basins are major objectives of this project. This work will allow correlations with sedimentary basins across the North Australian Craton to be better constrained.

The restructure of the Geoscience Directorate and major new projects, such as our involvement in the Mineral Exploration Cooperative Research Centre (MinEx CRC), has led to significant changes for GS56. Starting in the 2019–20 financial year, GS56 and GS61 (Albany–Fraser Orogen and Eucla Basement) have been amalgamated into a new project, Proterozoic Margins, which will operate out of GS65 and ES38 (see Geological Survey work program for 2019–20).

Highlights and activities

- Fieldwork was conducted in the northern and eastern Kimberley Basin to acquire samples for detrital zircon geochronology of the sedimentary basins. These samples complete the data collection required to re-evaluate the stratigraphy of Paleoproterozoic to Mesoproterozoic sedimentary basins in Western Australia allowing correlations across the North Australian Craton
- The area covered by the Montague Sound 1:250 000 map sheet has been digitized as interpreted bedrock geology (IBG) layers, forming part of the seamless coverage of the Kimberley region
- New SHRIMP U–Pb dates for Lamboo Province rocks were acquired, providing constraints on stratigraphic relationships
- Advancement of entries into the ENS database
- Compilation of Reports on the geodynamics of the Lamboo Province and Tanami region, and the sedimentology and stratigraphy of the Kimberley Basin
- Participation in the interpretation of the basement component of the Kidson seismic line.

Products released

- Kimberley, 2018, Geological Information Series data package, including LANDSDOWNE 1:250 000-scale digital layers, which were added to GeoVIEW.WA
- Tanami–Arunta, 2018, Geological Information Series data package, including the MCDONALD second edition 1:250 000 Geological Series map and associated digital layers, and the Interpreted regolith–landform geology of the Ngururrpa Area, northeastern Western Australia
- Record 2019/8 Metamorphic and isotopic characterization of Proterozoic belts at the margins of the North and West Australian Cratons.

GS57 West Musgrave Province

Manager: Heather Howard

Objectives

The Musgrave Province is an orogenic belt that lies at the nexus of three Archean to Proterozoic cratons and straddles the borders between Western Australia, South Australia and the Northern Territory. The west Musgrave Province is the Western Australian portion of the province. The rocks within this region have a long and complex geological history, and were formed and deformed during several major events, including the 1345–1293 Ma Mount West Orogeny, 1220–1150 Ma Musgrave Orogeny and the 1085–1040 Ma Giles Event. The rocks of the Musgrave Province were subjected to subsequent widespread deformation during the 630–520 Ma Petermann Orogeny. The intrusions of the Giles Suite have been the site of significant nickel, copper and PGE discoveries. The economic potential of extensive felsic volcanic sequences has not been fully explored; however, exploration in these rocks has uncovered significant gold mineralization.

Highlights and activities

- Completion of five detailed cross-sections through the Petermann Nappe Complex
- Completion of all lithostratigraphic units, tectonic units and events in ENS for the west Musgrave region
- Completion of geochronology reports for all dated samples from the west Musgrave region
- Compilation of a Report on the post-Mesoproterozoic evolution of the west Musgrave Province.

Products released

- External publications — see Appendices.

GS58 West Yilgarn

Manager: Tim Ivanic

Objectives

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

Highlights and activities

- Mapping, sampling and collection of new analytical data, including geochemistry, geochronology and isotopic data continued in the Dalgaranga and Sandstone areas
- Extensive geochemical sampling was undertaken across the Youanmi Terrane, including the Tallering, Gullewa, Koolanooka and Mount Gibson areas
- Cooperative projects continued, involving geochemistry, metamorphic and structural studies in the northern Youanmi Terrane, and structural and isotope studies in the Narryer Terrane
- Work continued on the volcanic geochemistry of the northern Murchison Domain project; however, the associated GSWA Report has been delayed until 2020 due to the extension of the supporting PhD project and the delay associated with external reviewers.

Products released

- Murchison, 2018 Geological Information Series data package
- Record 2019/3 Metamorphic history of the Mougooderra Formation, Yilgarn Craton, Western Australia
- Gabanintha 1:100 000 Geological Series map
- Murchison Supergroup update in ENS.

GS61 Albany–Fraser Orogen and Eucla Basement Project

Manager: Catherine Spaggiari

Objectives

The main objectives of the Albany–Fraser Orogen and Eucla Basement Project is to open up new frontiers in mineral exploration in these greenfields regions by understanding the magmatic, sedimentary and tectonic environments. This allows exploration teams to better evaluate prospectivity and potential targets, as exemplified by the discovery of the nickel–copper sulfide deposit at Nova–Bollinger in the Fraser Range.

This project covers a large region, with the Albany–Fraser Orogen flanking the southern and southeastern margin of the Archean Yilgarn Craton. A suture zone lies between the eastern part of the orogen and the adjoining Proterozoic Madura and Coompana Provinces, which collectively comprise the Eucla Basement, being entirely covered by younger basin rocks. The Coompana Province extends across the border into South Australia, and links to the Gawler Craton. A major objective of this project is to produce interpreted bedrock digital map layers of the basement rocks, and associated structures. Much of the region lies beneath younger cover rocks, so the mapping is dependent on drillcore studies linked to geophysical data interpretation.

Due to the restructure of the geoscience directorate and major new projects such as the MinEx CRC, GS61 and GS56 (North Australian Craton) have been amalgamated into a new project, Proterozoic Margins, which will operate out of GS65 and ES38 (see Geological Survey work program for 2019–20), from 2019–20 onwards.

Highlights and activities

- Completion of drillcore analysis of the eight GSWA stratigraphic drillcores and 11 mostly EIS co-funded exploration drillcores from the Eucla basement (includes detailed logging and sampling, petrography, geochronology, geochemistry and isotope analysis; currently being written up as a GSWA Report)
- Identification of a Proterozoic ophiolite, the Arubiddy Ophiolite Complex, in the sutured region between the east Albany–Fraser Orogen and the Madura Province
- Detailed structural and metamorphic analysis of the east Albany–Fraser Orogen, including:
  - capture and processing of 27 new 3D photogrammetry models of outcrops of the east Albany–Fraser Orogen and of the only exposed portion of the Arubiddy Ophiolite Complex (Point Malcolm), derived from drone imagery. A selection of these models was presented during a live demonstration at GSWA Open Day 2019, together with a workflow to produce semi-automated outcrop maps and structural analysis from point clouds and textured models
  - acquisition of 24 TESCAN integrated mineral analyser maps of polished thin sections from deformed rocks of the east Albany–Fraser Orogen, for non-conventional, in situ dating and *P–T* studies
  - electron microprobe micro-analyser mineral chemistry data collected for three samples from the Fraser Shear Zone for *P–T* studies
  - new U–Pb monazite dates from three metasedimentary rock samples from the Snowys Dam Formation within the Fraser Zone
- Results from the three modules of Minerals Research Institute of Western Australia (MRIWA) M470 project ‘Mineral systems on the margin of cratons: Albany–Fraser Orogen — Eucla basement case study’ were presented at GSWA 2019 Open Day and are being written as journal articles; these include sulfur isotope studies related to understanding nickel–copper mineralization in the Fraser Zone, regional geochronology and isotope studies to aid mapping and crustal evolution

understanding, and identification of a new gold mineralization event using U–Pb and trace element analysis of zircon and rutile

- Planning and implementation of the restructure into the Proterozoic Margins section (combined GS61 and GS56)
- Participation in the bid and project designs for the National Drilling Initiative (NDI) in the MinEx CRC (see also GS64)
- Participation in the interpretation of the basement component of the Kidson seismic line.

Products released

- Report 189 A magnetotelluric survey across the east Albany–Fraser Orogen, Western Australia
- Report 195 The cooling and exhumation of the Albany–Fraser Orogen, Western Australia, constrained by $^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb thermochronology
- External publications — see Appendices.

GS62 3D Geoscience

Manager: Ruth Murdie

Objectives

The aim of the 3D Geoscience section is to increase the knowledge of Western Australia's subsurface through the integration of geophysical, geological and geochemical data in 3D structural models. EIS-funded collaborative projects with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling, are a large part of the section's activities.

Highlights and activities

- Continued acquisition of passive seismic data over the Canning Basin. This is a major project in collaboration with the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS)
- Results obtained from the 2014–18 Capricorn Orogen passive seismic array (COPA) have been processed and placed into a lithosphere-scale 3D model of the Capricorn Orogen to enable a geodynamic-based interpretation of mineral systems
- The fault model of the northern Youanmi Terrane, Yilgarn Craton was finalized and will be published in 2019–20
- The Yangibana paleochannel, Capricorn Orogen, shallow passive seismic mapping is progressing
- Trialling of the use of the shallow passive seismic method for mapping regolith interfaces (limonite/saprolite boundary — important to First Quantum for processing) and depth to basement. Results from single station Tromino will be compared to other geophysical methods (seismic and ground penetrating radar) and drillcore data
- Yalgoo–Singleton greenstone belt 3D geomodel has been built and is being tested against geophysical data
- Completion of field mapping within the Yalgoo–Singleton dome area
- Mapping within the area of the Eastern Goldfields high-resolution seismic traverses in preparation for their interpretation.

Products released

- East Albany–Fraser Orogen 3D, 2018, 3D Geomodel Series data package
- Lawlers Anticline 3D, 2014, 3D Geomodel Series data package
- Record 2019/4 Compilation of geophysical modelling records, 2018
- External publications — see Appendices.

GS63 Pilbara and Hamersley

Manager: Heather Howard

Objectives

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

Highlights and activities

- Fieldwork and geochemistry sampling of felsic volcanics in the Gregory Range and Nullagine areas
- Completion of a Record on the Geology of the Hardey Syncline
- Acquisition of new geochemical and isotopic data from drillcore sampling in the Fortescue Group
- Completion of a detailed report on the geology, crustal evolution and mineralization of the east Pilbara Craton
- Digital surface geology compiled at 1:100 000 scale for the northwest Pilbara.

Products released

- Approximately 30 ENS lithostratigraphic unit reports completed for the east Pilbara Craton
- External publications — see Appendices.

GS64 Geoscience Mapping Through Cover

Manager: Richard Chopping

Objectives

Geoscience Mapping Through Cover is a new project in 2018–19 and incorporates the regolith and cover component of GS43 Geochemistry and Regolith, which finished in 2017–18. GS64 is linked to ES36, which is the EIS project area for the MinEx CRC.

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

Highlights and activities

- Focus has been on the production of the State regolith map (EIS-funded)
- Benchmarking geophysical methods to refine cover information e.g. depth and character of cover
- Commencement of the MinEx CRC (see ES36).

Products released

- 1:500 000 State regolith geology of northern Western Australia.

EXPLORATION INCENTIVE SCHEME

GS80 Editing and Publishing
GS81 Mapping and Events
GS82 Graphics
GS83 GIS Services
GS84 Spatial Systems
GS85 Geoscience Promotions

Manager: Stephen Bandy

Objectives

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

Highlights and activities

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

- enhancement of Western Australia's prospectivity at international and national conferences, open days and trade shows
- release of digital data layers downloadable from the Data and Software Centre and through GeoVIEW.WA
- provision of database and online systems training in Kalgoorlie and Perth for mining geologists and prospectors
- redevelopment of WAROX9
- delivery of mineral systems data via a mapping application (Mineral Systems Atlas)
- implementation of workflow and product allocation system Pubstats using K2.

Products released

- 30 manuscripts
- 6 geological maps (Series maps are no longer printed. These are included in the data packages)
- 18 data packages.

GS91 Statutory Mineral Exploration Information

Manager: Julia Thom

Objectives

The Mineral Exploration Information section manages 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:
  - 3672 mineral exploration reports and data were reviewed
  - Over 90% of reports are now received via the online submission wizard
  - 2904 reports were released to open file
  - 1298 drill collar files and related data files uploaded into the drillholes database comprising 174 997 individual drillholes and associated downhole data
  - 1370 surface geochemistry files uploaded into the drillholes database comprising 456 133 individual samples and associated geochemistry data
- HTML version of GeoVIEW.WA with WAMEX, Drillholes and Geochemistry searching capability was developed and in test at the end of the financial year
- Data requests:
  - 118 core library (mineral core) viewing and sampling requests approved
  - Proposed amendments to the Guidelines for Mineral Exploration Reports on Mining Tenements were linked on the website for feedback and a document responding to feedback received was also linked. The guidelines have been prepared for gazettal

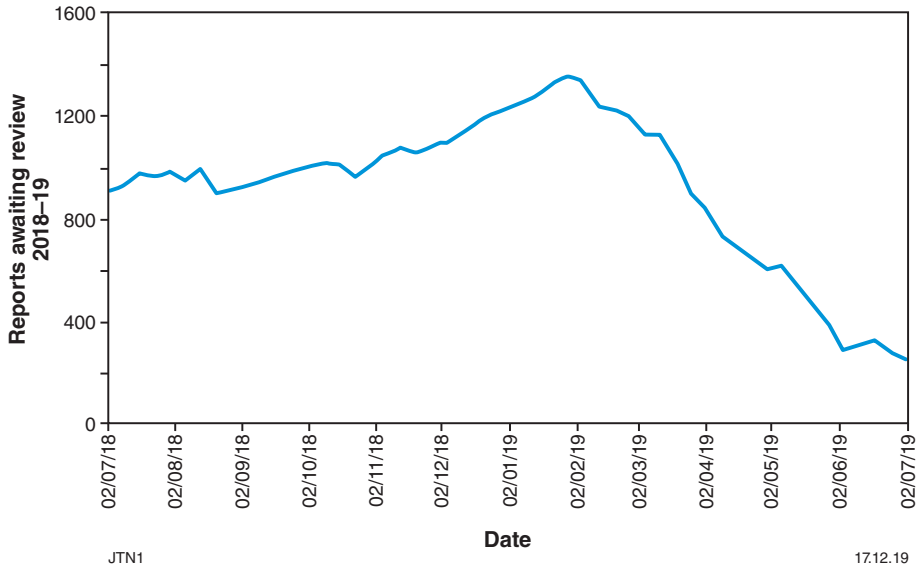


Figure 2. Mineral exploration reports awaiting review for the financial year ending 30 June 2019

- 464 Combined Reporting Groups were granted or amended
- Under the provisions of Regulation 96(4) of the Mining Act, commonly known as the 'sunset clause', 1208 reports received in 2013 and 81 reports received in 2008 (lapsed objections) were advertised on the website for release. A total of 1096 of the 2013 reports and 24 of the 2008 reports did not receive objections and were released.

