

RECORD 2021/1

GEOLOGICAL SURVEY
WORK PROGRAM 2021–22

Perth 2021



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

Geological Survey of
Western Australia





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Western Australia**

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

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Cover image: Wave and wind sculpted stromatolites at Flagpole Landing, Hamelin Pool in the world heritage site of Shark Bay, Western Australia (photo by Heidi Allen, DMIRS)

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Geological Survey work program 2020–21

Executive summary

As we move on from what has been an extraordinary year, the Geological Survey of Western Australia (GSWA) is preparing to return to some sense of normality in the 2021–22 financial year. This work program reflects that; GSWA has learnt valuable lessons from last year's Accelerated Geoscience Program (AGP) and intends to carry some of the aspects of how data and information were delivered from that program into the future.

I note as I am writing that iron ore has hit a new record of US\$194.50 per tonne; I acknowledge how the resources industry is helping the Western Australian economy recover.

Due to COVID-19 and the restriction around fieldwork, the 2020–21 financial year saw the implementation of the AGP. This program was designed to publish existing data into GIS layers, data integration and analyses in the Yilgarn Craton, perform a statewide critical minerals prospectivity study, and look at energy systems including petroleum, geothermal and carbon capture and storage.

The program delivered three Geological Exploration Packages (GEP) and several critical statewide data layers that have been delivered through GeoVIEW.WA and the Data and Software Centre. In addition, internal systems and processes have been streamlined to allow faster and more efficient delivery of data products.

In 2020–21, GSWA published its 2030 Strategy and the Geoscience Data Transformation Strategy 2021–25. The 2030 strategy builds upon four main pillars to develop our future:

- **Garnering geoscientific knowledge** – building our geological understanding of the State by acquiring and synthesizing pre-competitive data and utilizing collaborative research and strategic partnerships.
- **Transforming our data** – modifying the way we store, analyse and deliver our data to ensure it can move fluidly with emerging technology and innovation.
- **Strengthening our team** – building capacity for a high-performing workforce by attracting exceptionally skilled people, developing and enhancing their capabilities to ensure they have the resources to excel, and encouraging innovation.
- **Providing trusted information** – delivering trusted geoscientific information and advice to Western Australia's government, community, and resources industry.

We have already started on this journey and are looking especially at our data transformation; work in the AGP has already contributed to our learning. We created a Chief Geoscience Information Officer position which has been filled by Dr Deavi Purnomo who has started planning the implementation of the data strategy.

In 2021–22, GSWA's budget estimates are \$35.8 million (excluding departmentally funded projects), a combination of appropriated funding, EIS funding and final payment for the CAMECA ion microprobe.

Staffing will comprise:

- 178 permanent full-time equivalent (FTE)
- 12 permanent part time in 2020–21 (8.9 FTE)
- 8 FTE funded from the EIS
- 11 contract full or part time (10.8 FTE)
- ~10 short-term fee-for-service contractors (as of 1 July 2021).

This has resulted in a total of 219 staff.

We anticipate working on about 40 collaborative research projects partly funded by GSWA, including the ongoing National Collaborative Framework agreements.

GSWA plans to publish the following flagship products:

- Maps 5
- Data packages (USBs) 3
- Digital data layers 7
- Online data releases 13
- Publications 44

GSWA will also deliver the following:

- All the AGP data layers from 2020–21
- Map symbol database to manage colours and patterns for regolith and rock units
- Geochronology, isotope and mineral geochemistry data via an online application
- The new Geocentric Datum of Australia 2020 (GDA2020) for the Department of Mines, Industry Regulation and Safety's (DMIRS) Geoscience and Titles Information datasets.

The future will be challenging as we move towards Western Australia's target of zero net emissions by 2050. This will have a huge impact on the resources sector with the industry already talking about 'green' or carbon-neutral steel produced from green hydrogen and other sources of renewable energy. GSWA will meet this challenge head on. In keeping with the State and Commonwealth Government's strategic intent around battery and critical minerals as well as hydrogen and new energy, GSWA has designed the 2021–22 work program to leverage our vast data stores to deliver timely, focused and interoperable geoscience data for the resources industry.

Jeff Haworth

Executive Director

Geological Survey and Resource Strategy

Note: all currencies are Australian dollars unless otherwise indicated.

PART ONE

Detailed work programs

GS10 Energy Geoscience and Carbon Strategy

Manager: Deidre Brooks

Team members: Norman Alavi, Richard Bruce, Louisa Dent, Ameer Ghori, Peter Haines, Arthur Mory, Leon Normore, Charmaine Thomas, Yijie (Alex) Zhan

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 energy resources such as petroleum, coal, helium, natural hydrogen and geothermal energy resources, as well as identify subsurface areas for potential CO₂ sequestration and temporary hydrogen and gas storage to secure the State's energy future.

The team works in collaboration with other divisions of DMIRS and other organizations, including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), The University of Western Australia (UWA), Curtin University, Department of Jobs, Tourism, and Science Innovation (JTSI), Northern Territory Geological Survey (NTGS), Geological Survey of South Australia, Geological Survey of New South Wales and Geoscience Australia (GA).

The current focus of the branch is the Amadeus, Canning, Carnarvon, Officer and Perth Basins. All these basins have proven petroleum systems but are underexplored, particularly in the case of the vast Canning and Officer Basins and the Western Australian side of the Amadeus Basin. The branch will commence a new geological assessment of the characterization and distribution of salt within the basins of Western Australia to better understand the seal potential of salt-bearing formations, initially focusing on the Carnarvon, Canning and Officer Basins. Another new project for 2021–22 is the proof of concept of the existence of natural hydrogen in the Canning Basin. This includes a field trip and fluid inclusion stratigraphy analysis of core and cuttings from an old petroleum exploration well that may lead to the establishment of a new industry in Western Australia. A portable hydrogen gas monitor has been purchased through the Exploration Incentive Scheme (EIS) for use on this and related future projects. Multi-year studies on the stratigraphic and structural framework of the northern Perth Basin will start and include biostratigraphic evaluation, well correlations, seismic interpretation and two-way time (TWT), velocity, isopach and depth mapping.

During the 2021–22 financial year, the branch will continue to work with the Western Australian Petroleum and Geothermal Management System (WAPIMS) team to deliver meaningful data in useful formats to the energy industry through the Energy Systems Atlas (part of the AGP). The Energy Systems Atlas consists of GIS layers within WAPIMS relating to energy such as oil, gas, geothermal, CO₂ sequestration, helium and hydrogen. Existing layers show data availability, plots of key data types, and existing structure maps. Further interpretive information will be added in 2021–22.

The branch will continue to be involved with the compilation of the Digital Core Atlas for Barnicarndy 1 (previously known as Waukarlycarly 1) (see ES47 Petroleum Systems) which is a stratigraphic well drilled in the Barnicarndy Graben during 2019, in the western margin of the Canning Basin. The drilling of this well was funded by the Commonwealth Government Exploring for the Future program (EFTF) and was operated by DMIRS, in particular by the geoscientists within this branch. A related ES47 project that will continue in 2021–22 is the release of the record of the interpretation of the Barnicarndy 1 velocity data and well tie to the Kidson Sub-basin Seismic Survey, which was acquired in 2018 and co-funded by the EIS and EFTF.

Planned work program

Projects listed at the end of this section were the focus of geoscience studies during 2020–21 and will be released in 2021–22. All new data produced from these projects will be incorporated into the Energy Systems Atlas.

In addition to the new projects, work will continue or recommence on the following studies that will also provide relevant data that can feed into the Energy Systems Atlas in future years:

- Compilation of a Digital Core Atlas for Barnicarndy 1 (Canning Basin) as listed under ES47
- Documentation of results from fieldwork in the Lucas Outlier and the Prices Creek Group outcrop (Canning Basin)
- Age and composition of the basement underlying the Canning Basin
- Structure, stratigraphy and prospectivity of the Amadeus and Officer Basins
- Sedimentological description of the Harvey 2, 3 and 4 cores
- Perth Basin field guide.

Products planned for release

- Permian and Triassic source rocks of the Carnarvon Basin (Report)
- Cobb Embayment of the Canning Basin (Record)
- Mesozoic Unearthed (Booklet)
- Petroleum source rocks of Western Australia (Report)

GS12 Land Use Planning

Manager: Samantha Carter

Land Use Management: Louise Banks, Lauren Pike, Andrea Wootton

Land Use Geoscience: Steven Batty, Mark Fleming, Jordana Gardiner-Haukohl, Joshua Guilliamse, David Hamdorf, Kevin Ridge, Caroline Strong, Hannah Wallace

The Land Use Planning (LUP) branch helps shape and inform land use planning policy and outcomes by providing advice based on geoscience, resource mapping and prospectivity assessments.

The branch collaborates with other government departments such as the Departments of Planning; Lands and Heritage; Premier and Cabinet; Biodiversity, Conservation and Attractions; and Jobs, Tourism, Science and Innovation, as well as Local Government Authorities (LGA) to assist with land use decisions and managing impacts arising from land use/tenure changes.

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

In most cases, LUP's workload is externally generated and consists of core business as usual, State Government priorities and projects, and other initiatives/projects identified internally (workload permitting). Core work consists of proposals for land use/tenure changes and applications for licences and permits on Crown land, as well as private land subdivisions and other land use planning proposals, which are routinely received from State agencies and LGA. Competing interests in land across the State requires careful consideration and informed decision making by Government, including balancing conflicting land tenure/uses and managing potential unintended consequences. LUP also has a key role in providing high-level advice to State Government and an active involvement in State priority projects, such as the Plan for Our Parks. Each proposal is examined, its implications for access to mineral and energy resources assessed, with recommendations, advice and, where necessary and appropriate, approvals made accordingly.

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

Access to mineral and energy resources can be impacted by land use/tenure changes, and LUP aims to ensure the continuity of community benefits from Western Australia's resources endowment. This is underpinned by our core functions:

- Shaping land use policy and outcomes through engagement and collaboration with government agencies and LGA
- Informing decision making by providing advice and geoscientific resource mapping data to government, LGA, industry and the public
- Fostering coexistence, transitional and sequential land uses, particularly around townsite planning and rural land use
- Assessing proposals (including industry referrals) and providing approvals/recommendations for proposed land tenure and land use changes throughout the State.

Planned work program

The branch will continue to provide information, advice, assessment and approvals in response to routine requests from other government agencies, LGA, industry and internal requests, while being involved in the following key priority government projects:

- South West Native Title Settlement
- Willinggin Determination Area Indigenous Land Use Agreement (ILUA)
- Plan for Our Parks conservation initiative.

It is anticipated there will continue to be substantial land approvals and recommendations associated with the South West Native Title Settlement project over the next few years. Plan for Our Parks is a major conservation initiative comprising a minimum of five million hectares of new conservation reserves by 2024. LUP has undertaken significant consultation with industry and other government agencies during the assessment/refinement of these proposed park areas.

LUP will continue to engage collaboratively with key stakeholders, including other government agencies, LGA and industry regarding its core business and other initiatives to help clarify roles, streamline administrative arrangements and provide strategic land use planning advice.

Product planned for release

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

GS14 Resources Information

Manager: Nicole Wyche

Team members: Cecilia D'Ercole, Sue Murray, Sarah Sargent

The Statutory and Resource Information (SRI) branch tracks mineral exploration and mining activities in Western Australia by collating data on mineralized sites, exploration and mining projects, mineral resources and mineral production. This allows DMIRS to provide data and specialist technical advice and publications on most mineral commodities. Data users include DMIRS divisions, other government agencies, research organizations and a range of industries and individuals.

A key component of this work is the maintenance and enhancement of Western Australia's Mines and Mineral Deposits information database (MINEDEX). MINEDEX is a core DMIRS business system that provides a broad range of searchable data on minerals industry activity (current and historic), and hosts compliance documents such as environmental registration files. MINEDEX provides spatial and textual data for internal and public users. MINEDEX also generates unique site and project identification codes used throughout DMIRS to reference activities for compliance reporting in departmental business systems, including the Environmental Assessment and Regulatory System (EARS), the Royalties Management System (RMS) and the Safety Regulation System (SRS). MINEDEX also provides nightly updates of spatial data for use in DMIRS spatial data applications, including TENGGRAPH and GeoVIEW.WA, and provides data downloads via the Data and Software Centre.

The SRI branch produces commodity-related publications including the annual Mines – operating and under development and Major resource projects maps, the Atlas of mineral deposits and major petroleum resources book and map (produced every second year), investment opportunity commodity flyers, and posters showcasing trending exploration results. In 2020–21, the ability to deliver spatial layers of MINEDEX resource estimate data was developed. This will allow more custom spatial layers of resource estimate data to be released in 2021–22.

Planned work program

In 2021–22, the branch will focus on the following core business tasks:

- Populating MINEDEX with current industry activity data
- Maintaining and improving MINEDEX

- Managing the RMS production report and the data generated by this report
- Servicing other DMIRS databases with dependencies on MINEDEX
- Completing transition of Mining Act and related assessments to the LUP branch
- Providing specialist information to internal and external stakeholders on mining industry activities
- Providing specialist publications (see product list below)
- Providing MINEDEX training for internal and external customers.

Business improvement projects

The following projects are planned to improve our service delivery:

- Improving MINEDEX SQL reports
- Improving MINEDEX help documentation
- Incorporating MINEDEX capture in to WAMEX report assessment workflow.

Products planned for release

- [Major resource projects, Western Australia 2022 \(map\)](#)
- [Mines – operating and under development, Western Australia 2022 \(map\)](#)
- [Significant exploration activity in Western Australia \(poster for GSWA Open Day and Diggers and Dealers\)](#)
- [Investment opportunity/commodity flyers updated annually](#)
- [Release of spatial layers for resource estimate data](#)

GS20 Mineral Systems Studies

Manager: Warren Ormsby

Team members: Paul Duuring, Lena Hancock, Shane Kenworthy, Sidy Morin-Ka

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

The branch makes extensive use of the GSWA HyLogger (see GS95 HyLogger and the National Virtual Core Library) to assist with detailed studies of alteration assemblages in diamond drillcore and other specimens from mineral deposits and exploration drilling.

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

Planned work program

This year will see the integration and continuation of various projects commenced in the AGP, as well as commencement of new work, with a focus on the following themes:

1. Controls and indicators of mineralization using gold as the primary example due to this commodity having the most geochemical, geological and endowment-related information. For gold, there will be an emphasis on craton-scale mineralization controls, particularly in the South West Yilgarn and Pilbara regions
2. Information relevant to critical and battery minerals will continue to be compiled, examined and published, including integrating information obtained from the AGP and relevant collaborative studies and obtaining further relevant data from the Western Australian Minerals Exploration Database (WAMEX). Prospectivity studies will focus initially on rare-element pegmatites and brine-related commodities, particularly potash
3. Commence work on mineral systems associated with sediment-hosted base metals, especially those that have the potential to assist in locating related critical minerals such as cobalt, gallium, germanium and indium.

The branch will work collaboratively with other areas within GSWA to share resources and expertise to help achieve mutually beneficial objectives. An example of this will be the overlap with the New Energy Systems branch (GS98) in the battery minerals area. Collaboration with other government and academic institutions, and a network of affiliated exploration and mining companies via collaborative research projects funded by the EIS (see ES43 Mineral Systems) will continue where it contributes towards achieving the objectives of this program.

Current collaborative projects, most of which are wholly or partly funded by EIS (see Appendix and ES43 Mineral Systems), include:

- MRIWA project M532: Geology, mineralogy and metallurgy of eMaterial resources in Western Australia (partners: John de Laeter Centre, Curtin University; AXT Pty Ltd)
- Critical minerals (Li, Ta, Nb, W, REE) in the western Yilgarn Craton (partner: CSIRO)
- ARC Linkage project LP190100635 – Rare earth resources of northern Australia (partners: Adelaide University, GA, GSNSW, GSQ, resource companies)
- Pilbara gold fingerprinting (partner: TSW Analytical)
- Isotopic fingerprinting of gold from Western Australian deposits (partners: John de Laeter Centre, Curtin University).

In addition to involvement in the above projects, the branch will continue working on the following projects currently in progress:

- The Paterson Orogen metallogeny study will complement GSWA's contribution to Projects 8 and 9 of the Mineral Exploration Cooperative Research Centre (MinEx CRC; see ES36 MinEx CRC Program 3), by documenting the geological setting and characteristics of Cu–Au mineralization (e.g. at the Obelisk prospect), using drillcore stored at the Perth Core Library and sourced from resource companies working in the region.
- The compilation of GIS layers and information on manganese and potash will be completed and work will continue on a study of the John Galt Rare Earth Element deposit in the East Kimberley. This work will complement the ARC Linkage project on rare earth resources.

**Products planned for release
(in addition to the EIS projects listed in
ES43 Mineral Systems)**

- Mineralization characteristics of the Obelisk Cu–Au prospect (Report)
- Geology and mineralization potential of the Gerry Well greenstone belt (Collurabbie region), northeastern Yilgarn Craton (Record)
- Isotopic fingerprinting of gold from Western Australian deposits (Report) – Curtin University
- Potash GIS layers and documentation in the Mineral Systems Atlas
- Manganese GIS layers and documentation in the Mineral Systems Atlas
- External publications

GS52 East Yilgarn

Manager: Jyotindra Sapkota

Team members: Matthew De Paoli, Melissa Drummond

The Eastern Goldfields Superterrane (EGST) is a highly mineralized region with world-class gold and nickel deposits, and significant deposits of other commodities including base metals, rare earth elements (REE), lithium, uranium, gemstones and industrial minerals. This typical Archean upper crustal granite–greenstone terrane forms much of the exposed eastern part of the Yilgarn Craton, and is separated from the West Yilgarn by the Ida Fault.

The EGST has been divided into four shear zone bounded terranes. From west to east, they comprise the Kalgoorlie, Kurnalpi, Burtville and Yamarna terranes. The terrane architecture has previously been interpreted to reflect the accretion of several micro-continents between c. 2800 and 2650 Ma. However, local abundance of komatiites and associated thick basaltic successions, and the identification of a basement succession broadly similar in age to regions of the western Yilgarn Craton, suggests that subsequent closure following the c. 2.7 Ga mantle plume-fed rifting of an autochthonous basement may represent an alternative geodynamic model.

Although basalt-dominated greenstone sequences are mapped, intersected in drillcores and recognized in geophysical surveys throughout the EGST, correlating geological events, stratigraphy or structures within and between individual greenstone belts constitutes a major challenge. A detailed stratigraphic correlation has only been attempted in the Kalgoorlie Terrane between Norseman in the south and Agnew in the north based on systematic geological mapping at the 1:100 000 scale and supported by geochemical and geochronological datasets. In this region, most of the exposed greenstones belong to the 2801–2690 Ma Kalgoorlie Group, which comprises the lowermost mafic–ultramafic–upper mafic sequence that broadly characterizes most individual greenstone belts. Although not physically contiguous between belts, these sequences are broadly similar in rock type, stratigraphic variations and age, and so have been distinguished as stratigraphically equivalent subgroups of the Kalgoorlie Group. Greenstone sequences older than 2800 Ma are also locally exposed around Leonora (~2817 Ma), Menzies (>2803 Ma) and Norseman (~2930 Ma). The Kalgoorlie Group is overlain by the Black Flag Group (2690–2665 Ma, equivalent to the Mount White Group in the Agnew–Lawlers

region), which comprises mainly turbidite-type deposits, and felsic volcanic and volcanoclastic rocks. The Black Flag Group is unconformably overlain by 2664–2657 Ma sequences of mainly epiclastic origin, such as the Scotty Creek Formation (Agnew–Lawlers region), the Navajo Sandstone (southwest of Kalgoorlie), the Merougil Formation (west of Kambalda), and the Kurrawang Formation.

Planned work program

Much of the focus over the 2020–21 financial year was on improving the geological layers, specifically the detailed bedrock geological map, required to add value to ongoing interpretation of the high-resolution seismic survey conducted in early 2019 by GSWA, between Ora Banda and Kambalda. This will continue into the 2021–22 year, focusing mainly on the southern part of the seismic survey area. Detailed structural, metamorphic, geochemical, geochronological and isotopic data will be collected from outcrop and diamond drillcore to support the geological interpretation of the seismic data, together with the formulation of a model for the geological evolution of the area. After field verification, the available company geological maps and drillhole data will be used to consolidate GSWA's mapping and stratigraphic interpretation in selected areas. The Greenstone Geochemical Barcoding Program (ES49) will work towards a geochemical fingerprint of local to regional magmatic greenstone stratigraphy and support local and regional correlation. Work is ongoing to create a virtual field guide of important geological localities in the East Yilgarn.

Products planned for release

- East Yilgarn GIS 2021 (including updated interpreted bedrock geology layers across the region imaged by the seismic survey)
- Explanatory notes and stratigraphy update
- Metamorphism in the Ularring greenstone belt: current state of understanding and implications for the tectonic evolution of the Neoproterozoic Eastern Goldfields Superterrane (Record)

GS53 State Geoscience

Manager: David Martin

Team members: Heidi Allen, John Brett, Lucy Brisbout, Huntly Cutten, David Howard, Sarah Martin, Ruth Murdie, Angela Riganti

The State Geoscience branch is responsible for maintaining and communicating a coherent geoscience framework for Western Australia via GSWA databases, the GSWA website and social media, statewide layers on GeoVIEW.WA, published reports, and the State geological map. The branch was created as part of a restructure of the Geoscience Directorate in May 2021 to incorporate four sections:

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

The ENS and State Maps section of the State Geoscience branch works with project teams and groups, guiding and overseeing development and population of GSWA databases, contributing to products, validating database content, and coordinating work that spans more than one project. The section also works independently on geological problems not part of current GSWA project work and on statewide geological issues and datasets, and responds together with the Paleontology and Geoheritage section to many of the public enquiries received by GSWA.

The Paleontology and Geoheritage section is responsible for cataloguing and documenting the fossil record of Western Australia, developing the biostratigraphic framework of the State, managing the GSWA Paleontology collection, and identifying, registering and managing State sites of geological significance (State Geoheritage Sites and Reserves).

The Geophysics Acquisition and Processing section plans and manages regional geophysical data acquisition projects, to prepare datasets for delivery to the public and internal users, and to provide internal processing, interpretation services and advice as required. The section also manages the geophysical survey index and data repository (MAGIX), and the submission, archive and release of airborne and some ground survey datasets supplied by the exploration industry.