Performance measures

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

- Mineral exploration reports received and reviewed — currently 99% of data received and reviewed within 90 calendar days of receipt.
- Achievements — the team has managed to reduce the backlog of mineral exploration reports awaiting review from over 1350 in early 2019 to fewer than 300 by the end of the reporting year (Fig. 2).
- 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.

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

Objectives

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

Highlights and activities

- WAPIMS main enhancements:
  - 'Data by Depth' functionality – graphic representation of diverse data type available for a well (core, logs, biostratigraphy, thins sections, etc.)
  - WAPIMS/administration — advanced filtering on every single grid on the internal administration grids (Multi-Select filter)
  - WAPIMS/public — filtering on Report and Data Type
  - WAPIMS/public — easy data access from the home page to the main projects (Core Atlas, Core Analysis, South West Hub Carbon Storage)
  - WAPIMS/public — documents released searchable by date
  - Dynamic SQL interface — ongoing
  - Redesign sampling approvals workflows and forms — ongoing
- Data remastering — transcribed petroleum data to a modern stable media for industry and government:
  - 97 tapes from Northern Carnarvon (SPA 1/1993–94) transcribed to 3592 cartridges
  - 220 x 3590 cartridges from various seismic surveys in Perth basin copied to a hard drive and loaded in WAPIMS
  - 1996 S Files (folders) scanned — paper documents related to a particular activity (wells, seismic survey, title, general studies)
  - Scanned various legacy reports and logs received from GA's repository as part of the state data relocation project
- Data received and reviewed:
  - 247 reports, 13 logs, 107 survey data, 1172 slides and residues
  - 682 reports reviewed and information captured (new and legacy)
  - Other WAPIMS entries: monthly production (11 387), facility utilization (150), production tests (199), underground storage daily data (6843), underground storage monthly data (111)
- Data released — reports, well logs, survey data published in WAPIMS: 354 documents, 4445 slides and residues
- Sampling Approval Requests processed: 264 from 211 wells
- Statistics and metrics 2018–19:
  - 44 000 documents downloaded from WAPIMS
  - 6061 users accessed WAPIMS, more than half from Australia
  - 97% of reports received accessioned within 14 days
  - 86% of the sampling approvals processed within five days
  - 79% of the slides and residues received accessioned and archived within 14 days
- Achievements — the team received very positive feedback from Petroleum Subcommittee members for the WAPIMS functionality and enhancements, data delivery and client services.

GS94 and GS96 Core Library Services

Manager: Paul Stephenson

Objectives

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

Highlights and activities

- New display cabinets with various historical GSWA items at Carlisle
- Kalgoorlie Open Day — November 2018
- New outdoor core viewing area in Kalgoorlie.

Products released

- Updated versions of WAPIMS and core information management system (CIMS).

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Objectives

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

Highlights and activities

- From July 2018 to June 2019, 55 540 m of core from 206 drillholes were scanned and 100% of data were processed to at least level one. These comprised 135 EIS Co-funded holes, 40 historical and donated mineral holes, and 31 petroleum wells (Fig. 3). AuScope, as part of an NCRIS grant scheme, funded delivery and data processing of over 14 000 m of core from 42 EIS drillholes from the Joe Lord Core Library in Kalgoorlie.
- High-resolution core images and hyperspectral data for over 80 000 m of drillcore were delivered to the AuScope national portal and GeoVIEW.WA using the HyLogger database. To the end of June 2019, 160 datasets had been processed to level 1 and 74 datasets processed and interpreted to level 2 were uploaded.

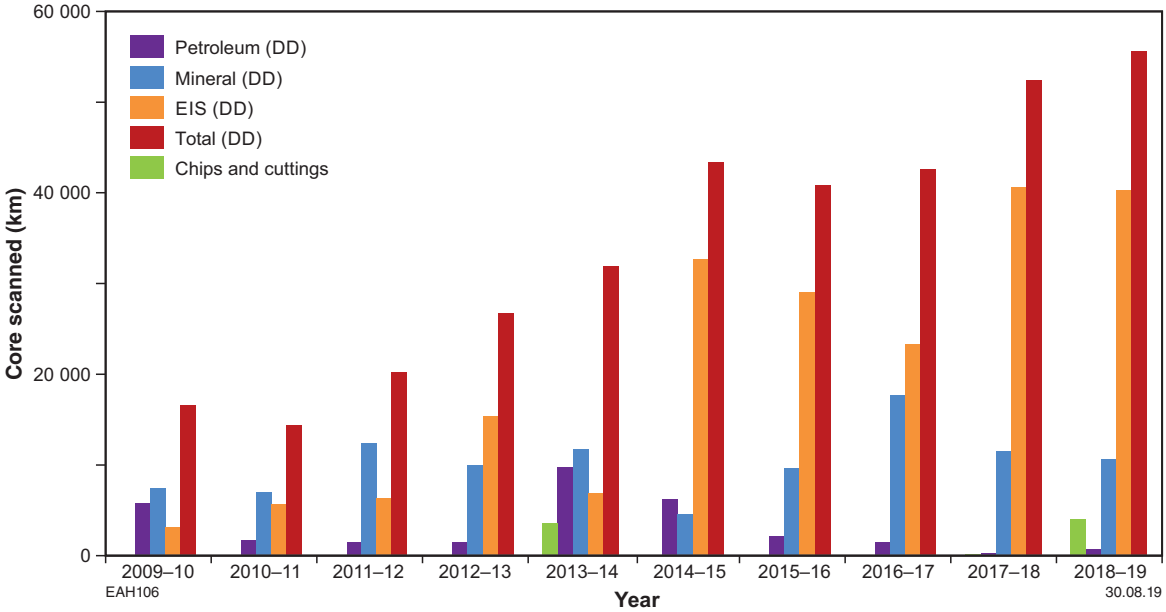


Figure 3. GSWA HyLogger facility usage statistics 2010–19. A total of 336 171 m of core from 1184 drillholes has been scanned using the NVCL GSWA HyLogger facility. Abbreviation: DD, diamond drilling

- HyLogger staff were actively involved in several GSWA, CSIRO, UWA and Curtin University research projects, including the northern Perth Basin petroleum system; stratigraphy and alteration assemblages of the Fortescue Group, Hamersley Basin; Collurabbie nickel mineral system, Eastern Goldfields; Mount Mulgine tungsten mineralization, Murchison Province; lithium mineralogy in Greenbushes and Londonderry pegmatite deposits; and characterization of Yangibana regolith, Gascoyne Province.
- The HyLogger team provided 14 tours for international and state delegations visiting the Perth Core Library, and manually delivered 310 datasets, excluding external portals.
- Hyperspectral data were systematically and rapidly validated using portable X-ray diffraction (pXRD) and scanning electron microscope energy dispersive X-ray spectroscopy (SEM-EDX). Technical supports were provided to GSWA geological staff using the pXRD facility.
- The HyLogger workshop, in collaboration with CSIRO, was delivered in May to academic and industry personnel to promote the use of the hyperspectral technology. Two technical workshops were organized for GSWA geological staff to support data processing and interpretation.

Products released

- HyLogging data processing and interpretation for assorted drillcores (28 HyLogger records)
- External publications — see Appendices.

EIS – Overview

EXPLORATION INCENTIVE SCHEME

EIS – Overview

EIS - Program review

EXPLORATION INCENTIVE SCHEME

Exploration Incentive Scheme – overview and major achievements

Overview

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

At the end of the 2018–19 financial year, the EIS had received $150.54 million (Fig. 4a–d) from variable funding sources (Table 4).

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

This change was brought forward by one year and introduced in the 2018–19 financial year. As the EIS had received the 2018–19 funding of $10 million from the Royalties for Regions program, and the MTR raised $5 million, the EIS was required to refund the Department of Primary Industries and Regional Development (administrators of the Royalties for Regions) $5 million at the beginning of the 2019 calendar year. This maintained the annual allocation of $10 million per year for the EIS.

Major programs

Five comprehensive programs provided the framework to stimulate an increase in private sector resource exploration, to bring about new mineral and energy discoveries and maintain Western Australia's ranking as the most attractive minerals investment destination. Most of the activities within the programs are focused in underexplored greenfields regions. The five programs were:

1. Innovative drilling

1.1 Co-funded Government–Industry drilling

2. Geophysical surveys

2.1 Airborne gravity and electromagnetic surveys; ground surveys

2.2 Deep crustal seismic and magnetotelluric surveys; passive seismic

3. Encouraging exploration through cover

3.1 Drilling decision support and targeting

3.2 Depth of the cover and its interfaces

3.3 Basement geology and evolution

3.4 Mineral systems analysis

4. 3D prospectivity mapping

4.1 Mineral systems

4.2 Petroleum systems

4.3 WA Geology Online

4.4 Exploration data analysis

4.5 3D lithospheric visualization

4.6 Mapping geodynamic setting

4.7 Enhanced geochronology and isotopic fingerprinting

5. Promoting strategic research with industry

5.1 MRIWA support

Major Highlights and activities

- ES20 Co-funded Exploration Drilling — Rounds 18 and 19 opened for applications in 2018–19 (Table 5).
- ES20 Co-funded Exploration Drilling — Bellevue Gold Limited announced the discovery of the Viago Lode in a co-funded drillhole. On announcement, the lode averaged 22 g/t of gold and represented one of highest grade recent gold discoveries globally.

EIS – Overview

Table 4. Funding sources for the EIS since 2009. Mining tenement rent only contributed in 2018–19

EIS phase	Year	Royalties for Regions	Consolidated revenue	Mining tenement rent (MTR)
EIS 1	2008–09 to 2012–13	$76 340 000	–	–
EIS 1A	2013–14	$24 200 000	–	–
EIS 2	2013–14 to 2016–17	–	$30 000 000	–
EIS 3	2017–18 to 2018–19	$15 000 000	–	$5 000 000

Table 5. Application statistics for EIS Co-funded Exploration Drilling Rounds 18 and 19

Round	Number of applications	Number of successful applications
18	74	40 (37 general, 3 prospector)
19	56	45 (38 general, 7 prospector)

Table 6. EIS Co-funded Exploration Drilling statistics for the 2018–19 financial year

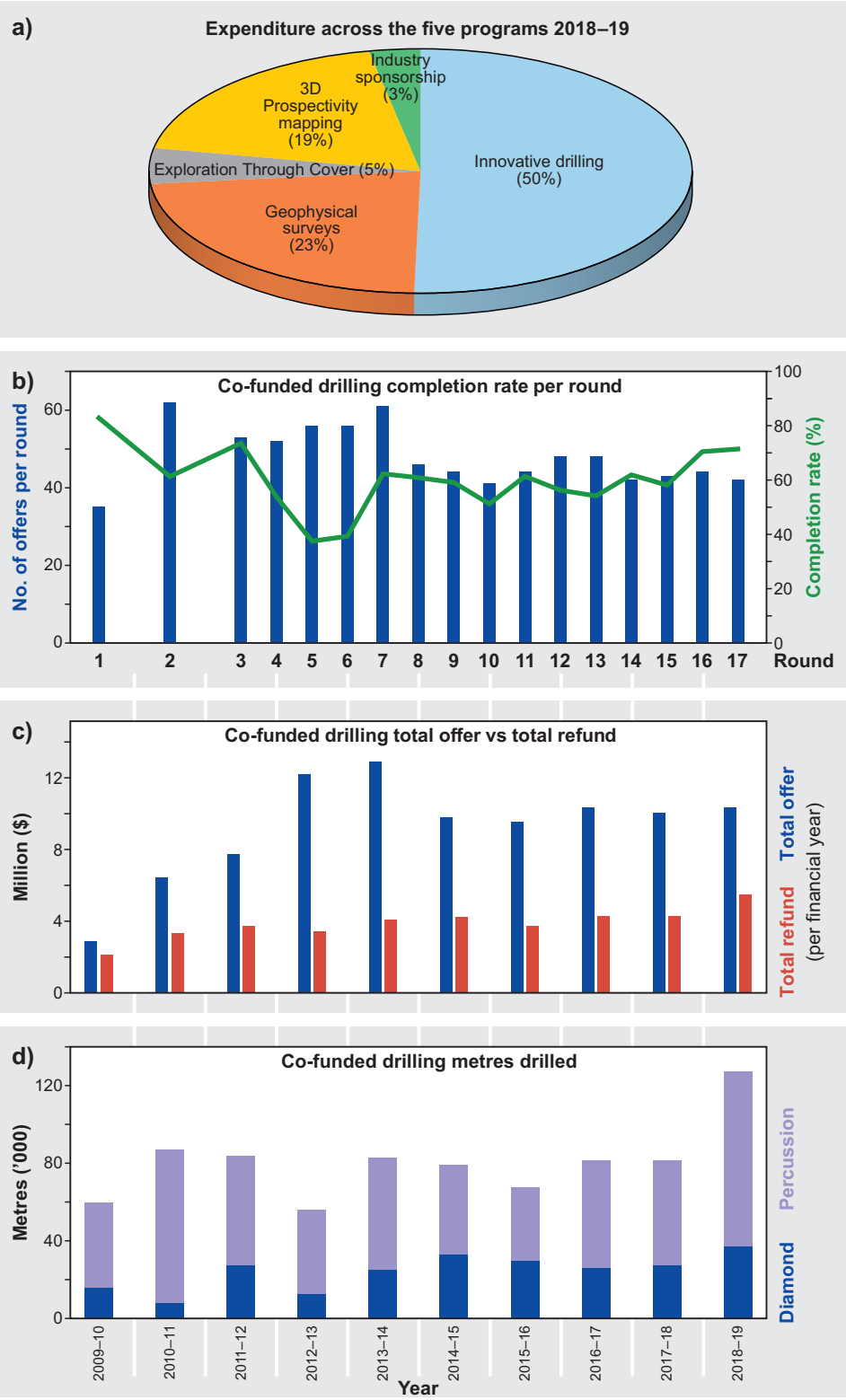
Diamond drilling (m)	Percussion drilling (m)	Total (m)	Co-funding offers	Projects completed
37 450	89 908*	127 357	84	58

* Value higher than average due to one company drilling 285 aircore holes for 23 789 m

- ES20 Co-funded Exploration Drilling — Round 16 (2018) and Round 17 (2018–19) had completion rates of 70% and 71%, respectively. The historical average is 58–59%.
- ES20 Co-funded Exploration Drilling — higher completion rates resulted in 127 km of drilling with 58 projects completed in the financial year (Table 6).
- ES30 Airborne and Ground Geophysical Surveys — acquisition and processing were completed on all three of the 2018 airborne gravity surveys of the Kimberley Basin, Little Sandy and Great Victoria Desert areas.
- ES30 Airborne and Ground Geophysical Surveys — second-generation gravity coverage of Western Australia was completed, with the Pilbara 2019 airborne gravity survey flown and completed in the second quarter of 2019.
- ES31 Deep Seismic Survey Program — Kidson Sub-basin 2D seismic line (872 km) acquisition was completed on 7 August 2018, and the first data release was at the Brisbane Australian Petroleum Production and Exploration Association conference in June 2019. The project was a GSWA–GA collaboration.
- ES33 Regolith geochemical and Resistate Minerals Surveys — the Greenstone Stratigraphic Geochemical Barcoding project released 500 whole-rock major and trace element geochemical data to open file. GSWA Record 2018/15 is published and results (on the barcoding project) presented at the GSWA Open Day 2019 are well received.
- ES37 Eastern Goldfields Seismic Survey — 2D seismic acquisition along seven lines (aggregated 300 km) from near Kalgoorlie–Boulder is completed.
- ES43 Mineral Systems Atlas — development and release of the online interactive, GIS-based Mineral Systems Atlas.
- ES45 Mapping geodynamic settings — quality assurance/quality control (QAQC) of new and legacy (107) geochemical data resulted in 1996 samples released to open file.
- ES46 Enhanced Geochronology and Isotopic mapping — completed the first release of zircon oxygen isotopic data to online applications (GeoVIEW.WA), making GSWA the first organization of its kind in the world to generate and release such high-quality isotopic data to the public.