The Earth Imaging and Observation section aims to increase the knowledge of Western Australia's subsurface through the integration of geophysical, geological and geochemical data in 3D models. The program's objective is to test specific theories to allow the extension of knowledge from exposed and well-understood areas to inaccessible or data-poor parts of the Earth's crust so as to create visualizations and numerical models of specific areas of Western Australia which are of particular interest to various exploration groups. The ultimate goal is to understand and visualize the whole of Western Australia. An important aspect of the program is cooperation with leading research institutions that complement GSWA's capabilities in data acquisition, analysis

and modelling. Collaborative projects with leading research institutions form a core part of the section's activities and are funded through the EIS under the ES42 Lithosphere Visualization Project.

Planned work program

The planned work program for 2021–22 for the ENS and State Maps section includes updates to State geological layers, the enhancement of the ENS, initiating capture of legacy geochronology baseline data and records as part of the handover of the newly developed Western Australian geochronology, isotope, metamorphic history and mineral chemistry (WAGIMS) database to GS54 Geochronology and Geochemistry.

The Paleontology and Geoheritage section will continue work on statewide paleontological and biostratigraphic projects including the biostratigraphy of Barnicarndy 1, the palynology of the southern Perth Basin, paleontology of Proterozoic sedimentary basins and the ichnology, paleontology and stratigraphy of the Southern Carnarvon Basin. Maintenance of GSWA's Paleontology collection will also continue, including continued conversion of specimen catalogues from analogue to digital, management of loans, and curation of new materials. Considerable time will be invested in cataloguing the current condition of the State's vulnerable geoheritage sites, along with improving processes and policies relating to the nomination, assessment and management of these sites. The section will also contribute to organizing and running the Palaeo Down Under conference (PDU3) and associated field trips.

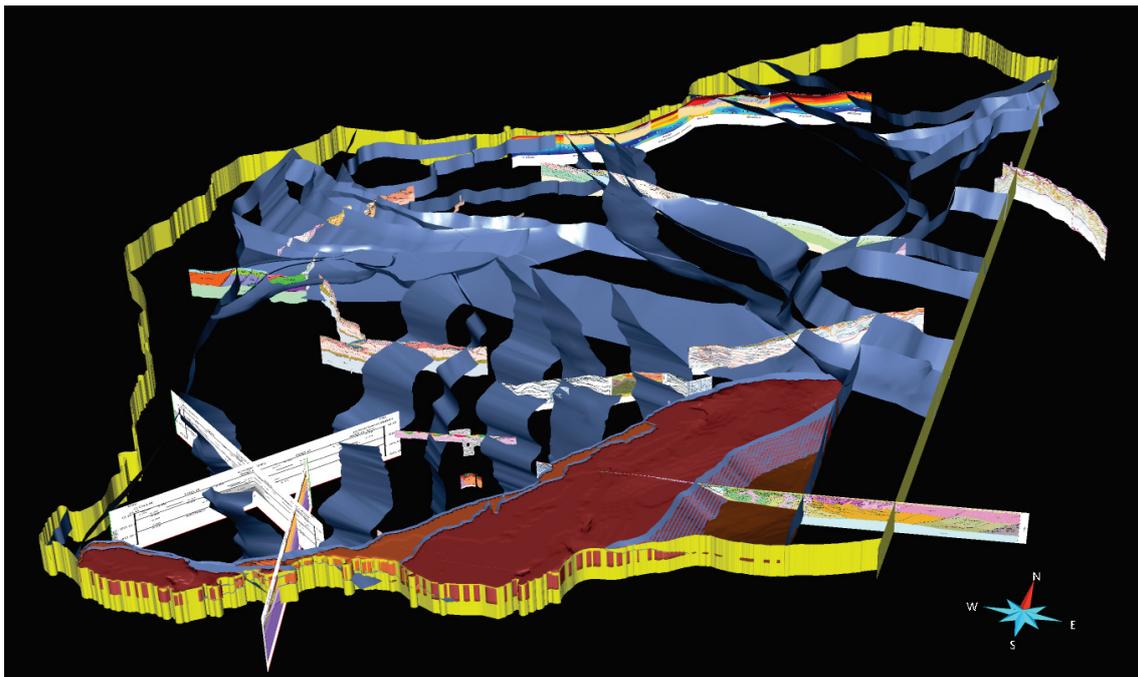
New magnetic, radiometric, and gravity datasets will be included in updates to the respective statewide compilation grids produced by the Geophysics Acquisition and Processing section. All new geophysical data acquisition projects are conducted as part of the EIS.

The Earth Imaging and Observation section will continue to contribute to regional mapping project teams, specifically in the Pilbara Craton, Canning Basin, Paterson Orogen, and the Yilgarn Craton (in particular the Southwest Terrane and Eastern Goldfields Superterrane). The section will continue to develop 3D stochastic modelling for the next generation of 3D modelling software by being part of ARC project LP170100985 Enabling 3D stochastic geological modelling (3D-LOOP), a large Monash University-led international project for reducing risk for the resources industry. Work in the Eastern Goldfields will focus on processing of petrophysical data and their integration with geochemical and other geophysical data, such as passive and active source seismic and magnetotellurics. These activities will be carried out in close collaboration with 'Yilgarn 2020' a MRIWA-sponsored, four-year project led by the Centre for

Exploration Targeting (CET) at UWA. The section will also expand its capacity to monitor natural and anthropogenic seismicity. Fieldwork is planned for the deployment of new passive seismic networks in Western Australia with the aim of redefining the large-scale architecture of Western Australia (Fig. 1) and to develop GSWA's seismic monitoring capability.

Products planned for release

- Updates to the 1:500 000 interpreted bedrock geology, tectonic units and orogenic events layers in GeoVIEW.WA
- Annual release of the Western Australian field observation database (WAROX)
- Completion of the geochronology, isotope and mineral chemistry system as a common repository of all data files and related information (WAGIMS)
- Delivery of extended ENS content and ongoing population of the database
- Paleontology Reports: reporting on paleontological analyses, including the Barnicarndy 1 stratigraphic drillhole, paleontology section projects and publication of consultancy reports
- Field guides for Palaeo Down Under conference (Records)
- Western Australian Sites of Geological Significance (State Geoheritage Sites): registration process (Record)
- Kalbarri Unearthed (book)
- Major crustal boundaries map and State 3D model explanatory notes (Record)
- Eucla basement petrophysical data and potential field modelling (Record)
- Southwest Yilgarn 3D model and data compilation
- 3D modelling of the Kalgoorlie region of the Eastern Goldfields
- 3D modelling of the Yalgoo–Singleton Dome
- 3D model of the Capricorn Orogen



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Figure 1. 3D crustal architecture of Western Australia as defined by available geophysical data and current geological understanding

GS54 Geochronology and Geochemistry

Manager: Michael Wingate

Team members: Imogen Fielding, Sarah Gain, Dominique Harmer, Frances James, Jack Lowrey, Yongjun Lu, Marlene Papiccio, Sandra Romano, Tom Scillieri, John Williams

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 contributes to enhancing the prospectivity of the State. Geochemical studies of rocks and regolith are essential for understanding the sources and petrogenesis of igneous suites, the relationships within and between igneous suites, the sources (provenance) and compositional characters of sedimentary rocks and regolith, and for constraining metamorphic modelling.

Geochronological techniques are applied to constrain the timing of magmatism, metamorphism, deformation, hydrothermal activity and mineralization, using a range of isotope systems (e.g. U–Pb, Ar/Ar, Re–Os and Rb–Sr) and a variety of minerals (zircon, baddeleyite, monazite, xenotime, titanite, hornblende, feldspars and micas). The Sensitive High-Resolution Ion Microprobe (SHRIMP) instrument in the John de Laeter Centre at Curtin University is used extensively by GSWA for U–Pb geochronology. GSWA also uses laser ablation inductively coupled mass spectrometry (LA-ICP-MS) instruments in the John de Laeter Centre and the Centre for Microscopy, Characterisation and Analysis at UWA to date detrital zircons, to date monazite and xenotime in thin sections in support of metamorphism and pressure–temperature–time (P–T–t) studies, and to measure the trace element compositions of minerals.

Whole-rock geochemistry is typically carried out for the complete set of major element oxides and a large suite of trace elements, but may also be restricted to certain element

groups (e.g. precious metals, platinum group elements, etc.) depending upon project requirements. Analytical services are outsourced to several Perth-based laboratories with the main techniques applied being X-ray fluorescence (XRF) spectrometry for major elements and some trace elements, and ICP-MS for trace elements. All data are compiled in the WACHEM database and made available through the online GeoChem Extract application.

Geochronology and geochemistry results and derivative materials are used extensively in GSWA's isotope geology studies, led by Yongjun Lu (see ES46 Enhanced Geochronology and Isotopic Mapping). These include specialized isotope geochemistry studies, including whole-rock Sm–Nd, Lu–Hf and Pb isotope analyses and zircon Lu–Hf and oxygen isotope analyses. These investigations are conducted in collaboration with external university laboratories.

The Laboratory section, managed by John Williams, supports the varied aspects of GSWA's geochronology, geochemistry and isotope geology programs with world-class sample preparation services provided in house by the GSWA laboratory at Carlisle. The Laboratory section also manages archiving and retrieval of materials in GSWA's extensive geological sample collection to support numerous internal and external research projects, and coordinates petrographic services for GSWA geologists.

Project work for the branch is funded through ES46. Accordingly, details of the work program are discussed within ES46.

GS58 West Yilgarn

Manager: Raphael Quentin de Gromard

Team member: Paul Duuring, Tim Ivanic, Jack Lowrey, Ivan Zibra

Primarily as a result of work and interpretations that emerged from the 2020–21 southwest Yilgarn AGP, the Youanmi Terrane project has again been expanded to include the South West Terrane and the Narryer Terrane, under the new title of the 'West Yilgarn' project (GS58). Thus, work under the new West Yilgarn project now examines the geology west of the Ida Fault, east of the Darling Fault and bounded to the north and south by the Proterozoic Capricorn and Albany–Fraser orogens respectively (Fig. 2). This large region is known to include significant concentrations of gold, iron ore, nickel, copper, lead, zinc, tungsten, molybdenum, bismuth, vanadium, titanium, beryllium, lithium, tin, tantalum and uranium in a range of inferred geological settings. The ongoing prospectivity of the region has only recently been highlighted by the discovery of extensive Ni–Cu–PGE mineralization only 60 km northeast of Perth, at Julimar. Understanding the geological evolution of the region, and how the varied and complex crustal entities within it have interacted geodynamically throughout the Precambrian is key to better realizing the further land-use potential of the west Yilgarn region.

The Narryer Terrane, in the northwest, contains the oldest rocks in the Yilgarn Craton and shares a tectonic contact with the Youanmi Terrane. The oldest rocks identified in the Narryer Terrane are 3.73 Ga migmatitic gneiss and layered mafic rocks; however, detrital zircon in quartzite and conglomerate at Mount Narryer and Jack Hills include zircons older than 4.0 Ga that pre-date any known rocks on Earth. These outstanding features have drawn considerable scientific attention to the felsic components of Narryer geology, but the geology of the supracrustal greenstones is, in contrast, very poorly known. Greenstones in the Narryer Terrane are restricted to several belts of strongly deformed and metamorphosed rocks yielding depositional ages between 3.1 and 2.7 Ga. Proterozoic volcanic and deformational episodes are also poorly studied.

The Youanmi Terrane in the western part of the Archean Yilgarn Craton comprises an extensive Archean granite–greenstone terrain with a long and complex geological history. The Youanmi Terrane greenstones, incorporating the older Madoonga and Gossan Hill Formations and the voluminous Norie, Polelle and Glen Groups, were deposited between 2.99 and 2.71 Ga. Felsic plutonic rocks intruded during each of these periods of volcano-sedimentary deposition and as voluminous syntectonic, synorogenic plutons along crustal-scale transpressional shear zones during the 2.73 – 2.65 Ga Yilgarn orogeny. Granitic magmatism continued during the late- to post-orogenic stages (2.64 – 2.60 Ga) that led to final cratonization of the Yilgarn Craton lithosphere.