Dashboard view of the EIS

Figure 4.
Dashboard view of the EIS: a) pie chart showing the expenditure across the five EIS programs for 2018–19; b) percentage of applicants offered a grant that completed a proposed drilling program for each round. From Round 3 onwards, there have been two application periods six months apart. Even-numbered rounds must start and finish drilling within a 12-month calendar period, and odd-numbered rounds within a 12-month financial-year period; c) money offered to successful applicants in a financial year vs the amount refunded. Factors affecting the refund include the number of applicants that withdraw, fewer holes drilled than estimated, and actual direct drilling costs being less than estimated; d) total number of metres drilled by diamond and percussion drilling. The increase in percussion drilling in 2018–19 is due to higher drilling completion rates, and one applicant undertaking a significant aircore program of over 23 000 m



ES20 Government–Industry Co-funded Exploration Drilling

EXPLORATION INCENTIVE SCHEME

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*

- Bellevue Gold Limited (formerly Draig Resources) announced to the Australian Securities Exchange (ASX) the Viago Lode, discovered by an EIS Co-funded Exploration drillhole (Round 15 drilling), and is one of the highest grade recent gold discoveries globally. A maiden Resource estimate of 1.9 Mt at 8.2 g/t gold 500 000 oz (1 August 2018) was announced
- Bellevue Gold Limited ASX announcement (21 May 2019) reports EIS Round 18 co-funded diamond hole has visible gold 150 m below the lowest level of historical underground workings. By the end of the 2018–19 financial year, Bellevue Gold has a compliant independent Joint Ore Reserves Committee (JORC) Inferred Resource inventory of 1 800 000 oz at 11.1 g/t gold
- Independence Group NL was successful in finding the Andromeda copper–zinc prospect with a co-funded diamond hole discovering the mineralization (Round 16)
- Other notable successful co-funded drilling includes: Antipa Minerals (Chicken Ranch project), Buxton Resources (Double Magic – Merlin Prospect), Lefroy Exploration (Lucky Strike prospect), Kingston Resources (Livingstone gold project)
- Round 16 — 12-month drilling period ended 31 December 2018 with a 70% completion rate
- Round 17 — 12-month drilling period ended 30 June 2019 with a 71% completion rate
- Last year of funding from Royalties for Regions ($5 million).

Products released

- The total number of EIS Co-funded Exploration Drilling reports released to open file was 64, including 15 with battery elements listed in target commodity (aluminium, cobalt, lithium, manganese, nickel, REE, graphite and vanadium).

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

EXPLORATION INCENTIVE SCHEME

ES21 Resource Investment Information

Manager: Gaomai Trench

Objectives

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

Highlights and activities

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

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

Industry engagement

In 2018–19, the project funded Western Australia's presence at a number of key international events including:

- Prospectors and Developers Association of Canada Annual Convention, Trade Show and Investors Exchange (PDAC)
- Annual China Mining Conference
- India–Australia Mineral Resources Investment Forums in Mumbai, Hyderabad and New Delhi
- exploration and mining investment seminars in Asia, including Beijing (China), Seoul (Korea) and Tokyo (Japan), in cooperation with Austrade and Australia Minerals
- Annual Mining Investment Asia Congress and Mines and Money Hong Kong.

ES30 Airborne and Ground Geophysical Surveys

Manager: David Howard

EXPLORATION INCENTIVE SCHEME

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 Collaboration Framework (NCF) agreements.

Highlights and activities

- Kidson 2017 airborne gravity survey — experimentation with alternative processing workflows took longer than anticipated. Final data will be released in July 2019.
- Acquisition and processing were completed on all three of the 2018 airborne gravity surveys in six blocks covering an area of some 450 000 km^2 with 177 000 line-km of traverses over large tracts of the Kimberley Basin, and the Little Sandy and Great Victoria Desert areas.
- Pilbara 2019 airborne gravity survey — acquisition of 70 000 line-km of data commenced in April 2019 and was completed in June. The Pilbara survey is the last stage of a long-term program to complete a second generation of gravity coverage of Western Australia, summarized in Figure 5.

Products released

- Preliminary gravity anomaly grids and images from the Kidson 2017 airborne gravity survey.
- Final vertical gravity data from the 2018 surveys in the Kimberley Basin, and the Little Sandy and Great Victoria Deserts (processing of the horizontal component data is still in progress).

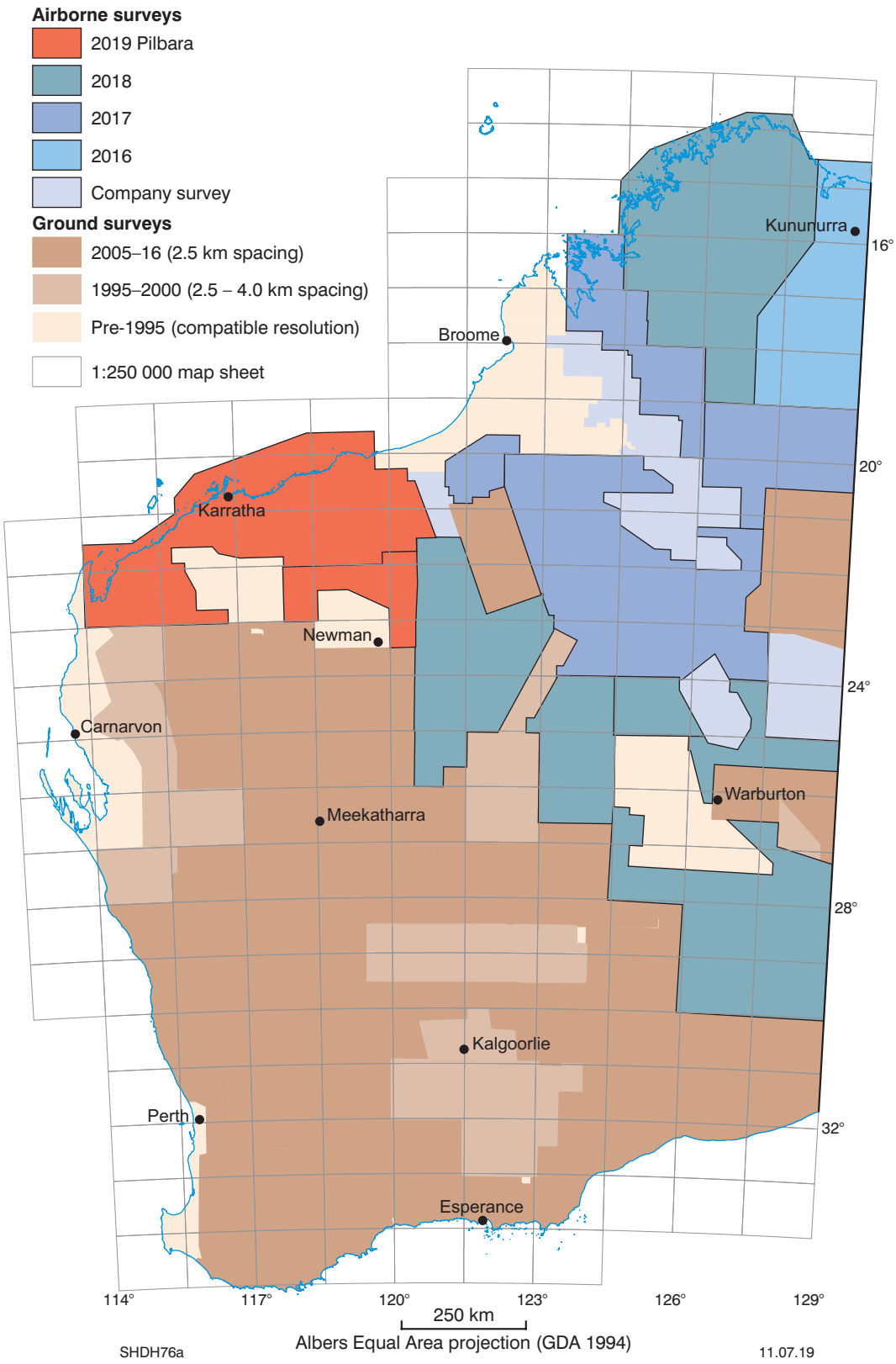


Figure 5. Progress of second-generation gravity coverage of Western Australia

ES31 Deep Seismic Survey Program

Manager: Klaus Gessner

EXPLORATION INCENTIVE SCHEME

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

Highlights and activities

- Acquisition and data release of 872 km of gravity and deep crustal reflection data collected for the Kidson Sub-Basin 2D seismic survey 18GA-KB1.
- Results obtained from the 2014–18 Capricorn Orogen passive seismic array have been processed and placed into a lithosphere-scale 3D model of the Capricorn Orogen to enable a geodynamic-based interpretation of mineral systems.
- Continued acquisition of passive seismic data over the Canning Basin. This is a major project in collaboration with IGG-CAS.
- Mapping within the area of the Eastern Goldfields high-resolution seismic traverses in preparation for their interpretation.
- Acquired and processed a significant magnetotelluric dataset leading to the publication of the following Report, which is listed under GS61 Albany–Fraser Orogen and Eucla Basement Project:
    - Report 189 A magnetotelluric survey across the east Albany–Fraser Orogen, Western Australia.

Products released

- External publication — see Appendices.

EXPLORATION INCENTIVE SCHEME

ES33 Regolith Geochemical and Resistate Mineral Surveys *

Manager: Hugh Smithies

Objectives

This cost centre was used to fund a large component of the analytical costs towards the Greenstone Stratigraphic Geochemical Barcoding project. This projects aims to geochemically characterize the igneous stratigraphy within greenstone belts of the Eastern Goldfields, to provide stratigraphic markers that might aid industry in assigning stratigraphic position to samples (e.g. rotary air blast samples) collected and geochemically analysed from areas with very little clear geological context.

Highlights and activities

- Approximately 500 whole-rock major and trace element geochemical data obtained and entered in WACHEM
- Provided the analytical data described in Record 2018/15 A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity (also reported under GS52).

Products released

- External publication — see Appendices.

* Final budget allocation occurred after publication of the relevant work program, therefore ES33 has no corresponding project area in the Geological Survey work program for 2018–19 and beyond. ES33 activities will be reported under ES49 in the work program for 2019–20

ES36 Participation in MinEx CRC

Manager: Richard Chopping

EXPLORATION INCENTIVE SCHEME

Objectives

ES36 is a new project in 2018–19 and is linked to GS64 Geoscience Mapping Through Cover. The MinEx CRC was granted by the Commonwealth Government in March 2018 and brings together industry, government and research organizations. MinEx CRC comprises three programs that commenced in early 2019. GSWA is a participant in Program 3, the NDI, and Project 6, Automated 3D Modelling. This participation includes placement of an embedded researcher from the University of South Australia in GSWA.

Highlights and activities

- Commencement of MinEx CRC on 1 July 2018, with GSWA related projects commencing as follows:
  - Project 6 in January 2019
  - Program 3 in June 2019
- Definition of framework for work prioritization in the NDI
- Initial planning for NDI work in Western Australia has highlighted 'The Gap' region as the focus area.

Products released

- No products were scheduled for release in 2018–19.

EXPLORATION INCENTIVE SCHEME

ES37 Eastern Goldfields Seismic Survey *

Manager: David Howard

Objectives

The objective of ES37 Eastern Goldfields Seismic Survey was to provide mineral explorers in the region with subsurface information in a depth range from about 300 to 5000 m or more in the area between Ora Banda and Kambalda (Fig. 6). As well as delineating areas that might be suitable for more detailed 3D seismic exploration surveys, we expect that interpretation of the data integrated with GSWA's field mapping, recent passive seismic and magnetotelluric survey projects, and other regional datasets will provide a substantially improved understanding of the geological framework in this region.