Much of the regional mapping and additional geoscientific work conducted so far in the Youanmi Terrane has concentrated on its Neoproterozoic greenstone sequences and on the relationship between synorogenic magmatism, metamorphism and deformation along large-scale shear zones. However, there is a large temporal gap in the understanding of the crustal evolution of the older components of the Yilgarn Craton, including the overall lithospheric architectural evolution, during the Mesoproterozoic from 3.1 to 2.9 Ga. The Youanmi Terrane hosts most of the craton's rocks within this period but they typically have a low geoscience data density and relatively poor map coverage. Thus, a primary objective of the West Yilgarn project is to add a new level of interpretation to the pre-Neoproterozoic history of the Youanmi Terrane. An expanded temporal framework including a documentation of new magmatic suites and a better understanding of the structural evolution of the Youanmi Terrane will allow for an improved context for exploring terrane endowment by volcanogenic massive sulfide, nickel, iron and gold mineral systems. The detailed study of the structural evolution of the Chunderloo Shear Zone, the Dalgaranga Dome and the Mount Magnet and Sandstone areas, which was suspended due to the 2020–21 southwest Yilgarn AGP, is planned to resume in 2022.

As a result of work and interpretations that emerged from the 2020–21 Southwest Yilgarn AGP, the southern extent of the Youanmi Terrane has been extended to include the Corrigin Tectonic Zone and the informal and superseded Lake Grace terrane. The redefined terrane boundary with the South West Terrane is now interpreted to lie at the footwall of the Corrigin Tectonic Zone and this boundary, together with the complex shear zone system of the Corrigin Tectonic Zone, forms an obvious new search space for mineral exploration. The Corrigin Tectonic Zone and the informal Lake Grace terrane are now interpreted to represent an amphibolite- to granulite-facies equivalent to the rest of the Youanmi Terrane. The redefined South West Terrane is thought to be dominated by rocks younger than c. 2.7 Ga. There is no formal stratigraphy for the greenstone successions in the South West Terrane.

Planned work program

Fieldwork related to the 2021–22 work program will include testing hypotheses and interpretations that emerged from the 2020–21 AGP, in particular from compiling the southwest Interpreted Bedrock Geology (IBG). This work will focus on structural observations aimed at consolidating the interpreted kinematics and age of major zones and on geochemical, geochronological and isotopic sampling. Work towards new ENS entries will commence.

Targeted geological mapping, geochemical and geochronological sampling will resume in the southern and western Youanmi Terrane, aimed at characterizing 3.1 – 2.9 Ga geology and on improving constraints on the age, duration and modality of synorogenic granite magmatism along transpressional shear zones. The main objective of this sampling is to understand the petrogenesis and geodynamic history of these rocks in relation to the existing stratigraphic and magmatic framework developed in the northern Youanmi Terrane.

Work in the Narryer Terrane over the 2021–22 period will primarily focus on compiling available geoscientific datasets, including transcribing legacy notes into WAROX, in preparation for significant field activities in 2022–23. However, limited initial fieldwork will target information required to commence the extension of the southwest Yilgarn IBG map completed under the 2020–21 AGP into the Narryer Terrane – with the ultimate aim of seamless interpreted geology across the Narryer and Youanmi Terranes.

Detailed fieldwork focusing on the Late-Archean, Proterozoic and Phanerozoic tectonic evolution of the western Yilgarn Craton margin commenced with the 2020–21 AGP and will be extended to the region around Harvey Dam and southwards to the Pemberton region. This will be included within a planned update of the West Yilgarn GIS package.

Cooperative projects with various universities will continue, and include geochemical, metamorphic and structural studies in the northern Youanmi Terrane, 3D modelling in the western Youanmi Terrane, and structural and isotopic studies in the Narryer Terrane.

Products planned for release

- [Explanatory notes update for Yilgarn granites and Youanmi Terrane greenstones](#)
- [West Yilgarn GIS package with updated project boundary including seamless IBG update across Youanmi and South West terranes at 1: 100 000 and 1: 500 000 scale](#)

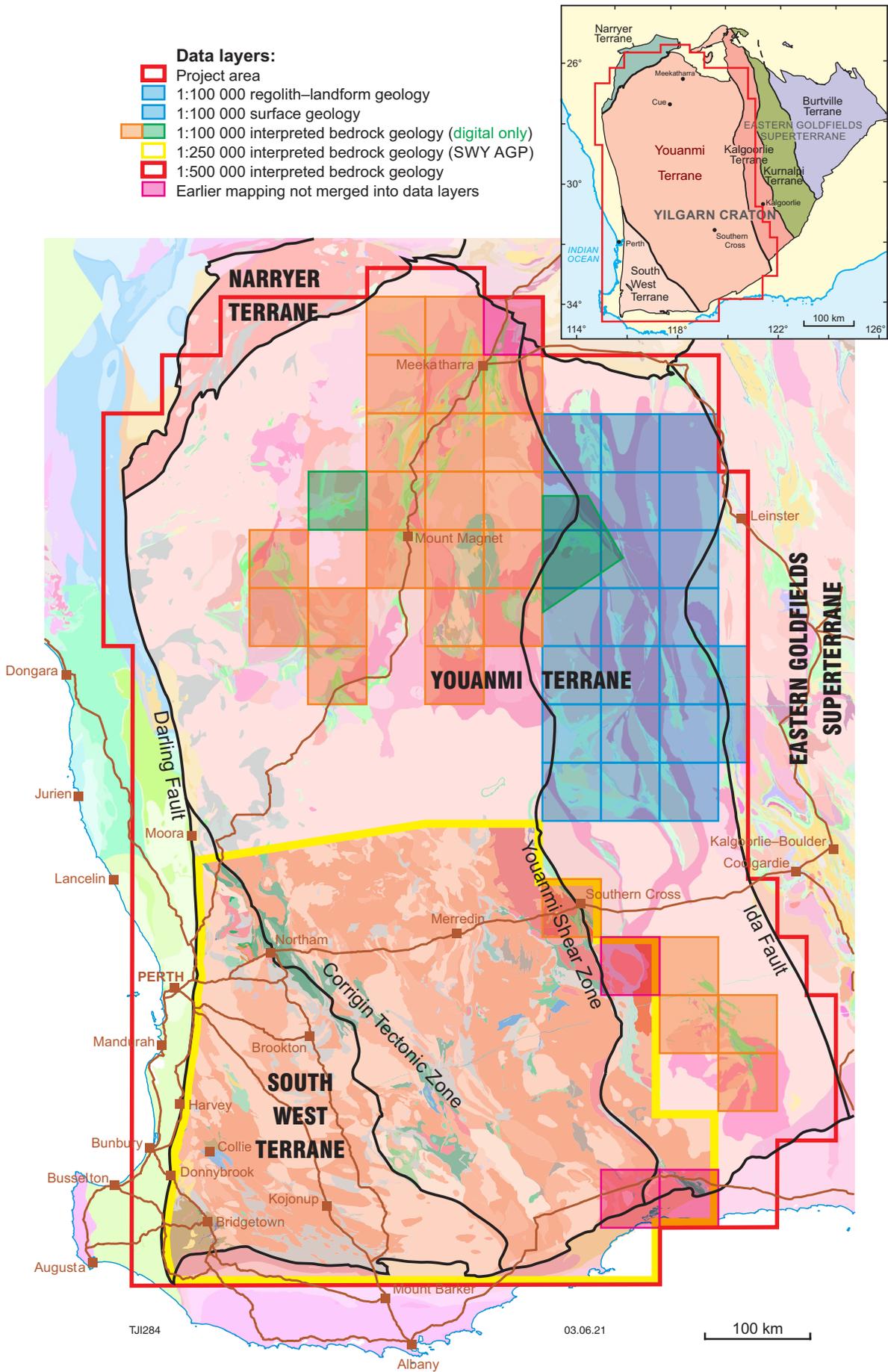


Figure 2. Simplified geological map of the 'West Yilgarn' project area showing the new mapping produced during the AGP and included into existing mapping of the Youanmi and Narryer Terranes

GS63 Pilbara and Hamersley

Manager: Heather Howard

Team members: Olga Blay, Arthur Hickman

The Pilbara Craton, northwest Western Australia, provides the world's best-preserved geological record of late Eoarchean to Neoproterozoic crustal evolution. The Eoarchean to Mesoproterozoic granite–greenstone terrane contains several of the world's oldest examples of porphyry-style mineralization, volcano-sedimentary base metal deposits, BIF, gold mineralization and pegmatite-hosted lithium, tantalum and niobium. It also hosts fossil evidence of the earliest life on Earth. Geological mapping of the granite–greenstone terranes at 1:1 000 000 scale was completed in 2005, along with a major revision of the stratigraphy, and revised interpretation of the structural and crustal evolution. Current work aims to make these data more accessible in digital format.

The granite–greenstones of the Pilbara Craton are unconformably overlain by the 2775–2630 Ma volcano-sedimentary Fortescue Group and the conformably overlying 2629–2420 Ma Hamersley Group of the Mount Bruce Supergroup. This supergroup incorporates 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. The prominent BIF, and the contained iron enrichments, are among the most economically important mineral deposits on the Australian continent.

The stratigraphy of the Fortescue Group has been previously described in detail by GSWA and a rift to passive margin setting suggested. Mantle plumes have been proposed to explain the evolution of the Fortescue Basin and a convergent setting for BIF and mafic and felsic rocks in the upper part of the Hamersley Group has been proposed. Nevertheless, the debate on stratigraphic definition, tectonic setting and evolution of the Mount Bruce Supergroup remains largely unresolved.

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

Planned work program

Stratigraphically controlled, high-precision geochemical, isotopic and geochronological data will be obtained from outcrop sampling to construct a 'magmatic stratigraphy' of the Mount Bruce Supergroup in key areas that can be extended to a regional scale. Targeted mapping this year, particularly in the East Pilbara region, will be carried out and detail added to the digital map layers as it becomes available.

Work will continue towards a new release of the Northwest Pilbara GIS package to include 1:100 000 interpreted bedrock geology layers. Continued geochemical data collection and interpretation will focus on a reassessment of the tectonic setting and geological evolution of the Fortescue and Hamersley Groups to be included in new Records.

Products planned for release

- [Fortescue–Hamersley GIS, 2022](#)
- [Northwest Pilbara GIS \(includes IBG on YULE, SATIRIST and HOOLEY\)](#)
- [Explanatory notes to accompany the 1:500 000 and 1:250 000 IBG digital map layers for the north and south Pilbara, respectively](#)

GS64 Geoscience Mapping Through Cover

Manager: Richard Chopping

Team members: Nadir de Souza Kovacs, Sara Jakica

Geoscience Mapping Through Cover commenced in 2018–19 and is aligned with the work of GS65 Proterozoic Margins. It is linked to ES36 Participation in the MinEx CRC and contributes to the understanding of the MinEx CRC project area for Western Australia ('The Gap' – see GS65 Proterozoic Margins). Activities will be conducted within MinEx CRC, with support for the National Drilling Initiative (NDI), and conducted through ES36 MinEx CRC Program 3. Collaborative research will be funded through the EIS from two project areas: ES34 Regolith and 3D Paleosurface Mapping.

The mapping of different regolith types and thickness 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 [AEM], passive seismic) linked to field-based studies and analysis of drillcore. 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.

Over the past decade, GSWA has demonstrated the application of single-station passive seismic (using Tromino instruments) to provide estimates of the depths to various horizons or basement in shallow cover and up to a depth of 1 km. The focus for 2021–22 is continuing the application of multiple geophysical techniques with an emphasis on passive seismic approaches to understand regolith mapping using near-surface geophysics in areas of interest for the MinEx CRC drilling project and other key areas of GSWA interest.

This will include coordination of work to jointly use passive and active seismic methods around recently acquired reflection lines, for example, the Kidson line in northern Western Australia or the Eastern Goldfields high-resolution seismic survey near Kalgoorlie. Additionally, joint interpretation with other available geophysics to better define thickness of cover will be undertaken to support NDI (ES36) drilling programs.

Additionally, the link to GS65 Proterozoic Margins will be enhanced by integration of landscape/landform evolution and understanding of key Proterozoic aged margins of

the State. Modern landscapes are derived from potentially ancient subsurface features and the integration of the work of these groups will assist in mapping the covered geology of the State.

Planned work program

- Regolith–landform mapping and regolith studies including HyLogger spectral analysis and dating of regolith materials using the (U–Th)/He method to be conducted under the auspices of any special geoscience program to support MinEx CRC NDI (ES36) drilling programs and a CSIRO/GSWA South West Yilgarn Terrane collaborative project; the work will include field-based studies, legacy drillcore analysis, HyLogger data analysis, and satellite imagery interpretation
- Further application of small-array passive seismic data acquisition to map regolith layers and paleochannels in conjunction with geophysical data, and to provide estimates of depth to basement
- Dating of regolith materials using the (U–Th)/He method, in collaboration with the John de Laeter Centre
- A targeted geochemical sampling approach, in conjunction with geochronology and biochemistry sampling, will be used during regolith mapping and regolith profile studies. This will provide information about paleoweathering patterns and local geochemical dispersion patterns from bedrock
- Assistance to the Department of Primary Industry and Regional Development in geological understanding of the western Yilgarn Craton, primarily in the Wheatbelt, for groundwater in fracture aquifer systems.

Products planned for release

- State 1:100 000-scale digital regolith regimes (digital map)
- Assessment of the Kimberley ASTER Version 2: geoscience products for regolith–landform mapping (Report)
- Multi-physics regolith thickness mapping in the Ravensthorpe region (external publication)

GS65 Proterozoic Margins

Manager: Fawna Korhonen

*Team members: Erin Gray, David Kelsey, Chris Phillips,
Jennifer Porter (MinEx CRC Embedded Researcher)*

The Proterozoic Margins section amalgamates the activities of the former GS56 North Australian Craton and GS61 Albany–Fraser Orogen and Eucla basement projects, and resides within the Geoscience Mapping Through Cover branch. The primary objective is to investigate and map the geology of the remote greenfields regions in the vicinity of the Northern Territory and South Australian border (Fig. 3), informally known as ‘The Gap’, and to provide essential data and knowledge towards GSWA’s commitment to the NDI of the MinEx CRC (see GS64 and ES36). Collaborative projects with leading research institutions will be funded through the EIS under the ES38 Proterozoic Margins project.

Much of the region is covered by younger basins and regolith, and a major component of the work program of ES38 is to interpret geophysical data and produce interpreted bedrock geology maps. This work incorporates knowledge gained from field mapping and drillcore analysis, with particular emphasis on using EIS co-funded drillcore housed at the Perth and Kalgoorlie core libraries. The project builds on the successful approach developed in the Albany–Fraser Orogen and Eucla basement projects. Currently, the West Arunta region and the Paterson Orogen are the main focus of new work.

One of the aims of the Proterozoic Margins section is to open up new frontiers in mineral exploration by understanding the magmatic, sedimentary and tectonic environments. This provides fundamental information to enable exploration teams to evaluate prospectivity and generate new project areas, and search for potential targets. The integration of statewide metamorphic studies to Proterozoic Margins will strengthen the geological mapping and prospectivity assessments of greenfields in Western Australia.

Planned work program

The primary work program for Proterozoic Margins for 2021–22 is on geological interpretations and products to support understanding of basin and basement geology of The Gap region. Continued focus on the sampling and analysis of diamond drillcore from the West Arunta and Paterson Orogens will continue, with some structural and metamorphic analysis on the Mesoproterozoic Albany–Fraser Orogen also to occur. Basin studies will focus on Meso- to Neoproterozoic basins in the region, pending fieldwork access to the Birrindudu Basin. Interpretation of airborne electromagnetic (AEM) data over the Canning Basin will be conducted collaboratively with GA, assisting understanding of the basin itself and any potential for basin-hosted resource systems. Two Reports from previous work in the Kimberley are in the final stages of completion and will also be released.

This year will be the final year for the MRIWA collaborative research project M471 studying the Paterson Orogen. This will provide a solid basis in the coming years for products providing a deeper understanding of this key region for minerals exploration.

Products planned for release

- Basement geology and fluid systems of the West Arunta from drilling data (Record)
- Sedimentology and stratigraphy of the Kimberley Basin (Report)
- The Hart-Carson Large Igneous Province, Kimberley, north Western Australia (Report)
- ENS entries for geological studies conducted as appropriate

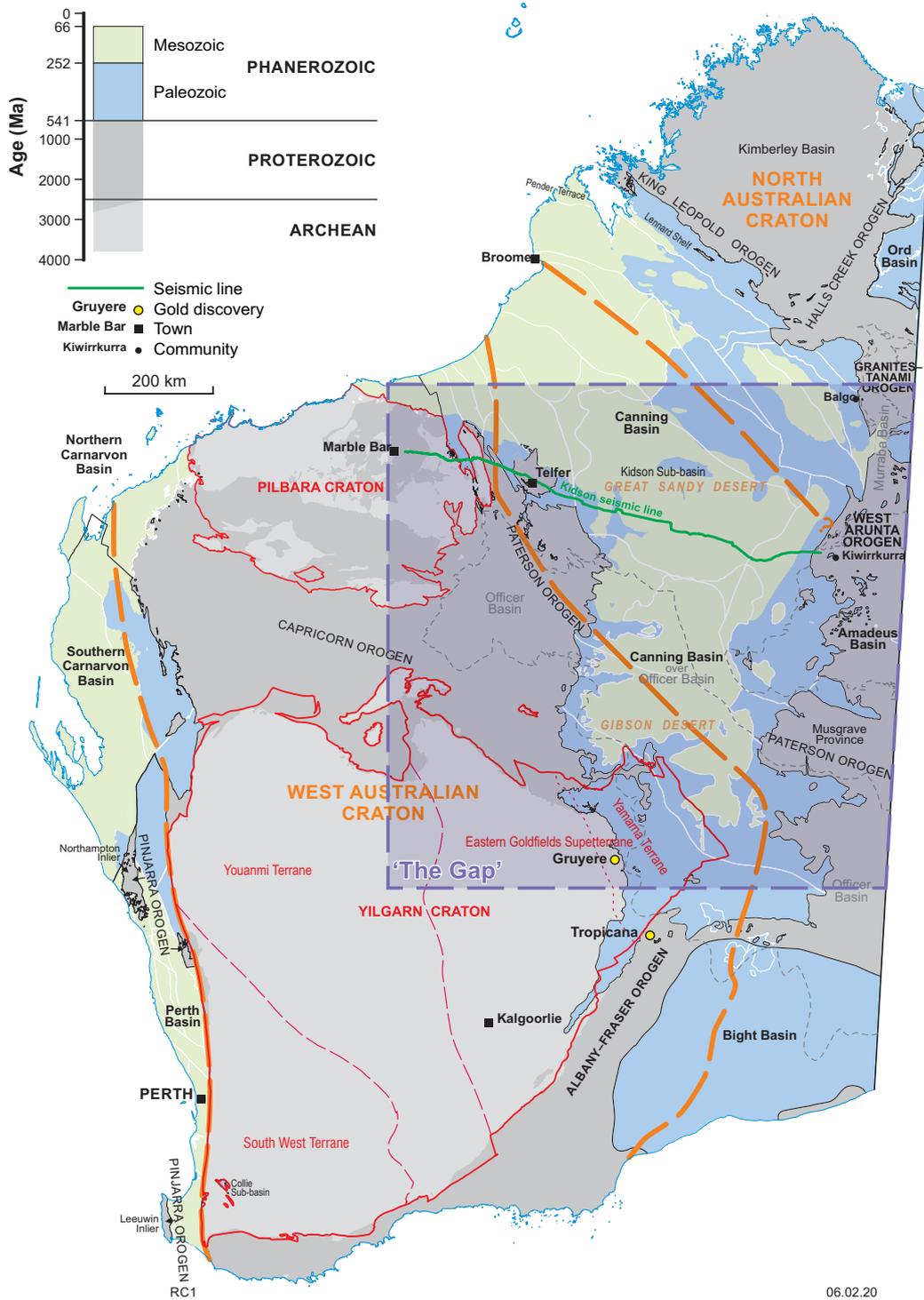


Figure 3. Location of 'The Gap', which is the informal name for the region of the remote desert country of central eastern Western Australia

GS81 Mapping and Events

Manager: *Shaun Coldicutt*

Team members: *John Bennett, Xavier Bezu, Irena Lesiak, Sue Mulligan*

The Mapping and Events team is made up of geospatial officers that produce geoscience, resource, and petroleum and mineral titles maps, as well as presentation material for events hosted and participated in by GSWA. While complex State and project maps are produced each year, the section has the capability of creating maps with a quick turnaround for discussion purposes as requested by the Division's geoscience professionals.

Xavier Bezu and John Bennett have recently joined the team. They have brought their extensive mapping abilities where they provide assistance with petroleum title queries for staff in the Resource Tenure Division.

Products planned for release

- Major resource projects, western australia 2021
- Mines — operating and under development 2022
- Aboriginal land, conservation areas, mineral and petroleum titles, and geology 2022
- Kimberley resource projects 2022
- Petroleum titles map 2022
- Posters for events



GS82 Graphics

Manager: Michael Prause

Team members: Deenikka Loprese, Adam Symonds

The Graphics section provides support to numerous sections within GSWA, with the variety of the work produced by these sections innately driving the type of 'graphical' support provided.

The principal role of the section is to help authors prepare figures for publication and/or display. This can vary from simply applying in-house formatting rules to diagrams, cleaning up and annotating photographs, assisting in the assembly of posters for display, to cooperatively helping authors with complex projects from an early creation stage, all while maintaining the uniform professional look expected from GSWA publications.

An example of the assistance of the Graphics team in a complex project can be seen by Adam Symond's work in helping the Energy and Basins section create the Digital Core Atlas series from scratch. He assisted the implementation of a flipbook solution for viewing core tray data, and subsequently manipulated this data into an appropriate graphical format.

Manipulating raw data into an easy-to-read graphic is a process the section does well. Helping authors visualize concepts in 3D and transfer this knowledge to a reading audience via a simple 2D graphic is another way the section helps the business of other GSWA sections (Fig. 4).