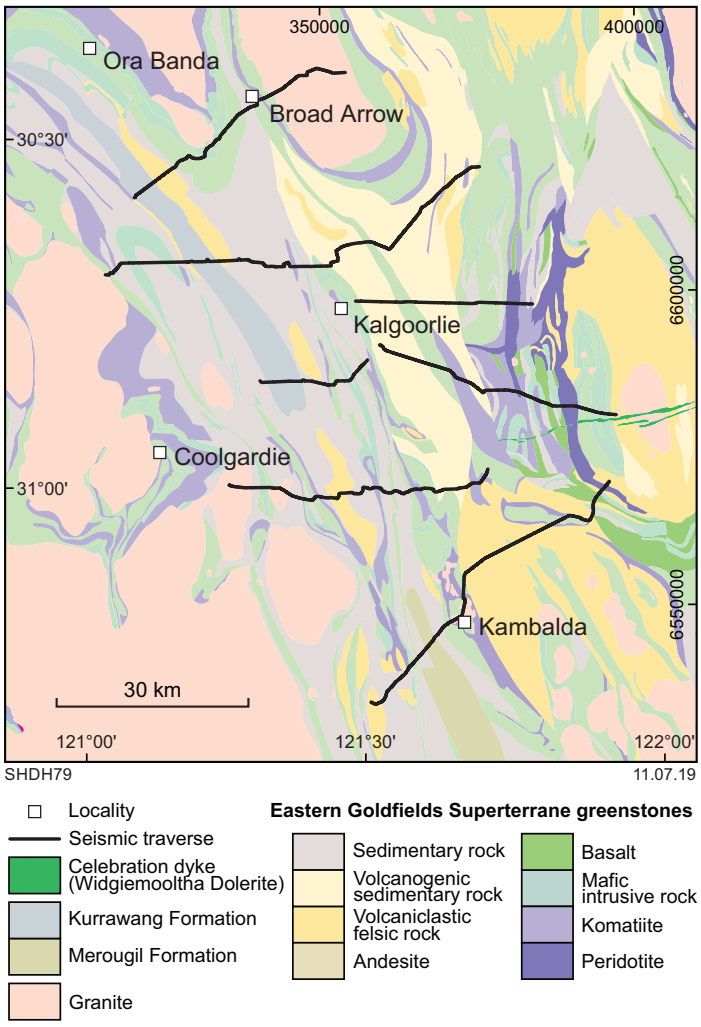


Figure 6. Location of seismic traverses across the Eastern Goldfields on a regional geology base map

Highlights and activities

- A comprehensive planning and stakeholder liaison phase was undertaken between July and December 2018.
- Data acquisition occurred in March and April, along an aggregate 300 km in seven traverses on established roads and tracks.
- Data processing was underway at the end of 2018–19. Processing and preliminary interpretation were completed in August and September 2019, and the final data package released in September 2019.

Products released

- Data from the project will be available for release in the final quarter of 2019.

* The ES37 project area is a subset of ES31. ES37 activities were reported under ES31 in the Geological Survey work program for 2018–19 and beyond, but will be reported under ES37 in the work program for 2019–20

ES40 Geology Online

Manager: Darren Wallace

EXPLORATION INCENTIVE SCHEME

Objectives

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

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

Highlights and activities

- Enhancement of ENS to include regolith and mineral systems
- Implementation of the Mineral Systems Atlas
- Implementation of the GeoResources Spatial Data Capture Tool, an innovative solution for the capture of MINEDEX spatial data. This tool has provided significant efficiency improvements to spatial data capture
- Ongoing upgrade of GeoVIEW.WA Silverlight to HTML5 version
- Ongoing upgrade of the MINEDEX User Interface
- Ongoing Section 40E reporting
- Implementation of CIMS
- Enhancements to Pubstats (Publication Management Tool).

EXPLORATION INCENTIVE SCHEME

ES42 3D Lithosphere Visualization Project *

Manager: Klaus Gessner

Objectives

The aim of the 3D Lithosphere Visualization Project is to visualize and model relevant portions of the solid Earth in Western Australia. The objective is to extend knowledge from exposed and well-understood areas of the Earth's crust and lithosphere to inaccessible or data-poor parts using 3D structural analysis, modelling and numerical simulation techniques. These techniques also test the validity of conceptual models and interpretations. An important aspect of ES42 is the cooperation with leading research institutions that complement GSWA's capabilities in data acquisition, analysis and modelling. In addition to collaborating with GA, GSWA 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, magnetotelluric surveys and next generation 3D modelling techniques. These activities closely relate to the GS62 3D Geoscience section.

Highlights and activities

- Results obtained from the 2014–18 COPA passive seismic array have been processed and placed into a lithosphere-scale 3D model of the Capricorn Orogen to enable a geodynamic-based interpretation of mineral systems.
- Continued acquisition of passive seismic data over the Canning Basin. This is a major project in collaboration with IGG-CAS.
- Mapping within the area of the Eastern Goldfields high-resolution seismic traverses in preparation for their interpretation.
- The fault model of the northern Youanmi Terrane, Yilgarn Craton was finalized and will be published in 2019/20.
- Yalgoo–Singleton greenstone belt 3D geomodel has been built and is being tested against geophysical data.
- Commencement of Australian Research Centre (ARC) Linkage Project LP170100985 Enabling 3D stochastic geological modelling – that brings together geological surveys and research institutions in Australia, Canada, France, Germany and the UK to found a new open-source initiative to build the next generation of 3D geological modelling tools.
- Publication of the following products, which are formally listed as products under GS62 3D Geoscience:
  - East Albany–Fraser Orogen 3D, 2018, 3D Geomodel Series
  - Lawlers Anticline 3D, 2014, 3D Geomodel Series
  - Record 2019/4 Compilation of geophysical modelling records, 2018.

Products released

- External publications — see Appendices.

* ES42 activities were reported under GS62 in the Geological Survey work program for 2018–19 and beyond, but will be reported under ES42 in the work program for 2019–20

ES43 Mineral Systems Atlas

Manager: Trevor Beardsmore

EXPLORATION INCENTIVE SCHEME

Objectives

Under ES43 Mineral Systems Atlas, GSWA has entered into research agreements with external groups and individuals to provide GIS-based exploration targeting products that effectively extol the potential of underexplored regions of Western Australia in easy-to-understand formats for geoscientists in the exploration industry. Many of these projects are managed or monitored by GSWA's Mineral Systems branch, and in some instances have received in-kind funding from the GS20 recurrent budget; however, the majority of these minerals-oriented research projects have been partly to fully funded by the EIS.

Highlights and activities

The most significant project undertaken in 2018–19 was development of the online interactive, GIS-based Mineral Systems Atlas, which delivers 'mappable geological proxies' for critical metallogenic processes that are derived from systematic 'mineral systems analyses' of known or probable mineral systems in Western Australia (see GS20 for more details). The online Mineral Systems Atlas Guide complements the GIS platform by describing the derived data layers, explaining the reasoning behind their inclusion in the specific mineral systems and documenting their creation via an SQL query of GSWA source data.

Products released

- Mineral Systems Atlas (www.dmirs.wa.gov.au/mineralsystemsatlas; Fig. 7)
- Mineral Systems Atlas Guide (http://help.internal.dom/wsmhelp/msa; Fig. 8).

Figure 7.

Western Australian geochemistry data have been queried by selecting for ultramafic rocks and then calculating Mg numbers (100 * (MgO% / (MgO% + Fe_2O_3T%)) as defined by Rollinson (1993). Ultramafic rocks are shown in blue

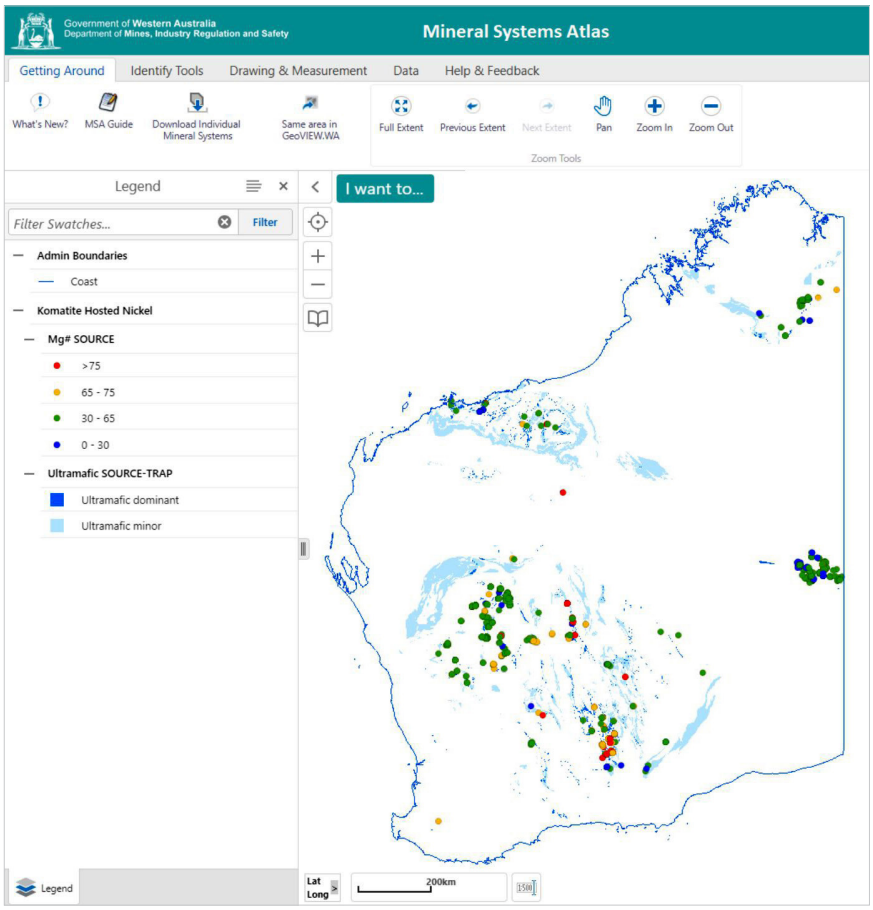
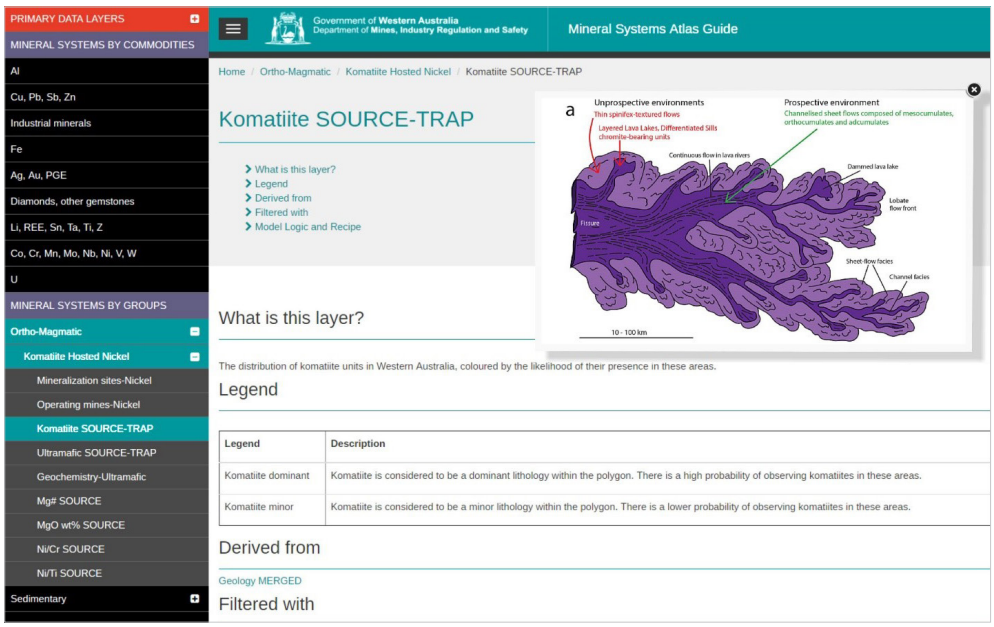


Figure 8.

Example description of the komatiite layer with an expanded model of a komatiitic lava flow. The online Mineral Systems Atlas Guide complements the GIS platform by describing the derived data layers, explaining the reasoning behind their inclusion in the specific mineral systems and documenting their creation via an SQL query of GSWA source data



ES45 Mapping Geodynamic Settings Program

Manager: Hugh Smithies

EXPLORATION INCENTIVE SCHEME

Objectives

The Mapping Geodynamic Settings Program will continue a program of whole-rock and isotope geochemistry of magmatic rocks aimed at developing an understanding of the geodynamic evolution of the Western Australian crust from the Hadean to the present day. Geodynamic setting is a predictive tool in regional-scale exploration targeting. The aim is to produce a series of updateable geodynamic setting maps at particular times in Western Australia's geological history thought to be particularly prospective for mineral deposits. The maps will identify fossil suture zones and rifted continental margins where fluid pathways may have enhanced metal fertility through the influx of juvenile, mantle-derived and subduction-modified magmas.

Highlights and activities

- This cost centre was used to pay for contract staff working within other mapping projects, specifically GS58 (Jack Lowrey, Stephen Wyche) and GS52 (Melissa Drummond, Stephen Wyche) and their contributions are primarily accounted for within products and outcomes attached to those projects. Much of the role undertaken by Stephen Wyche was to validate legacy ENS entries for the eastern and western Yilgarn Craton. A significant additional component of Jack Lowrey's role involved facilitating whole-rock geochemical analysis and QAQC of data upon return from the laboratories. The need for this aspect of his role was to accommodate the influx of samples related to the Greenstone Stratigraphic Geochemical Barcoding Project (ES33). Melissa Drummond's role involved stakeholder engagement and liaison relating to various activities run out of the Kalgoorlie Regional Office and the Joe Lord Core Library, including the high-definition seismic acquisition program (ES37).
- MRIWA Project M521* — Lithospheric and crustal-scale controls on multistage basin evolution: impacts on mineralizing systems. This proposal will use an integrated basin studies approach combining interpretation of multiple regional data sets (e.g. new seismic reflection, drillcore, gravity, magnetics) with numerical modelling to investigate multiscale (lithospheric and crustal) and multistage deformation processes. These will provide insight into the link between basement and basin evolution, and subsequent mineralization processes. The 'natural laboratory' used for this study is primarily the Paterson Orogen, in central Western Australia. This project will align more with ES38 Proterozoic Margins into the future and will be reported as such.

* Reported under ES50 in the Geological Survey work program for 2018–19 and beyond

EXPLORATION INCENTIVE SCHEME

ES46 Enhanced Geochronology and Isotopic Mapping

Manager: Michael Wingate

Objectives

This project enhances GSWA's geochronology program (GS54) with the addition of Lu–Hf and oxygen isotope and trace element analysis of zircons, Sm–Nd isotope analysis of whole-rock samples, and additional isotope-related techniques (such as whole-rock Lu–Hf and Pb–Pb isotopes) conducted in collaboration with university research groups (Fig. 9). These techniques enable construction of a range of isotopic maps at different scales, which are powerful in imaging lithospheric and crustal architecture, identifying metallogenic terranes and favourable geodynamic environments, and constraining the 4D evolution of the lithosphere.

Highlights and activities

- Release of 70 new Sm–Nd isotope data, 58 new Lu–Hf isotope data and 43 new oxygen isotope data
- Zircon oxygen isotope data released by GSWA for the first time, integrated with geochronology records in GeoVIEW.WA and the Compilation of geochronology information, 2019
- Updated the Sm–Nd isotope map for the Yilgarn Craton with 27 new Sm–Nd isotope data from the South West Terrane
- Completed writing of Report 197 Zircon fingerprinting of magmatic–hydrothermal systems in the Archean Yilgarn Craton. This Report will constitute GSWA's first release of zircon trace element data. This work shows that zircon, a common mineral in granitic rocks, can be used to distinguish between fertile and barren rocks in ancient terranes, and provides a new way of searching for economic mineralization. It has attracted significant interest from giant, mid-tier and junior exploration companies, including BHP, Rio Tinto, Newmont Goldcorp, Anglo American plc, Gold Road Resources Limited, Independence Group NL, Saracen Mineral Holdings Limited, Antipa Minerals Ltd, Encounter Resources Limited and Great Boulder Resources Limited. Presented at GSWA Open Day 2019 and included in Record 2019/2 extended abstracts.
- Completed the functional specifications for design of a geochronology, isotope and mineral chemistry database (WAGIM)
- Completed MRIWA project M446 — 4D evolution of Western Australian ore systems: Re–Os sulfide geochronology (waiting for final report following acceptance of PhD thesis)
- Completed MRIWA project M448 — 4D evolution of Western Australian ore systems: rutile – pathfinder to ores (waiting for final report following acceptance of PhD thesis)
- Completed MRIWA project M470 — Mineral systems on the margin of cratons: Albany–Fraser Orogen / Eucla basement case study (waiting for final reports following acceptance of PhD theses).

Products released

- 982 Sm–Nd data (70 new), 492 Lu–Hf data (58 new), and 43 new oxygen data released to online applications (GeoVIEW.WA and/or GeoChem Extract)
- Report 194 In situ U–Pb geochronology of hydrothermal xenotime and monazite to date gold mineralization in the northern Capricorn Orogen, Western Australia
- Record 2018/13 (U–Th)/He dating of ferruginous duricrust, Boddington gold mine, Western Australia
- External publications — see Appendices.

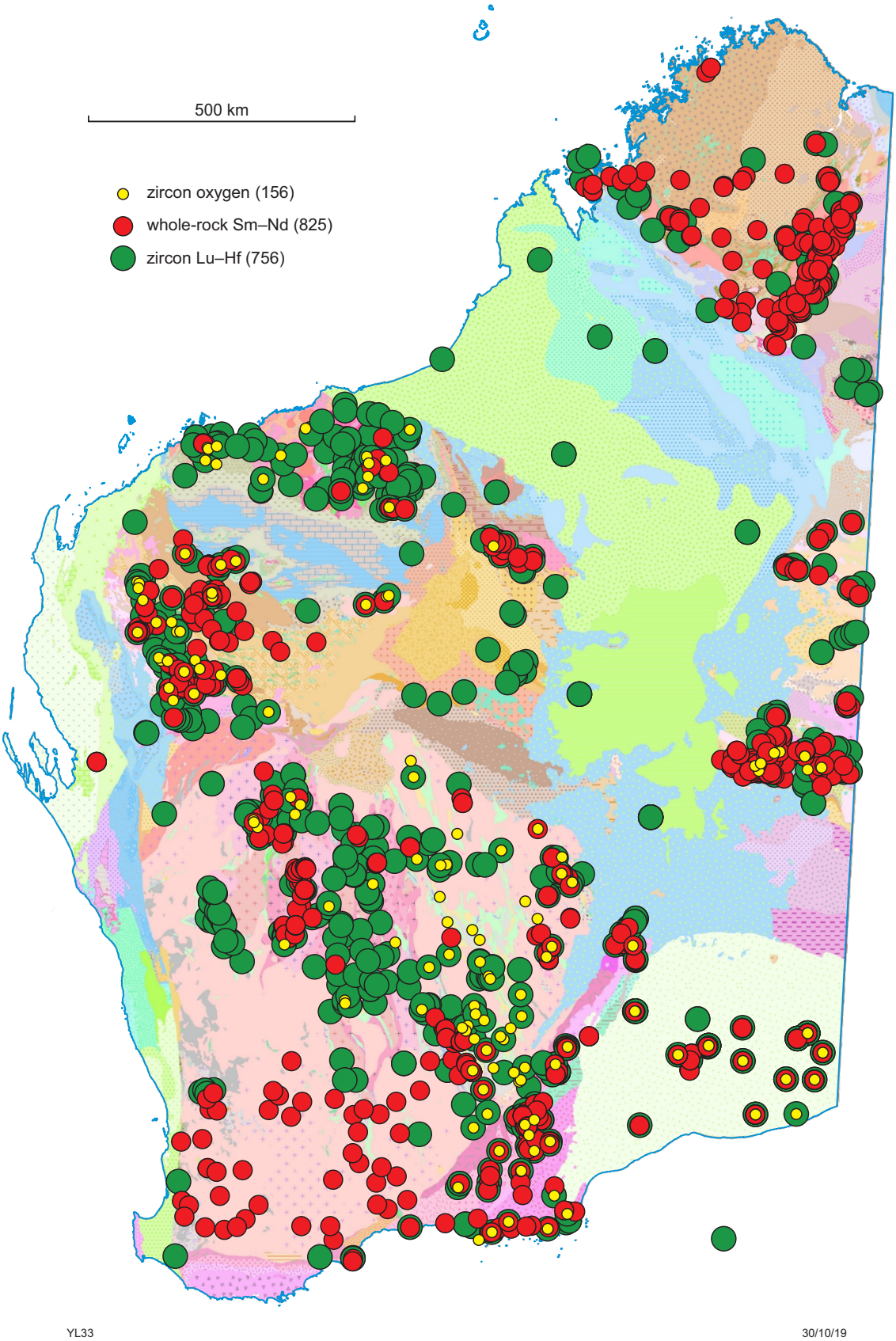


Figure 9. Locations of GSWA samples for isotope studies for which data have been acquired under the EIS (total numbers of analyses in brackets)

EXPLORATION INCENTIVE SCHEME

ES47 Petroleum Systems

Manager: Deidre Brooks

Objectives

The objective of this program is to collect pre-competitive data to assist in determining the State's potential for petroleum and alternative energy sources that might provide for the State's growing energy requirements. This program comprises a number of distinct subprograms which were mostly completed during the 2018–19 financial year.

Highlights and activities

- The project assessing coal resources within Western Australia was completed at the end of June 2019. The first two Records were published in June 2019. One additional record and a GIS database of coal drillholes in the Eucla, Canning and northern Perth Basins will be released in 2019–20.
- The revised SEEBASE (depth to basement) product over the Carnarvon Basin was completed by Frogtech Geoscience and released at GSWA Open Day 2019 through eBookshop. The full GIS package with Report is also available to purchase as a USB. The SEEBASE image is shown in Figure 10.
- The Senagi 1 sample analysis results undertaken as part of the Canning Basin collaborative core analysis project were compiled into a digital core atlas, which was released through the WAPIMS database.
- The seismic reprocessing of selected regional vintage 2D seismic lines in the Canning and onshore Carnarvon Basins was completed. The SEG-Y data for each line and the associated reprocessing reports were released through the WAPIMS database. The location of the reprocessed seismic data in the Carnarvon Basin and Canning Basin are shown in Figures 11 and 12, respectively.
- The Kidson Sub-basin deep crustal 2D seismic survey was acquired in 2018. The survey was recorded as a single continuous 872 km-long line along the existing road which links the Kiwirrkurra community, near the Western Australian / Northern Territory border in the east, to Marble Bar in the west (Fig. 12).

Products released

- Record 2019/5 Mesozoic coal resources of the northern Perth Basin: exploration and evaluation history
- Record 2019/6 Cenozoic coal resources of southern Western Australia: exploration and evaluation history
- Digital Core Atlas for Senagi 1, Canning Basin (interactive digital product) released through the WAPIMS database
- Report 191 Carnarvon Basin 2018 SEEBASE Study and GIS
- Processed SEG-Y data of the Kidson Sub-basin deep crustal seismic survey released through the WAPIMS database
- Reprocessed SEG-Y data from the seismic reprocessing of regional vintage 2D seismic data from onshore Southern Carnarvon Basin and Coolcalalaya sub-basin of the northern Perth Basin released through the WAPIMS database
- Reprocessed SEG-Y data from the seismic reprocessing of regional vintage 2D seismic data from three areas of the Canning Basin released through the WAPIMS database:
  - Kidson Sub-basin
  - northwest Canning Basin regional 1988 deep crustal lines
  - Cobb Embayment.

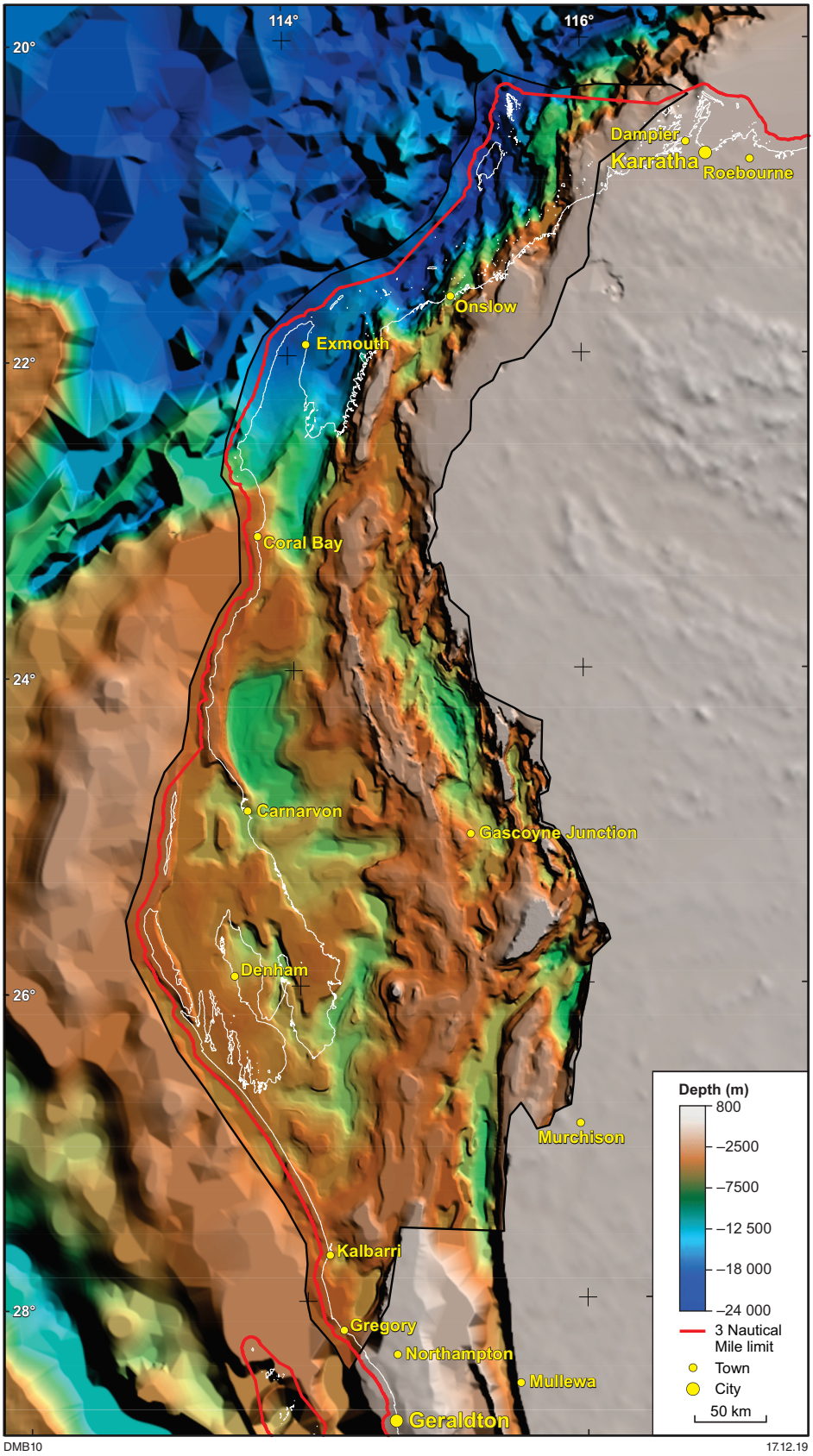


Figure 10.