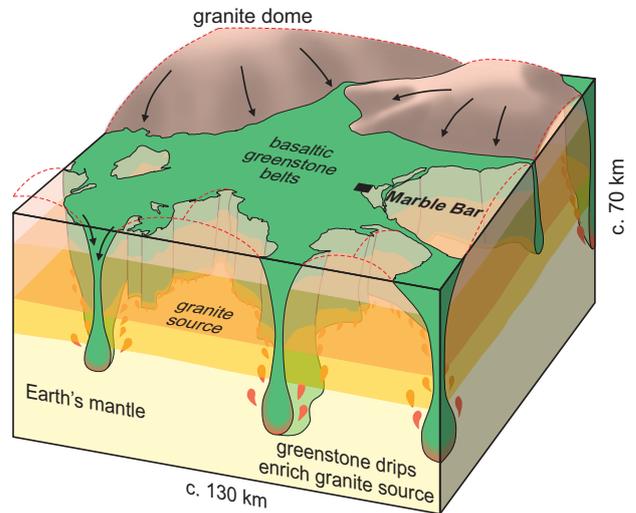


Figure 4. Using figures to tell the geological story of how greenstone drips are melted by the mantle to enrich the source of granite domes

GS83 Geoscience Data Services

GS84 Geoscience Data Delivery

GS86 Geoscience Data Governance

Manager: Deavi Purnomo

Team members: Daniel Then (Manager GS83), Gary Hartley, Joe Hogen-Esch, Stewart Jefferys, John Kirk, Brad Tapping, Leo Liu (Manager GS84), Terry Farrell, Annick Francois, Wendy Hampton, Callan Joiner, Yanrong Li

Staff members in these teams include data management, geospatial and web mapping professionals. These program areas reside in the Geoscience Data branch, which is responsible for:

- Data creation, management, delivery and production of GSWA's geoscience data
- Acquisition and integrity of both mineral and petroleum titles information in DMIRS Spatial Data Infrastructure environment
- Provision of geoscience data development, management and delivery for the division
- Development and maintenance of quality assurance processes that align with national and international standards
- In cooperation with internal and external geoscience bodies, the branch develops the data models and standards required for spatial geoscience data management
- Development and management of web-based applications as a data publications platform.

Products planned for release

In cooperation with other sections, the team will continue to produce geoscientific digital datasets, layers and packages as follows:

- | | |
|------------------------|----|
| • Data packages (USBs) | 3 |
| • Digital data layers | 7 |
| • Online data releases | 13 |

GS85 Resource Investment Information

Manager: Warren Ormsby

Team member: To be appointed

The objective of the Resource Investment Information branch is to facilitate the provision of resource-related information to investors for mineral and energy investment in Western Australia to accelerate exploration and development of new resources. This involves providing geoscientific, policy and regulatory information to assist with attracting new resource investment.

Activities are undertaken individually by GSWA or in cooperation with 'Australia Minerals' (the collective name given to investment collaboration between the State and Territory geological surveys and GA). Activities undertaken include:

- Preparing Western Australian investment-oriented presentations for delivery at virtual conferences or in person at local and overseas events
- Providing geoscientific and policy information sessions
- Responding to investor requests for geoscience and policy, and providing information and advice
- Collaborating with JTSI, Austrade and other government offices at a State and national level to provide advice and information on Western Australia's resources industry and mineral endowment.

Planned work program

Several national and international events and conferences have been affected by the COVID-19 pandemic with subsequent travel bans and border closures. In 2021–22, the project will fund Western Australia's presence in some capacity at key national and international events (it is not clear whether attendance will be virtual or in person):

| | |
|-----------------------------|-----------------------------------|
| 2–4 August 2021 | Diggers & Dealers |
| 9 August – 3 September 2021 | NAPE Summit |
| 8 September 2021 | RIU Good Oil Conference |
| 17–19 September 2021 | Astro Fest |
| 17–19 September 2021 | Perth Gem and Mineral Show |
| 15–20 September 2021 | AEGC, Brisbane |
| 26–28 October 2021 | IMARC, Melbourne |
| 9–10 November 2021 | New Gen Gold Conference |
| 12 November 2021 | GSWA Open Day |
| 18–19 November 2021 | Goldfields Big Day Out |
| February 2022 | RIU Explorers Conference |
| February 2022 | PDAC, Toronto |
| 2–4 March 2022 | AOG Energy, Perth |
| April 2022 | Mines and Money, London |
| June 2022 | APPEA 2022 Oil and Gas Conference |
| June 2022 | Battery Metals Conference |

Titles Information

Incorporates GS87 Title Certification, GS88 Title Support, GS90 Title Services (Native Title)

Manager: Craig Wainwright

The Titles Information section is a highly experienced group of spatial science officers dedicated and committed to their vital role of supporting the grant of title process and maintenance of all relevant spatial data layers in DMIRS TENGRAPH Web (Fig. 5). They ensure that all lease and licence holders' tenements are reliably maintained as they pass through the various dealings and compliance processes during their life cycle. Staff manage a vast array of spatial layers all required to accurately appraise and assess grant conditions on tenements. This section also delivers historical and live tenement data to the State Solicitor's Office (SSO) as part of the process of determining Native Title claims across Western Australia through the Federal Court of Australia.

Titles Information is always looking to innovate and improve its business process and spatial systems. Some recent and significant milestones achieved include:

- Replacement of TENGRAPH DB2 Legacy maintenance modules with the introduction of 'TENGRAPH Pro' – spatial capture and maintenance within ESRI's ArcGIS PRO GIS Mapping software
- Introduction of online lodgement of surveyors' documents
- Survey data leveraging an enhanced Mineral Titles Online
- An 80% reduction in the Survey Lease backlog over the last two years to address mining industry concerns.

These are all significant achievements accomplished and delivered concurrently despite the great challenges that 2020–21 delivered.

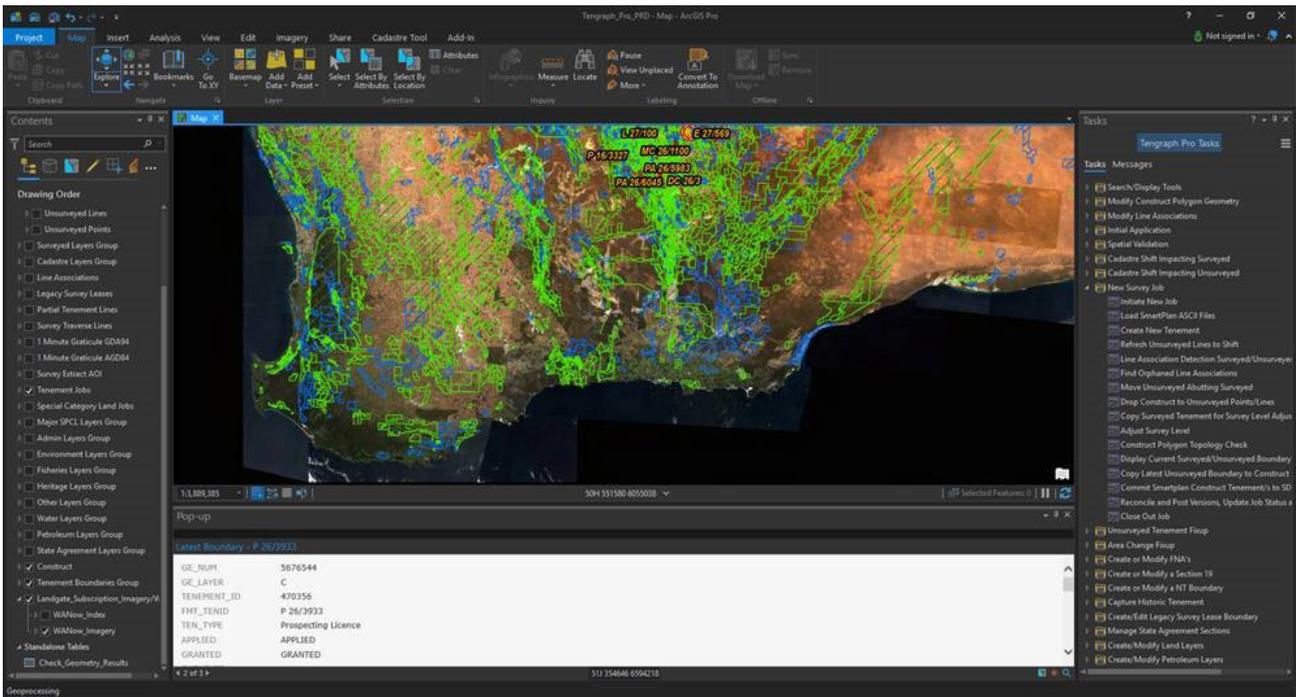


Figure 5. TENGRAPH Pro: spatial capture and maintenance of all Titles Information layers now performed within ESRI's ArcGIS Pro – implementation 22 February 2021

GS87 Title Certification

Manager: Andrew Pollard

Team members: Matt Aravidis, Dennis Bettsworth, Neil Dinnison, Greg Dutkiewicz, Dean Hubbard, Rasa Kam, Lucio Pallotta, Dale Rayner, Phil Sinagra, John Stevens, Graham Wyles

The Title Certification section performs a vital statutory role in relation to surveying and certification of Mining Leases required under Section 80 of the *Mining Act 1978*, which requires issuing of survey instructions for survey of all leases at time of grant of the lease. The section engages with leaseholders and approved surveyors to manage the survey process. Survey Projects are managed within eMiTS, Survey Projects Screen. Survey instructions are issued to a holder's nominated approved surveyor who performs the survey of lease/s within a project. Online lodgement of surveyors' field notes, digital CSD File and Surveyors Form 44 Report was implemented in September 2020. Lodged surveys are integrated into Landgate via SMARTPLAN and into DMIRS TENGRAPH Web via ArcGIS Pro. The section is responsible for the production of legal Certified Survey Documents in ArcGIS Pro. It plays a statutory support role for the certification and spatial validation of all unsurveyed applications and the various boundary changes that occur due to dealings on tenements as they pass through their life cycle from initial lodgement, Grant and through the variety of compliance processes that impact the spatial extent of tenements. This section also monitors the impacts that Landgate cadastre updates have on DMIRS surveyed and unsurveyed mining tenure, and spatially adjusts tenement boundaries as required.

Planned work program

- Ongoing management of the survey process in conjunction with DMIRS approved list of surveyors
- Management of Survey Projects in eMiTS

- Surveying of Mining and General Purpose Leases under Section 80 of the *Mining Act 1978* – survey backlog reduction
- Integration of new surveys in Landgate's SMARTPLAN and DMIRS TENGRAPH Web, and the production of legal survey documents
- Certification and plotting of unsurveyed tenement applications – graticular and non-graticular
- Spatial update of surveyed and unsurveyed tenements impacted by Landgate's cadastre update
- Scanning of survey documents.

Special projects

- Digital signatures on survey diagrams allowing for remote expedited authorization of survey documents
- Digital legal documents – cessation of hard copy legal documents
- Online access to survey documents via TENGRAPH Web, eMiTS or Cloud storage solution
- Survey document production in ArcGIS PRO (decommissioning Bentley MicroStation solution)
- GDA2020 implementation – proposed March 2022.

GS88 Title Support

Manager: Sean Doherty

Team members: Tanya Quaglia, Sue Shadbolt

The Title Support section supports the process of granting of mining titles. The section is responsible for maintaining all other layers in TENGRAPH Web other than tenements and Native Title claim layers. It is also responsible for ensuring all DMIRS administrative layers including File Notation Areas (Section 16(3)) layers and Section 19s are maintained, Landgate cadastre is updated on a quarterly basis, and all other special category land layers are sourced from respective agencies to retain currency. This is to ensure accurate appraisal of tenements and the setting of grant conditions.