2018 Carnarvon Basin SEEBASE (Frogtech Geoscience, 2019) with Phanerozoic OZ SEEBASE in the background (Frogtech Geoscience, 2005). The area of interest is shown by the red polygon

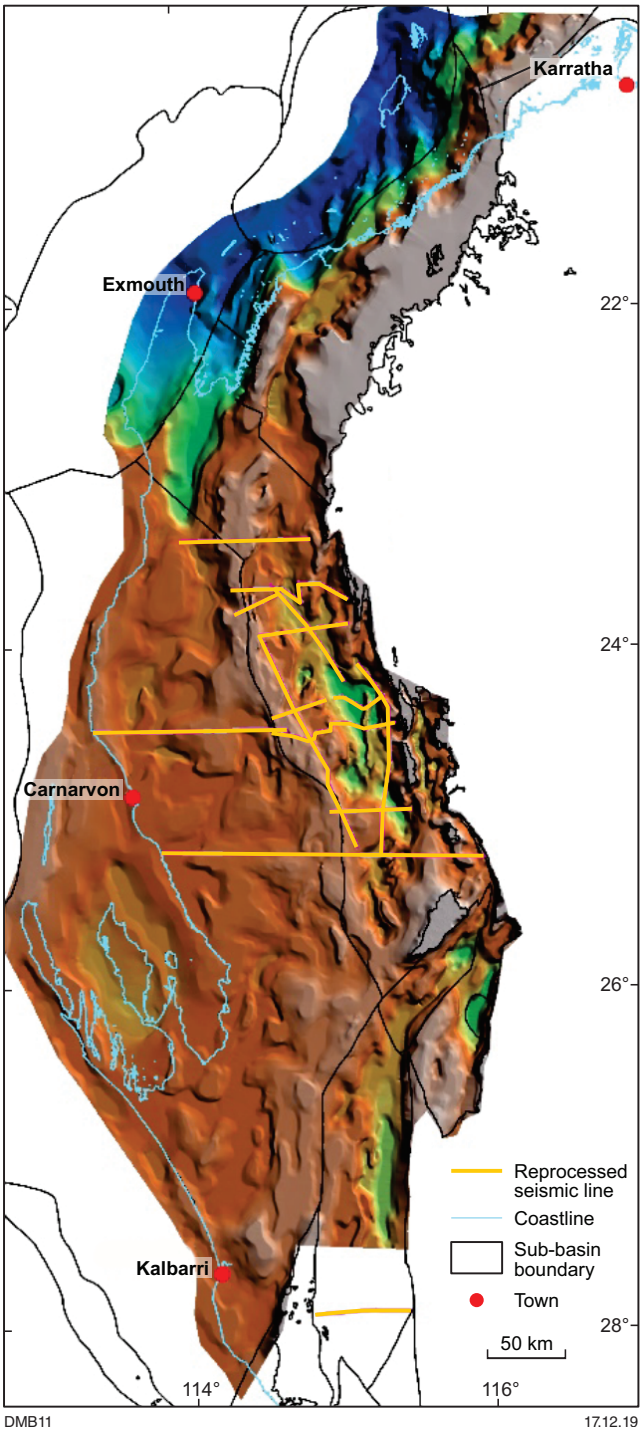


Figure 11. Location of 2D vintage seismic lines reprocessed in the Carnarvon Basin shown as yellow lines

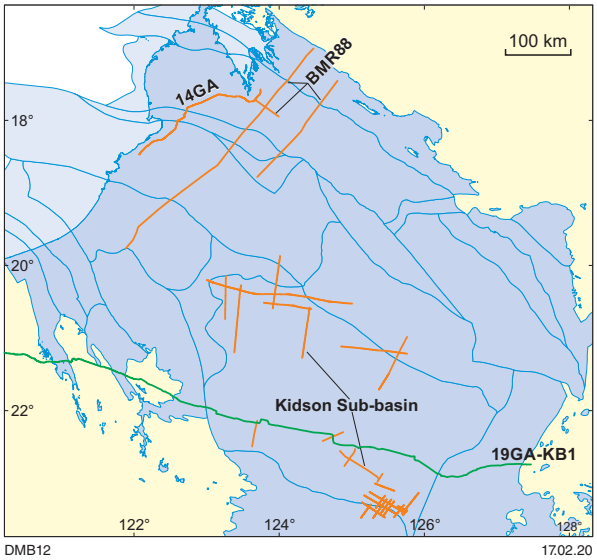


Figure 12. Location of 2D vintage seismic lines reprocessed in the Canning Basin shown as orange lines

ES48 Pilbara Field Mapping

Manager: Heather Howard

EXPLORATION INCENTIVE SCHEME

Objectives

This cost centre was used to fund the salary of Senior Geologist David Martin in the field mapping component of the Pilbara and Hamersley Project. The aims of the project are outlined under GS63 Pilbara and Hamersley project.

Highlights and activities

- Completed writing of the Geology of the Hardey Syncline – Record, due for release 2019–20
- New mapping of the Turee Creek and Wyloo Groups in the western Pilbara.

Products released

- External publications — see Appendices.

References

Frogtech Geoscience 2005, OZ SEEBASE Study 2005, Public Domain Report to Shell Development Australia: Geological Survey of Western Australia, 182p.

Frogtech Geoscience 2019, 2018 Carnarvon Basin SEEBASE study and GIS data package: Geological Survey of Western Australia, Report 191, digital data package.

Geological Survey of Western Australia 2018, Geological Survey work program for 2018–19 and beyond: Geological Survey of Western Australia, Record 2018/1, 115p.

Rollinson, HR 1993, Using geochemical data: Evaluation, presentation, interpretation: Pearson Education Ltd, Harlow, England, 352p.

United States Geological Survey 2019, Mineral commodity summaries 2019: United States Geological Survey, 200p. doi:10.3133/70202434.

ARC Linkage Project LP130100922 — Chronostratigraphic and tectonothermal history of the northern Capricorn Orogen: providing a framework for understanding mineralizing systems

EXPLORATION INCENTIVE SCHEME

Project manager: Birger Rasmussen

Partner researchers/institutions: Birger Rasmussen, Janet Muhling, Stephen Sheppard, Zi J-W, Nishka Piechocka, Imogen Fielding (Curtin University), Jamie Rogers (Northern Star Resources Ltd)

GSWA contact: Simon Johnson **Duration of project:** 2014–17 **Completed:** 02/2019

Project description

This project combined innovative geochronology with targeted field mapping to date sedimentary successions, metamorphic events, crustal fluid flow and hydrothermal mineralization along the recently acquired Capricorn seismic transect. The construction of a new and improved geological framework linked to deep seismic information has provided breakthroughs in our understanding of the history of this long-lived orogen and the ore deposits that it contains. The project identified the major structures and tectonic events controlling mineralization, underpinning the generation of successful exploration models.

GSWA deliverables

Korhonen, FJ and Johnson, SP 2015, The role of radiogenic heat in prolonged intraplate reworking: The Capricorn Orogen explained?: Earth and Planetary Science Letters, v. 428, p. 22–32, doi:10.1016/j.epsl.2015.06.039.

Johnson, SP, Korhonen, FJ, Kirkland, CL, Cliff, JB, Belousova, EA and Sheppard, S 2017, An isotopic perspective on growth and differentiation of Proterozoic orogenic crust: From subduction magmatism to cratonization: Lithos, v. 268–271, p. 76–86, doi:org/10.1016/j.lithos.2016.11.003.

Korhonen, FJ, Johnson, SP, Wingate, MTD, Fletcher, IR, Dunkley, DJ, Roberts, MP, Sheppard, S, Muhling, JR and Rasmussen, B 2017, Radiogenic heating and craton-margin plate stresses as drivers for intraplate orogeny: Journal of Metamorphic Geology, v. 35, p. 631–661, doi:10.1111/jmg.12249.

Fielding, IOH, Johnson, SP, Zi, J-W, Rasmussen, B, Muhling, JR, Dunkley, DJ, Sheppard, S, Wingate, MTD and Rogers, JR 2017, Using In Situ SHRIMP U–Pb Monazite and Xenotime Geochronology to Determine the Age of Orogenic Gold Mineralization: An Example from the Paulsens Mine, Southern Pilbara Craton: Economic Geology, v. 112, no. 5, p. 1205–1230, doi:10.5382/econgeo.2017.4507.

Fielding, IOH, Johnson, SP, Rogers, JR and Elliot, LK 2017, Paulsens gold deposit, *in* Australian Ore Deposits *edited by* GN Phillips: Australasian Institute of Mining and Metallurgy, Monograph 32, p. 405–410.

Piechocka, AM, Gregory, CJ, Zi, J-W, Sheppard, S, Wingate, MTD and Rasmussen, B 2017, Monazite trumps zircon: applying SHRIMP U–Pb geochronology to systematically evaluate emplacement ages of leucocratic, low-temperature granites in a complex Precambrian orogen: Contributions to Mineralogy and Petrology, v. 172, no. 8, p. 63, doi:10.1007/s00410-017-1386-5.

Fielding, I, Johnson, SP, Zi, J, Rasmussen, B, Muhling, JR, Dunkley, DJ, Sheppard, S, Wingate, MTD and Rogers, JR 2017, In situ phosphate dating of orogenic gold mineralization at Paulsens mine, southern Pilbara, *in* GSWA 2017 Extended abstracts: promoting the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2017/2, p. 14–17.

Fielding, IOH, Johnson, SP, Zi, J-W, Sheppard, S and Rasmussen, B 2018, Neighbouring orogenic gold deposits may be the products of unrelated mineralizing events: Ore Geology Reviews, v. 95, p. 593–603, doi:10.1016/j.oregeorev.2018.03.011.

Collaborative research projects completed

Piechocka, AM, Sheppard, S, Fitzsimons, ICW, Johnson, SP, Rasmussen, B and Jourdan, F 2018, Neoproterozoic $^{40}Ar/3^{9}Ar$ mica ages mark the termination of a billion years of intraplate reworking in the Capricorn Orogen, Western Australia: Precambrian Research, v. 310, p. 391–406, doi:10.1016/j.precamres.2018.04.006.

Fielding, IOH, 2019, In situ U–Pb geochronology of hydrothermal xenotime and monazite to date gold mineralization in the northern Capricorn Orogen, Western Australia: Geological Survey of Western Australia, Report 194, 304p.

Fielding, IOH, Johnson, SP, Meffre, S, Zi, J, Sheppard, S, Large, RR and Rasmussen, B 2019, Linking gold mineralization to regional-scale drivers of mineral systems using in situ U–Pb geochronology and pyrite LA-ICP-MS element mapping: Geoscience Frontiers, v. 10, no. 1, p. 89–105, doi:10.1016/j.gsf.2018.06.005.

Piechocka, AM, Zi, J-W, Gregory, CJ, Sheppard, S and Rasmussen, B 2019, SHRIMP U–Pb phosphate dating shows metamorphism was synchronous with magmatism during the Paleoproterozoic Capricorn Orogeny: Australian Journal of Earth Sciences, v. 66, no. 7, p. 973–990, doi:10.1080/08120099.2019.1587644.

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

Collaborative research projects completed

Crustal evolution of Western Australia

EXPLORATION INCENTIVE SCHEME

Project manager: Chris Kirkland (Curtin University)

Partner researchers/institutions: Chris Kirkland, Narelle Gardiner, Tim Johnson, Martin Danišík, Noreen Evans, Chris Clark, Chris Spencer, Brad McDonald (Curtin University); Heejin Jeon (CMCA, UWA); Simon Bodorkos (GA); Jian-Xin Zhao (University of Queensland)

GSWA contact: Michael Wingate **Duration of project:** 2015–18 **Completed:** 2018

Project description

The project aims were to:

- produce contoured, time-dynamic Hf isotope maps from selected regions of Western Australia
- implement secondary ion mass spectroscopy oxygen analyses of GSWA mounts and contribute to isotopic data.

GSWA deliverables

- Co-branded GSWA Reports and GIS layers

Kirkland, CL, Spaggiari, CV, Johnson, TE, Smithies, RH, Danišík, M, Evans, N, Wingate, MTD, Clark, C, Spencer, C, Mikucki, E and McDonald, BJ 2016, Grain size matters: Implications for element and isotopic mobility in titanite: Precambrian Research, v. 278, p. 283–302, doi:10.1016/j.precamres.2016.03.002.

Kirkland, CL, Gardiner, N, Smithies, RH, Spaggiari, CV, Wingate, MTD, Quentin de Gromard, R, Clark, C and Belousova, EA 2017, Proterozoic crustal evolution of the Eucla basement, Australia: Implications for destruction of oceanic crust during emergence of Nuna: Lithos, v. 278–281, p. 427–444, doi:10.1016/j.lithos.2017.01.029.

Gardiner, NJ, Hickman, AH, Kirkland, CL, Lu, Y, Johnson, TE and Wingate, MTD 2018, New Hf isotope insights into the Paleoarchean magmatic evolution of the Mount Edgar Dome, Pilbara Craton: Implications for early Earth and crust formation processes: Geological Survey of Western Australia, Report 181, 41p.

Gardiner, NJ, Hickman, AH, Kirkland, CL, Lu, Y, Johnson, TE and Zhao, J-X 2017, Processes of crust formation in the early Earth imaged through Hf isotopes from the East Pilbara Terrane: Precambrian Research, v. 297, p. 56–76, doi:10.1016/j.precamres.2017.05.004.

Gardiner, NJ, Maidment, DW, Kirkland, CL, Bodorkos, S, Smithies, RH and Jeon, H 2018, Isotopic insight into the Proterozoic crustal evolution of the Rudall Province, Western Australia: Precambrian Research, v. 313, p. 31–50, doi:10.1016/j.precamres.2018.05.003.

Johnson, SP, Kirkland, CL, Evans, NJ, McDonald, BJ and Cutten, HN 2018, The complexity of sediment recycling as revealed by common Pb isotopes in K-feldspar: Geoscience Frontiers, v. 9, no. 5, p. 1515–1527, doi:10.1016/j.gsf.2018.03.009.

Gardiner, NJ, Johnson, TE, Kirkland, CL and Smithies, RH 2017, Melting controls on the lutetium–hafnium evolution of Archaean crust: Precambrian Research, v. 305, p. 479–488, doi:10.1016/j.precamres.2017.12.026.

Geological Studies of Gabbroic Rocks Intruding the Arid Basin in the Albany–Fraser Orogen

Project manager: Tim Johnson (Curtin University)

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

GSWA contact: Catherine Spaggiari **Duration of project:** 2015–18 **Completed:** 2018–19

Project description

The principal aims of the project were to:

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

GSWA deliverables

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

Glasson, KJ, Johnson, TE, Kirkland, CL, Gardiner, NJ, Clark, C, Blereau, E, Hartnady, MIH, Spaggiari, C and Smithies, H 2019, A window into an ancient back arc? The magmatic and metamorphic history of the Fraser Zone, Western Australia: Precambrian Research, v. 323, p. 55–69, doi:10.1016/j.precamres.2019.01.011.

MRIWA Project M462 — Multi-scaled near surface exploration using ultrafine soils

EXPLORATION INCENTIVE SCHEME

Project Manager: Ryan Noble (CSIRO)

Partner researchers/institutions: CSIRO

GSWA Contact: Paul Morris **Duration of project:** 2016–19

Project description

The aim of this project was to greatly refine analytical methods and enhance surface exploration success with sampling and analysing microparticulate and nanoparticulate metals and fine particle size fractions in local site orientation surveys, as well as broad regional sample sets in Australia (Yamarna greenstone belt, Paterson Province, and northeast Yilgarn margins and Northern Yandal edge). Samples from previous orientation surveys from CSIRO, industry and previous or current regional soil surveys (GSWA or industry) were subject to a variety of size separation analyses and assessed in relation to other physical (e.g. texture), mineralogical (e.g. iron oxides, kaolinite), biological (e.g. organic carbon) and chemical (e.g. pH, electrical conductivity) properties of the samples. Microparticulate and nanoparticulate metals were characterized and assessed with respect to known mineralization to understand mobility in a landscape evolution context.