The section supports:

- LUP branch by mapping File Notation Areas (Section 16(3) clearances under the *Mining Act 1978*) to alert stakeholders to Crown Land use proposals
- Resource and Environmental Regulation branch by mapping land that is exempt from mining activities as defined under Section 19 of the Mining Act. Landgate administrative and cadastre layers and other special category land layers are sourced from the respective agencies, e.g. heritage, conservation and water.

Planned work program

- Ongoing management of DMIRS Administrative Layers, Cadastral Layers, Standard Survey Marks, Environmental and all Special Category Land layers within TENGRAPH Web, File Notation Areas, Section 16(3), Section 19
- Support the appraisal and grant process by providing current Land and Administrative Layers facilitating accurate appraisal and grant conditions on Mining Leases and Exploration/ Prospecting Licences.

GS90 Title Services (Native Title)

Manager: Amanda Roscoe

Team members: Ireen Akter, June Graham, Jason Knott, Sreedhar Nallan, Suzanne Panton

The Title Services section is primarily responsible for providing services stipulated under an agreed Memorandum of Understanding (MoU) established with the Department of The Premier and Cabinet (DPC) and SSO. This MoU relates to the provision of historical and current mining tenement title and spatial details that contribute towards the Federal Court's determination of Native Title claims lodged over the State of Western Australia. This takes the form of GIS packages of historical and current mining title data delivered to the SSO via Landgate.

The section also produces GIS analysis and 'Right to Negotiate' and Resource Access Native Title maps for the Resource Tenure Division. Recently, the team has become involved in research and data collation for the first phase of the Tjiwarl Native Title claim Compensation Area.

The Native Title Project is a long-standing project with a 20-year life span to date which, due to the nature of Native Title, is diversifying and unfolding into other areas of work. The DPC, SSO and DMIRS are in negotiation to establish permanency to this team by providing current contractors

employed under the MoU via funding by DPC, an alternative direct funded model, to ensure security for the professional staff that have served this project so well over many years. This section is also responsible for maintaining Native Title related layers within TENGRAPH Web.

Planned work program

- Provide support to the National Native Title Tribunal and Federal Court for determinations of Native Title claims under an MoU with the DPC and SSO
- Provide historical and current Mining Title data to support Native Title litigation, negotiation and compensation matters relating to Native Title claims
- Produce GIS datasets and GIS mapping and analysis products to assist all matters relating to Native Title
- Manage Native Title layers in TENGRAPH Web.

GS91 Mineral Exploration Information Management

Manager: *Julia Thom*

Team members: *Monique Brouxhon, Subashni De Biran, Dale Finnigan, Narelle Gardiner, Fiona MacCorquodale, Robert Pizzi, Christine Suchodolski*

DMIRS has a statutory obligation to manage the collection, storage and release of company exploration reports containing geoscience information on mining tenements in Western Australia; this function is performed by GSWA. The archive of statutory exploration information is a valuable resource, providing a means whereby companies can assess the potential of an area and develop exploration strategies using legacy data, which minimizes duplication of exploration effort and enables more efficient exploration.

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

The Mineral Exploration Information section also manages the company mineral drillhole and surface geochemistry database, which contains all company drilling and surface geochemistry data that has been submitted to DMIRS in digital format.

In addition, the section manages the processes that allow internal and external stakeholders to view and sample the valuable mineral core collection housed in the two core libraries.

Planned work program and outcomes

Planned activities and outcomes are to:

- Review and release surrender reports and their associated annual reports as they are received, together with the 15th annual release of reports under the provisions of Regulation 96(4) of the Mining Act, commonly known as the 'sunset clause'; this will ensure that access to this historical data increases
- Release reports that relate to exploration on dead tenements, although many of these relate to tenements under the *Mining Act 1904*, to which the 'sunset clause' does not apply

- Continue to review the mineral exploration reports for compliance with the Guidelines for Mineral Exploration Reports on Mining Tenements, to ensure all data is included in the report prior to archiving, and it is then ready for release via the 'sunset clause' or normal cancellation process
- Expand the reviewing process to allow reviewing geologists to enter information from company exploration reports into the MINEDEX database
- Convert all sunset clause release reports in WAMEX to searchable text for upload to the database and to the WAMEX search site
- Work on continual improvements to the WAMEX database to increase its searchability
- Continue work of cleansing and harmonizing geochemistry data in the Mineral Drillholes database and improve the search interface
- Continue training in the use of the WAMEX and mineral drillhole and surface geochemistry databases in both Perth and Kalgoorlie, and develop, update and deliver training and exercise manuals on those databases
- Develop a core library database, in collaboration with WAPIMS, for mineral core with links to the mineral drillhole and WAMEX databases, to enable better searching for drillcore and a more efficient and less manual process of managing, viewing and sampling the mineral core
- Continue to identify and collect historical drillcore suitable for the Perth and Kalgoorlie core libraries
- Continue the capture of attribute information for legacy mineral exploration core submitted to the core libraries in Perth and Kalgoorlie.

GS92 Statutory Petroleum Exploration Information

Manager: Felicia Irimies

*Team members: Alan Bloore, Fiona Dodd, George Karniewicz,
Janine Malligan, Richard O'Brien, Yasinta Situmorang*

The 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.

From 1 January 2012, the National Offshore Petroleum Titles Administrator (NOPTA) assumed responsibility for a range of regulatory and administrative functions for Commonwealth Waters that had previously been the responsibility of the designated authorities. This includes the regulation of documentary information and petroleum mining samples (petroleum data), in accordance with Part 7 and Part 8 of the Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011 (RMA Regulations).

Under the State–Commonwealth National Collaboration Framework, DMIRS will continue to provide services to the Commonwealth in the handling of core, cuttings and thin sections that relate to petroleum exploration in offshore Commonwealth-controlled waters. It will continue to make those samples available for viewing, further sampling and loan. DMIRS is also assisting NOPTA and GA to develop and maintain the National Offshore Petroleum Information Management System (NOPIMS), with close links to WAPIMS and the Core Information Management System (CIMS).

The section adds quality-assured geoscience information to the WAPIMS database, undertakes transcription and scanning programs related to State activities, and ensures data submitted are complete and in a format easily used by explorers. It also manages the release of data online through WAPIMS, including documents related to offshore activities occurring before 1 January 2012.

Priorities for transcribing and scanning legacy data are set in part by the future activities of GS10 Energy Geoscience and Carbon Strategy and the Specific Area Gazettes conducted by the Resource Tenure Group.

Planned work program and outcomes

The section will continue loading legacy scanned and transcribed data for access via the web and add new data as received, continue quality control for onshore well log data submitted from industry and create reports and data packages, available through WAPIMS.

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

Planned activities and outcomes are to:

- Collaborate with NOPTA/GGA for better integration of our systems (WAPIMS, NOPIMS, National Electronic Approvals Tracking System [NEATS], Petroleum Geothermal Register [PGR])
- Continue creating enhancements to WAPIMS including:
 - upload the scanned seismic sections (depending on DMIRS data storage capacity)
 - create forms and public reports to release online all the public geoscientific data captured in WAPIMS (State and Commonwealth)
 - add new map layers
 - add new data to 'Data By Depth' functionality
- Continue vectorizing all the onshore line sections without digital data to SEG-Y; priorities based on work done by Energy Geoscience and Carbon Strategy branch
- Continue data transcription program including the remaining nine track tapes
- Continue accessioning the thin sections submission for State and Commonwealth wells and release them to the public
- Continue sampling approvals for State and Commonwealth activities and monitor retrieval of the analysis reports and the slides generated
- Assist in relocating Western Australian core from GA to the Perth Core Library
- Prepare relocation of thin sections relinquishment collection to Carlisle and plan for future scanning of the collection
- Review the archived items stored at Iron Mountain and prepare for uploading the digital data into a Cloud system
- Review and update Guidelines for petroleum data submission and release based on Parts 8 and 9 of the Mines and Petroleum Regulation Amendment Regulations 2018.

GS95 HyLogger and the National Virtual Core Library

Manager: Lena Hancock

Team members: Edward Rogers, Michael Wawryk

The GSWA HyLogger facility is one of six State and Territory geological survey-based nodes that were established in 2009 as part of the National Collaborative Research Infrastructure Strategy (NCRIS), to provide objective mineralogical data and interpretations from drillcore (and other rock samples), thereby improving our understanding of the composition of the Australian crust. HyLogger-3 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.

HyLogger-3 will be replaced by the new HyLogger-4 instrument, which will have the additional capability of recording the mid-infrared (MIR) spectral range and higher resolution digital images to produce higher quality data over a wider spectral range.

The data are processed and posted to a dedicated national database (the AuScope NVCL portal) and to GeoVIEW.WA, where they can be viewed using open-access software. Full datasets are also available upon request. The list of scanned datasets and the links to the drillcore images and other publications are updated every six months and are available on the [DMIRS website](#).

Planned work program

The facility will continue to collect and interpret spectral data from drillcore that contributes directly to increasing the knowledge of Western Australian geology, and mineral and petroleum systems. Material to be analysed will include that requested by GSWA staff, academic researchers, students and industry engaged in collaborative or other research with GSWA (including core obtained as part of the EIS). Priority of scanning is determined by a GSWA committee in order to balance the competing objectives, demands and priorities of users.

Other regular activities for 2021–22 will include periodic uploading of processed HyLogger data to the NVCL database, ensuring the release of non-confidential data to the AuScope national portal and to the GeoVIEW.WA HyLogger layer.

In collaboration with CSIRO, HyLogger staff will deliver to GSWA, academic and industry personnel two workshops promoting the use of the hyperspectral technology. These will be conducted in the Perth and Kalgoorlie core libraries.

HyLogger staff will also commence the systematic collection of geochemical data from scanned drillcore using portable XRF technology, thereby increasing the information available for drillcore archived in the core libraries and complementing mineralogical interpretations from hyperspectral data. An evaluation of the use of pXRF geochemical data will be provided in a GSWA Record.