GSWA deliverables

Noble, R, Lau, I, Anand, R and Pinchand, T 2018, MRIWA Report No. 462: Multi-scaled near surface exploration using ultrafine soils: Geological Survey of Western Australia, Report 190, 99p.

Structural and metamorphic evolution of the east Albany–Fraser Orogen

Project manager: Catherine Spaggiari

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

GSWA contact: Catherine Spaggiari **Duration of project:** 2013–19 **Completed**: 2018–19

Project description

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

GSWA deliverables

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

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

Oorschot, CW 2011, P–T–t evolution of the Fraser Zone, Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Record 2011/18, 101p.

Adams, M 2012, Record 2012/4 Structural and geochronological evolution of the Malcolm Gneiss, Nornalup Zone, Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Record 2012/4, 134p.

Clark, C, Kirkland, CL, Spaggiari, CV, Oorschot, C, Wingate, MTD and Taylor, RJ 2014, Proterozoic granulite formation driven by mafic magmatism: An example from the Fraser Range Metamorphics, Western Australia: Precambrian Research, v. 240, p. 1–21, doi:10.1016/j.precamres.2013.07.024.

Kirkland, CL, Spaggiari, CV, Johnson, TE, Smithies, RH, Danišík, M, Evans, N, Wingate, MTD, Clark, C, Spencer, C, Mikucki, E and McDonald, BJ 2016, Grain size matters: Implications for element and isotopic mobility in titanite: Precambrian Research, v. 278, p. 283–302, doi:10.1016/j.precamres.2016.03.002.

Scibiorski, E, Tohver, E, Jourdan, F, Kirkland, CL and Spaggiari, CV, 2016, Cooling and exhumation along the curved Albany–Fraser Orogen, Western Australia: Lithosphere, v. 8, no. 5, p. 551–563, doi:10.1130/L561.1.

Scibiorski, E, Tohver, E and Jourdan, F 2015, Rapid cooling and exhumation in the western part of the Mesoproterozoic Albany–Fraser Orogen, Western Australia: Precambrian Research, v. 265, p. 232–248, doi:10.1016/j.precamres.2015.02.005

Scibiorski, E 2019, The cooling and exhumation of the Albany–Fraser Orogen, Western Australia, constrained by $^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb thermochronology: Geological Survey of Western Australia, Report 195, 677p.

Collaborative research projects completed

(U–Th)/He geochronology of iron oxides in duricrust at Boddington Gold Mine

Project Manager: Martin Wells (Curtin University)

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

GSWA contact: Paul Morris, Michael Wingate **Duration of project:** 2016–18 **Completed:** 2018

Project description

This study assessed the type of duricrust material (e.g. fragmental vs pisolitic) most suitable for application of the (U–Th)/He dating technique by systematically collecting samples from exposures in the Boddington Gold Mine, characterizing these materials by microscopy and isotopic techniques, and comparing the results with those obtained previously by other authors. The combined results have provided a quantitative temporal framework for understanding landscape evolution and regolith formation in the Darling Range.

GSWA deliverables

Wells, MA, Danišík, M, McInnes, BIA and Morris, PA 2019, (U–Th)/He-dating of ferruginous duricrust: Insight into laterite formation at Boddington, WA: Chemical Geology, v. 522, p. 148–161, doi:10.1016/j.chemgeo.2019.05.030.

Wells MA, Danišík M and McInnes BIA 2018, (U–Th)/He dating of ferruginous duricrust, Boddington gold mine, Western Australia: Geological Survey of Western Australia, Record 2018/13, 14p.

Completed projects with Geoscience Australia: National Collaborative Framework (NCF) activities

Exploring for the future – Kidson Sub-basin seismic acquisition (002850)*

EXPLORATION INCENTIVE SCHEME

Completed: 2018

* All project information and publications can be reviewed in ES47 Petroleum Systems

GSLC Terms of Reference

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

DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY

GEOLOGICAL SURVEY LIAISON COMMITTEE (GSLC)

TERMS OF REFERENCE

1. Purpose

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

2. Key responsibilities

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

3. Relationship with other Committees

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

4. Decision Making

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

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Department of **Mines, Industry Regulation and Safety**

- Dissenting view/s can be recorded in the minutes if so requested by the member/s

5. Membership

5.1 Committee membership

The Committee will consist of 11 members:

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

5.2 Qualifications for members

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

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

5.3 Appointment

- The Director General or his proxy will appoint members and proxies to the Committee on the recommendation of the institutions named above;

  * These members will also be the Chairs of the technical subcommittees described below; and
- The members are appointed for a period of three years, and although they are eligible for reappointment, rotation is preferred, and the Chair will seek nominations from the represented organisations that recognise the need for gender balance, and for skills and experience relevant to the committee.

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6. Technical Subcommittees

6.1 Minerals Technical Subcommittee (MTSC)

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

6.1.2 Membership will consist of 8 members:

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

6.2 Petroleum Technical Subcommittee (PTSC)

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

6.2.2 Membership will consist of 7 members:

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

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Department of **Mines, Industry Regulation and Safety**

6.3 Qualifications of Subcommittee members

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

7. Meetings

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

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8. Executive Support

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

9. Review

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

10. Induction of new members

New Members will be inducted by the Chair.

ENDORSED BY THE DEPUTY DIRECTOR GENERAL:

Phil Gorey
Deputy Director General
Resource and Environmental Regulation Group
04 September 2019

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

11. APPENDIX Committee Membership

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

12. APPENDIX Minerals Technical Sub Committee Membership

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

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Department of **Mines, Industry Regulation and Safety**

13. APPENDIX Petroleum Technical Sub Committee Membership

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

GSLC September 2018 report

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

Mr David Smith
Director General
Department of Mines, Industry Regulation and Safety
100 Plain Street
East Perth WA 6004

Through: Dr Phil Gorey

Dear David

REPORT OF THE GEOLOGICAL SURVEY LIAISON COMMITTEE – SEPTEMBER 2018

The Geological Survey Liaison Committee (GSLC) met on 18 September 2018, to provide the Director General of the Department of Mines, Industry Regulation and Safety (DMIRS), through the Deputy Director General Resource and Environmental Regulation (RER), feedback and review from industry, government geoscience organisations, and university research institutions on the performance of the Geological Survey. This marks the resumption of meetings following the merger of the Department of Mines and Petroleum with the Department of Commerce in July 2017, and represents an opportunity to assess the future role of the Committee, and of its mineral and petroleum technical subcommittees.

- The committee requests that the Geological Survey name be reinstated to ensure that the Geological Survey and its functions will be visible to industry, other Government Departments, researchers and the public within the DMIRS structure. Reassurance is sought that GSWA will maintain its recurrent budget, core strengths and breadth of geoscience programs.
- The committee was previously chaired by the Director General of DMP, and is concerned at its apparent downgrading. With the chair being delegated to the Executive Director Geological Survey, the committee believes that its role is compressed with that of the technical sub committees. It would welcome the active participation of the DG and DDG in its deliberations.
- The committee can advise the DG and DDG on the role of GSWA and DMIRS within the overall WA and national mineral and petroleum exploration

geoscience environment, providing a strategic view within the context of the COAG Energy Council exploration strategies, the national UNCOVER initiative, and the Resources 2030 Taskforce report. This will ensure that Western Australia maintains its position as a Fraser Institute 'Top 5' jurisdiction.

- The committee noted the important role of GSWA in encouraging exploration in Western Australia through funding and in-kind support for strategically important geoscience data acquisition and research through the Exploration Incentive Scheme (EIS). Ongoing funding of EIS through an increase in mineral and petroleum title rents is viewed as an opportunity to further strengthen the relationship between the minerals and petroleum industry and DMIRS.
- The committee will report to the DG and DDG on the performance of GSWA in relation to its Work Program and service delivery, EIS, and its future Work Program, including technical review and feedback on GSWA's program and products by the technical subcommittees (to be renamed as the Minerals Technical Sub Committee and the Petroleum Technical Sub Committee).
- Sub committee review and feedback:
    - GSWA's geoscience program is well-structured and integrated providing key pre-competitive geoscience data and geological understanding of Western Australia.
    - Ongoing field mapping in selected regions throughout the state should remain a key role for GSWA. Discontinuing '2D' printed (or PDF format) series geological maps in favour of digital map products is supported.
    - The MinEx CRC Program 3 is an excellent way forward to continue building the basement geology and cover mapping framework on which mineral systems prospectivity and targeting studies are based.
    - Collaboration with Geoscience Australia in northern Australia as part of Exploring for the Future is encouraged, including the successful joint acquisition of the 872 km-long Kidson Sub-basin Deep Crustal Survey, and the proposed drilling of a deep stratigraphic well sited on the seismic line, together with acquisition of regional AEM across northern WA at 20 km line spacing.
    - Access to important datasets via the DMIRS website with web browsers other than the obsolete Internet Explorer, and ease of searching for information, and its extraction, within some key minerals databases should be addressed urgently. This is causing reputational damage for GSWA and DMIRS when compared to the access to, and ongoing development of, WAPIMS.
    - The ranking criteria for EIS co-funded exploration drilling can be revised to encourage the acquisition of diamond core. The definitions of

greenfields and brownfields areas can be improved to encourage applications in underexplored areas.

- Land access remains a key impediment to mineral exploration in greenfields and 'frontier' regions in WA, which are the focus of EIS programs.
- It is suggested that GSWA projects should be defined against more specific timelines and delivery dates to manage public expectation, and identify project completion priorities and potential resourcing conflicts.
- The sub committees noted that communication to GSWA clients is inconsistent and reactive rather than proactive. There is a need for greater stakeholder engagement to build relationships with industry and the public, and to improve communication by identifying marketing opportunities around the delivery of products and services.

Yours sincerely

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

4 January 2019

GSLC June 2019 report

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

Mr David Smith
Director General
Department of Mines, Industry Regulation and Safety
100 Plain Street
East Perth WA 6004

Through: Dr Phil Gorey

Dear David

REPORT OF THE GEOLOGICAL SURVEY LIAISON COMMITTEE – JUNE 2019

The Geological Survey Liaison Committee (GSLC) met on 7 June 2019, to provide the Director General of the Department of Mines, Industry Regulation and Safety (DMIRS), through the Deputy Director General Resource and Environmental Regulation (DDG RER), feedback and review from industry, government geoscience organisations, and university research institutions on the performance of the Geological Survey.

- The committee welcomes the addition of 'Geological Survey' to replace 'Geoscience' in the name of the Geological Survey and Resource Strategy Division of DMIRS.
- The committee also notes the presence of DDG RER, Phil Gorey, at the meeting. As the equivalent to the previous Director General of DMP, GSLC welcomes Phil's active participation in the deliberations of the committee.
- The committee reviewed a proposed Terms of Reference for its activities, with the amended version to be agreed before the next meeting in November 2019.
    - The committee agreed that it will report to the DG on the performance of GSWA in relation to its Work Program and service delivery, the Exploration Incentive Scheme, and its future Work Program, including technical review and feedback on GSWA's program and products by the technical subcommittees.
    - In order to achieve its purpose and key responsibilities the Committee and the technical subcommittees intend to meet at least two times a year preferably in May/June (FYQ4) and November/December (FYQ2) The Q4

meeting will review and provide feedback on the GSWA program plan; and the Q2 meeting on the Annual Review, including staffing and budget;

  - The Committee will provide advice on future mineral and petroleum resources exploration and mining trends in Western Australian, nationally and globally; and provide a strategic view of exploration geoscience and targeting, including emerging opportunities for cooperative research.
  - The lack of gender diversity on both the committee and the technical subcommittees was recognised, and the aim is to achieve gender balance through rotation of committee and subcommittee members in 3 years.

- A planned review of the effectiveness of EIS was welcomed, and it is recommended it should address geoscientific impact as well as economic impact.
- The Committee discussed a GSRSD data strategy and improvements that can be made to WAMEX and the Drillhole and Surface Geochemistry Database.
  - Lack of accessibility for data mining and machine learning programs is seen as an impediment to exploration. A well-structured, cleaned database would allow quicker ground selection and target identification, and examples leading to discovery are available.
  - Restructuring and the QA/QC of legacy data in GSWA databases would be a one-off project, but would improve WA's reputation as a destination for exploration. A medium-term, large-cost project is beyond the scope of current EIS funding, and would involve the adoption of national standards and integration with initiatives through GA, the other state and territory geological surveys, CSIRO and AuScope.
  - The Committee recommends that this initiative be adopted as a priority under 'Growing Exploration' in the government's DiversifyWA policy.
  - GSRSD agreed to cost and develop a business plan to present to the Minister and ERC.
- Subcommittee reviews and feedback:
  - GSWA is seen as a world-leading geoscience organization delivering key precompetitive geoscience data and geological understanding of Western Australia. Consolidation of EIS funding is welcomed.
  - Balance is recommended between investigation of regions that are well understood and those that are poorly understood, e.g. the Eastern Goldfields vs 'The Gap' between central Australia and the Kimberley, and the Pilbara.

- Future work programs should take account of the current exploration focus on energy minerals associated with batteries metals.
- The airborne gravity program will complete modern gravity coverage of WA at the equivalent of 2.5 km to 4 km station spacing.
- Cooperation with GA was welcomed in northern Australia on their Exploring for the Future programs. This includes the successful acquisition and release of the Kidson deep crustal seismic reflection survey, the funding of the Waukarlycarly 1 stratigraphic well, and the upcoming AusAEM airborne survey.
- There was a strong endorsement of opportunities for collaboration/co-funding with MRIWA, making full use of EIS and GSWA expertise on minerals related key projects.
- There was strong support for MinEx CRC, and GSWA involvement in the National Drilling Initiative.
- Also strong support for the deep lithosphere mapping initiative, contributing to AusLAMP and AusARRAY, to help in understanding lithospheric architecture and guiding minerals and petroleum ground selection and exploration targeting. There is a need to consider how data is provided to the public in a usable/understandable form.
- It was noted that digital maps could be improved with more attributing of structures in terms of history of movement, and that the geochronology program should be expanded to include dating of mineral deposits.
- The production of the WA digital regolith layer was strongly endorsed. Digital State map coverage delivered via GeoVIEW, together with WAROX and ENS, are very useful products to assist exploration targeting at all scales.
- The greenstone geochemical barcoding project in the Eastern Goldfields was strongly endorsed, adding value to current map and data layers. It was recommended for expansion across the whole of the Yilgarn, and beyond.
- Mineral Systems, is developing an excellent program to assist predictive targeting for key commodities in greenfields, which adds to the attractiveness of WA for exploration. Mineral Systems Studies should be extended beyond the Yilgarn Craton, which is the current focus.
- HyLogger provides quantitative data on selected drillholes, which can be useful for machine learning. The committee supports continuation of HyLogging, but recommends planning for machine replacement in the near future.

- The subcommittee noted that land access continues to have the potential to be a key impediment to exploration in WA, and asked if there is the opportunity for the Land Access Branch to take to take input from the broader geological community on prospectivity?
- It is again suggested that GSWA projects should be defined against more specific timelines and delivery dates to manage public expectation, and identify project completion priorities and potential resourcing conflicts.
- The subcommittees noted that there is still a need for greater stakeholder engagement to build relationships with industry, who contribute to EIS funding through mineral tenement rents, and with the public. Communication can be improved around the delivery of products and services.

Yours sincerely

Jeffrey Haworth | Executive Director Geological Survey and Resource Strategy
Geological Survey and Resource Strategy Division
Department of Mines, Industry Regulation and Safety
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Products and services delivered

Category	Product/service type	Total
Maps*		6
Text publications **		28
Data packages #		18
Data acquisition	Explanatory Notes System (ENS) online — new or major revisions — for series and non-series maps (per unit)	658
	HyLogger scanning (metres scanned)	55 540
	Aeromagnetic survey (line-km)	0
	EIS Co-funded Drilling — diamond (metres drilled)	37 695
	EIS Co-funded Drilling — other (metres drilled)	82 008
	Gravity — ground (number of stations)	0
	Gravity — airborne (line-km)	177 963
	Electromagnetic survey (line-km)	0
	Deep crustal seismic survey (line-km) — acquisition	872
	Deep crustal seismic survey (line-km) — reprocessing	3690
	Passive seismic survey (number of stations)	109
	Geochemistry (number of samples analysed)	3118
	Geochronology (reports)	94
	Hyperspectral scanning summary (per drillhole)	9
	Paleontology record	2
	Isotopic analysis (number of samples)	171
	GSWA stratigraphic drilling (metres drilled)	0
Information and advice services	Core Library — core released (pallets)	271
	Core Library — cuttings and vials released (pallets)	28
	Core Library — pallets laid out for viewing	3172
	Industry exploration reports — minerals reports released only	2754
	Industry exploration reports — petroleum reports released only	4445
Information and advice services — Statutory and Resource Information	Geological advice regarding Mining Act administration (mining lease applications, expenditure exemptions, extensions of term, retention licence, retention status, SPL reports for the Warden)	595
	Core Library — cuttings and vials released (pallets)	28
	Core Library — pallets laid out for viewing	3172
	Industry exploration reports — minerals reports released only	2754
	Industry exploration reports — petroleum reports released only	4445
Information and advice services — Land Use	Geological advice (Mining Act s 16(3)) — South West Native Title Settlement and GASA — full assessments	1193
	Geological advice (Mining Act s 16(3)) — South West Native Title Settlement and GASA — indicative assessments	2611
	Geological advice — land use referrals assessed	408

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

** Includes Memoir, Bulletin, Report, Record, books, external publications, newsletters and Fieldnotes or equivalent. Two text publications — Paleontology Records — have been accounted for under the data acquisition heading

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

Maps, books and datasets released

Maps

1:100 000 Geological Series maps

- Gabanintha, WA Sheet 2644 *by SS Romano*

Non-series maps

- Aboriginal land, conservation areas, mineral and petroleum titles and geology, Western Australia — 2019 *by KJ Ridge*
- Major resource projects, Western Australia — 2019
- Mineral deposits and major petroleum projects, Western Australia — 2019
- Mines — operating and under development, Western Australia — 2019
- Western Australia Atlas of mineral deposits and major petroleum projects 2019

Publications

Reports

- Report 184 Regional seismic interpretation and structure of the southern Perth Basin *by CM Thomas*
- Report 188 Petroleum geochemistry and petroleum systems of the Perth Basin *by KAR Ghori*
- Report 189 A magnetotelluric survey across the Albany–Fraser Orogen, Western Australia *by J Spratt, MC Dentith and CV Spaggiari*
- Report 190 Multi-scaled near surface exploration using ultrafine soils *by RRP Noble, IC Lau, R Anand and T Pinchand*
- Report 191 2018 Carnarvon Basin SEEBASE Study and GIS *by Frogtech Geoscience*
- Report 194 In situ U–Pb geochronology of hydrothermal xenotime and monazite to date gold mineralization in the northern Capricorn Orogen, Western Australia *by IOH Fielding*
- Report 195 The cooling and exhumation of the Albany–Fraser Orogen, Western Australia, constrained by $^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb thermochronology *by E Scibiorski*

Records

- Record 2017/1 Geological Survey work program for 2017–18 and beyond
- Record 2018/1 Geological Survey work program 2018–19 and beyond
- Record 2018/11 The Cryogenian Aralka Formation, Amadeus Basin: a basinwide biostratigraphic correlation *by HJ Allen, K Grey, PW Haines, CJ Edgoose and VJ Normington*
- Record 2018/12 Capricorn Orogen rutile study: a combined electron backscatter diffraction (EBSD) and laser ablation split stream (LASS) analytical approach *by D Plavsa, S Reddy, C Clark and A Agangi*
- Record 2018/13 (U–Th)/He dating of ferruginous duricrust, Boddington gold mine, Western Australia *by MA Wells, M Danisik and BIA McInnes*
- Record 2018/15 A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity *by RH Smithies, Y Lu, CL Kirkland, KF Cassidy and DC Champion*
- Record 2018/8 Geology, resources and exploration potential of the Ellendale diamond project, west Kimberley, Western Australia *by G Boxer and G Rockett*
- Record 2019/2 GSWA 2019 extended abstracts: advancing the prospectivity of Western Australia
- Record 2019/3 Metamorphic history of the Mougooderra Formation, Yilgarn Craton, Western Australia *by S Parmenter*
- Record 2019/4 Compilation of geophysical modelling records, 2018 *by L Brisbout and RE Murdie*
- Record 2019/5 Mesozoic coal resources of the northern Perth Basin: exploration and evaluation history *by AS Millar*
- Record 2019/6 Cenozoic coal resources of southern Western Australia: exploration and evaluation history *by S Simons*

Maps, books and datasets released

- Record 2019/7 A syn-depositional sill intrusive model for the Golden Mile Dolerite, Kalgoorlie, Western Australia *by RM McMann*
- Record 2019/8 Metamorphic and isotopic characterisation of Proterozoic belts at the margins of the North and West Australian Cratons *by JR Anderson*

Non-series books

- Calendar 2018: Geological Survey of Western Australia *by JF Johnston and A Riganti*
- Calendar 2019: Geological Survey of Western Australia *by A Riganti, SC Goss and SR White*
- F52644–F52652: Tonian stromatolite *Tungussia erecta* in the Pollock Hills, Amadeus Basin, Western Australia *by HJ Allen and PW Haines*
- Fieldnotes: GSWA newsletter July 2018 number 87
- Fieldnotes: GSWA newsletter October 2018 number 88
- Fieldnotes: GSWA newsletter January 2019 number 89
- Fieldnotes: GSWA newsletter April 2019 number 90
- Stromatolite assemblage, including *Eleonora boondawarica* and *Acaciella savoryensis* from mineral drillhole 07THD003 *by HJ Allen and PW Haines*
- Understanding the Meckering earthquake, Western Australia, 14 October 1968 *by JF Johnston and SR White*

Datasets

Geological Information Series

- Kimberley, 2018
- Tanami–Arunta, 2018
- Western Capricorn Orogen, 2018

Data packages

- 1:100 000 State intepreted bedrock geology of Western Australia
- 1:500 000 State regolith geology of northern Western Australia, 2018 *by S Jakica and N de Souza Kovacs*
- 2018 Carnarvon Basin SEEBASE Study and GIS *by Frogtech Geoscience*
- Compilation of geochronology information, 2019
- Compilation of HyLogger records, 2019 *by P Duuring, L Burley, JN Guilliamse, C Laukamp and L Pires*
- Compilation of WAROX data, 2019
- East Albany–Fraser Orogen, 2018: 3D Geomodel Series *by L Brisbout*
- GSWA Harvey 1, Perth Basin: Digital Core Atlas *by S Gamarra and A Symonds*
- GSWA Open Day 2019
- Lawlers Anticline 3D, 2014: 3D geomodel series *by N Thébaud, JM Miller and RE Murdie*
- Meteorite impact structures of Western Australia, virtual tour 2019 *by SC Goss*
- Mineral Systems Atlas *by S Morin-Ka, T Beardsmore, P Duuring, JN Guilliamse and L Burley*
- Senagi 1, Canning Basin: Digital Core Atlas *by LM Dent, LS Normore and AK Symonds*
- WA Petroleum Day, 2018
- Western Australian geoscientific imagery, 2019

Posters

- 73 geoscience posters

External publications

GS10 Energy Geoscience and Carbon Strategy

Allen, H and **Haines, P** 2018, *Arumberia banksii*: how well can MISS tell time?, *in* AGCC 2018 Abstract Volume: Australian Geoscience Council; Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience, Adelaide, South Australia, oral presentation, 14–18 October 2018, p. 292.

EXPLORATION INCENTIVE SCHEME

Allen, H and **Martin, D** 2018, Chicken or Egg? A diverse microbialite assemblage coeval with the Great Oxidation Event, *in* AGCC 2018 Abstract Volume: Australian Geoscience Council; Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience, Adelaide, South Australia, oral presentation, 14–18 October 2018, p. 754.

EXPLORATION INCENTIVE SCHEME

Allen, H and **Martin, D** 2018, Chicken or Egg? A diverse microbialite assemblage coeval with the Great Oxidation Event *in* AGCC 2018 Abstract Volume: Australian Geoscience Council; Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience, Adelaide, South Australia, poster, 14–18 October 2018, p. 754.

Allen, H, Grey, K, **Haines, P,** Edgoose, C and Normington, V 2018, A Cryogenian biostratigraphic update: hold the ice, *in* AGCC 2018 Abstract Volume: Australian Geoscience Council; Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience, Adelaide, South Australia, oral presentation, 14–18 October 2018, p. 545.

Allen, H, Grey, K, **Haines, P**, Edgoose, C and Normington, V 2018, A Cryogenian biostratigraphic update: hold the ice *in* AGCC 2018 Abstract Volume: Australian Geoscience Council; Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience, Adelaide, South Australia, poster, 14–18 October 2018, p. 545.

Craddock, JP, Ojakangas, RW, Malone, DH, Konstantinou, A, **Mory, A**, Bauer, W, Thomas, RJ, Craddock Affinati, S, Pauls, K, Zimmerman, U, Botha, G, Rochas-Campos, A, dos Santos, PR, Tohver, E, Riccomini, C, Martin, J, Redfern, J, Horstwood, M and Gehrels, G 2019, Detrital zircon provenance of Permo-Carboniferous glacial diamictites across Gondwana: Earth-Science Reviews, v. 192, p. 285–316, doi:10.1016/j.earscirev.2019.01.014.

Dent, L, Normore, L and Forbes, A 2018, First record of Lower – Middle Ordovician (Tremadocian–Dapingian) carbon isotope ($\delta^{13}C_{carb}$) chemostratigraphy in the Canning Basin, Western Australia: calibrated with geochronology/biostratigraphy and implications for global correlations, *in* IGCP 668 Abstract Volume: International Geoscience Programme; IGCP 668 Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics, Bangkok, Thailand, 29–30 November, p. 19–22.

EXPLORATION INCENTIVE SCHEME

Edgoose, CJ, Normington, VJ, **Haines, PW** and **Allen, HJ** 2018, Revised Neoproterozoic stratigraphy in the Mount Conner area, Amadeus Basin, Northern Territory: Northern Territory Geological Survey, Record 2018-008, 11p.

Haines, P, Wingate, M, Maidment, D and **Zhan, Y** 2018, Initiation of the Canning Basin: extensional magmatism in the middle Cambrian? *in* AGCC 2018 Abstract Volume; Australian Geoscience Council: Australian Geoscience Council Convention: Big Issues and Ideas in Geoscience; Adelaide, South Australia, 14–18 October 2018, p. 148.

Martin, RJ, Redfern, J, Horstwood, MSA, **Mory, AJ** and Williams, BPJ 2019, Detrital zircon age and provenance constraints on late Paleozoic ice-sheet growth and dynamics in Western and Central Australia: Australian Journal of Earth Sciences, v. 66, p. 183–207, doi:10.1080/08120099.2019.1531925.

Morón, S, Cawood, PA, **Haines, PW,** Gallagher, SJ, Zahirovic, S, Lewis, CJ and Moresi, L 2019, Long-lived transcontinental sediment transport pathways of East Gondwana: Geology, v. 47, p. 513–516, doi:10.1130/G45915.1.

Normore, L and **Dent, L** 2018, Looking for a volcanic source for Lower Ordovician (Tremadocian – Floian) ash beds from the Canning Basin, Western Australia, *in* IGCP 668 Abstract Volume: International Geoscience Programme; IGCP 668 Equatorial Gondwanan History and Early Palaeozoic Evolutionary Dynamics, Bangkok, Thailand, 29–30 November, p. 24–25.

EXPLORATION INCENTIVE SCHEME

Zhan, Y 2018, DMIRS Geophysical projects in the Canning Basin, Western Australia: RIU Good Oil Conference, Perth, Western Australia, oral presentation, 11–12 September 2018.

External publications

GS20 Mineral Systems Studies

Duuring, P and Laukamp, C 2018, Spectral signature of alteration zones associated with iron ore deposits in the Yilgarn Craton, Western Australia: XXII Meeting of the International Mineralogical Association; International Mineralogical Association, Melbourne, Australia, 13–17 August, 536p.

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