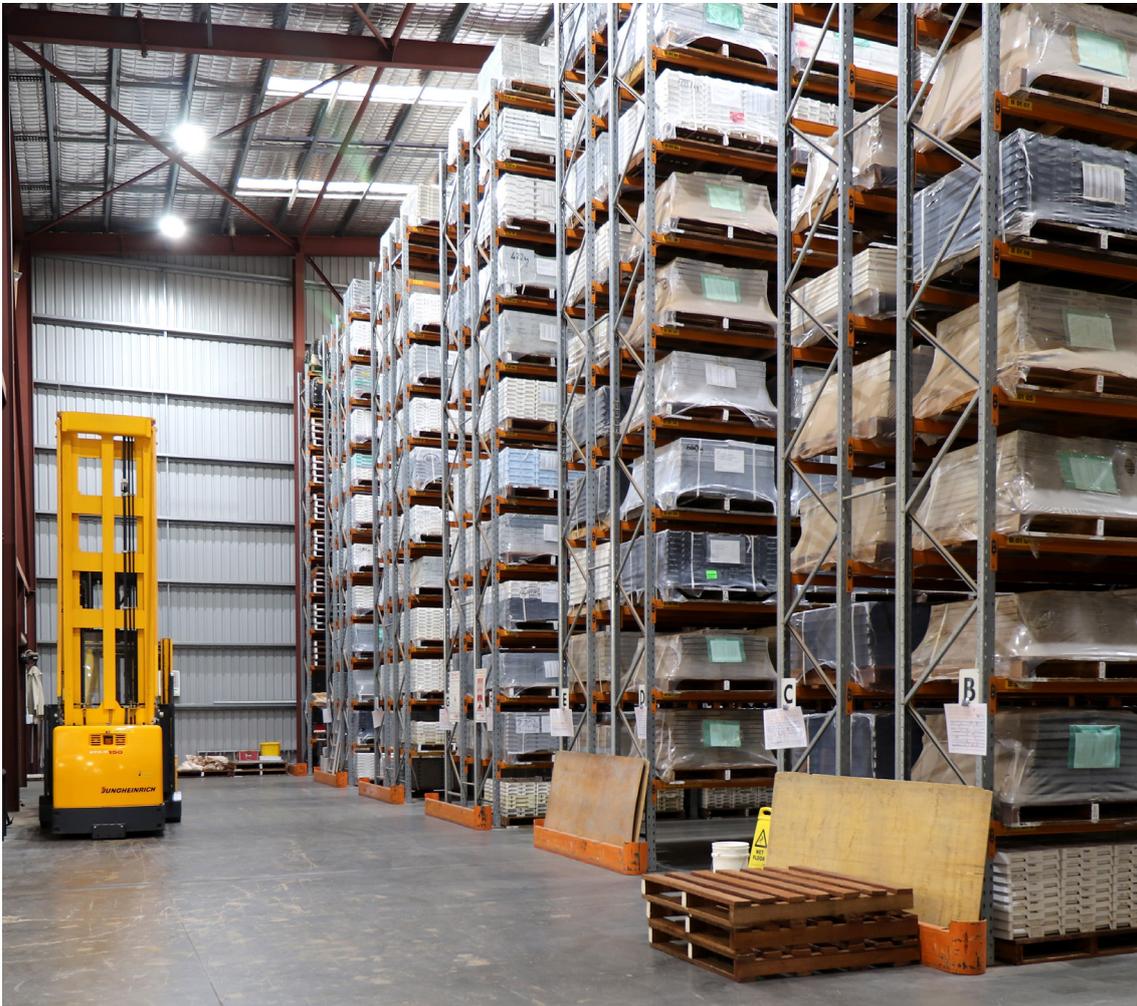
Products planned for release

- [Using pXRF in DMIRS core libraries for drillcore geochemical data \(Record\)](#)

Western Australian Core Libraries

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

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



GS94 Perth Core Library

Manager: Paul Stephenson

Team members: Bill Anderson, Matthew Chappell, Fiona Dodd, Peter Drobek, Simon Fanning, Mark Harrison, Andy Leighton, Shane Preedy, Diran Rinal, Josh Williams

The Perth Core Library is the western hub of the National Offshore Petroleum Data and Core Repository (NOPDCR). It will store two-thirds of all Commonwealth-managed petroleum core derived from offshore drilling from around Australia. This is managed under two agreements between DMIRS, GA and the National Offshore Petroleum Titles Administrator (NOPTA), providing a significant step towards a seamless service to the petroleum exploration industry.

The Perth Core Library is used by DMIRS, industry and academia as a geoscience training facility, and also houses the HyLogger spectral scanner, one of the six nodes of the National Virtual Core Library (NVCL) that collects extensive, objective, pre-competitive mineralogical data from archived drillcore.

Usage of the Perth Core Library remains at very high levels (Fig. 6).

Planned work program and outcomes

Staff will continue to maintain the same level of service to stakeholders. Developments include:

- Potentially receiving donations from Exxon Mobil of core and cuttings from Victoria and Tasmania (~250–300 pallets); discussions between Exxon Mobil and GSWA are in progress
- A new forklift, and Almonte cutting saw has been acquired
- Provision of XRF and XRD service

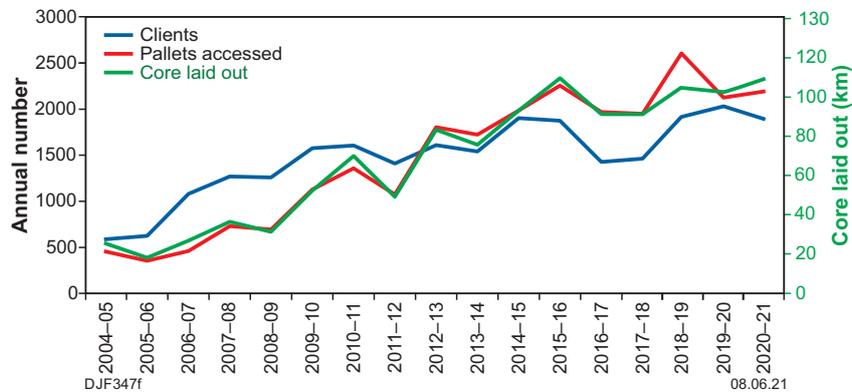


Figure 6. Use of Perth Core Library services

GS96 Joe Lord Core Library

Manager: Debbie Caple

Team members: Steven Black, Jason Dunstone

Site works have been completed at the Joe Lord Core Library expansion in Kalgoorlie.

Local Aboriginal business Yonga Djena was appointed to complete the site works, while building contractor ACorp Construction has sourced employees from the local area. This expansion has created 100 new jobs for the local Kalgoorlie–Boulder community. A local Aboriginal artist will create original artwork for the project.

The State Government announced \$7 million of funding in July 2020 to support the core library extension as part of its COVID-19 Goldfields–Esperance Recovery Plan. The world-class library stores core samples containing valuable geoscientific information for exploration companies and others searching for new resource discoveries.

Researchers and explorers can inspect the samples and review results to reduce the technical and financial risk of exploration activities. The extension will provide better access, more space and improved facilities to view and analyse the drillcores.

Construction is due for completion in late 2021.

Planned work program and outcomes

In 2021–22, staff will continue to maintain the same level of service to stakeholders.

Developments include:

- A 6750-bay expansion with proactive engagement to improve current usage levels, which have seen an increase in otherwise normally quiet times
- Expansion of the outdoor viewing area to provide an additional 16 roller tables for viewings
- A review about the relocation of slides from the Core Store in Kalgoorlie to the core library to enable customers the opportunity of having the slides available when viewing core
- Continuing to maintain a high level of service to the mining industry as well as to the academic sector.

GS97 Discover Geology

Manager: Stephen White

Team members: Ryan Aston, Sarah Goss

The Discover Geology team was established in January 2021 to focus on delivering geoscience products for the public.

The main objectives are to:

- Repurpose published GSWA products in diverse, innovative, interactive formats pitched to levels suitable for a general audience
- Increase recognition among the public and the geotourism industry of GSWA as the authoritative source of geoscience information about Western Australia
- Support geotourism initiatives within DMIRS and in collaboration with outside organizations.

Planned work program

The Discover Geology team will initially develop its product series in two formats:

- Online products using ArcGIS StoryMaps
- Printed books in A5 format.

As the planned products in these formats are published, consideration will be given to adapting the content for a mobile app. Content for these products will mainly be derived from existing GSWA publications, including data products. The team will work with other sections in the Geoscience and Titles Information branch, such as Graphics, Mapping and Events, and Editing and Publishing, and consult geoscience specialists to adapt content so it is suitable for the intended format and a general customer base.

Interactivity of the online products will be achieved by including spatial data, specialist photography, video, audio and links to other online material, which will be introduced incrementally as the process evolves. The team will research other modes of innovative content delivery, such as animations, augmented reality and virtual reality, for future products.

Two field trips will be undertaken to acquire photographic and video material to complement content already available from previous GSWA publications.

Products planned for release

- Meteorite impact structures (StoryMap)
- Murchison region (StoryMap)
- John Forrest Heritage Railway Reserve geotrail (A5 book)
- John Forrest Heritage Railway Reserve geotrail (StoryMap)

GS98 New Energy Systems

Manager: Trevor Beardsmore

Team members: ad hoc via collaboration

In November 2020, the State Government released the Western Australian Climate Policy to coordinate action to meet the challenge of reducing net greenhouse gas (GHG) emissions to zero in accordance with international commitments, while building a prosperous and resilient economy. This policy embraces a raft of initiatives such as the Energy Transformation Strategy and the Future Battery Industry Strategy, that aim to capitalize on the State’s impressive natural resource endowment, technical know-how and prime geographic location to shift to predominantly ‘green’ domestic energy generation. It also aims to build a fully integrated green energy industry that exports products and expertise to a demanding world.

This New Energy Transition (NET) will impact the entire Western Australian community, and a whole-of-government approach will be required to manage it. Within this context, GSWA can make important contributions, by providing geoscientific information and advice that:

1. Promote the discovery and recovery of necessary mineral and energy resources
2. Assist with mitigating resultant waste streams
3. Inform the development of government policies and regulations to stimulate and govern the impact of activities to bring about the NET.

Resources in this context include those required for the technologies to generate energy from renewable and non-renewable sources, and to store this energy for future use (including export). They might be primary or byproduct materials and energy occurring in conventional or novel settings, including bedrock, groundwaters, mine residues and disused mine infrastructure. Wastes include solid residues from physical mining and processing of raw materials, and

actual and ‘embedded’ greenhouse gas emissions from resource extraction activities and energy generation – but might also be potential resources in a regenerative ‘circular’ economy.

The resources industry and Government both require information on the known or prospective availability of relevant raw material and storage resources in Western Australia, and on evolving trends in domestic and international market demand for these resources. The role of the recently created New Energy Systems branch is to develop and coordinate a work program specifically focused on delivering this information.

Planned work program

In 2021–22, the New Energy Systems branch will commence work on the following initial portfolio of projects addressing GSWA’s commitment to the NET:

- Characterize the actual and prospective type, quantity and value of byproduct or co-product ‘battery/critical’ mineral resources in conventional and novel mineral deposits in bedrock, groundwaters and mining/mineral processing residues. This will highlight regions of future development and capital expenditure, and place Western Australia’s resource endowment in the context of global demand, quality and value
- Characterize geological reservoirs for the temporary storage of ‘new energy’ sources (hydrogen, ‘pumped’ water) and permanent geosequestration of waste greenhouse gases, in sedimentary basins, mafic–ultramafic bedrock packages, mine residues (tailings and rock waste), and old mine infrastructure (open pits)



- Review current and projected domestic and international production and demand for 'battery/critical' minerals, to guide commodity research and promotion strategies
- Review current and projected domestic production of greenhouse gases, to inform evaluations of the sufficiency of capacity in Western Australia's known and potential greenhouse gas storage inventory
- Establish a 'material flow' database for Western Australian 'battery/critical' mineral and energy resources and derivative products up to the point of export, that includes waste streams
- Review current domestic and international governance frameworks relevant to the NET, to identify opportunities for improving State Government mineral and petroleum policy and regulation in areas including land access by competing interests, environmental and safety issues, royalty and taxation considerations or concessions, and other industry incentives.

There will necessarily be close intra- and inter-Agency collaboration to harvest the data and knowledge that will be needed to achieve the proposed outcomes. Mutually beneficial alliances are anticipated with staff and work programs in GSWA Minerals Systems, GSWA Energy Geoscience and Carbon Strategy, GSWA MINEDEX, GSWA Mineral Exploration Information (WAMEX), GSWA Petroleum Exploration Information (WAPIMS), GSWA Abandoned Mines, DMIRS Resource Strategy, DMIRS Environment Division, JTSI, Western Power, research organizations, and mining and petroleum companies.

Products planned for release

- Catalogue of current and proposed 'battery mineral' projects in Western Australia
- Preliminary catalogue of mining residues in Western Australia that may contain 'battery minerals' (Report and database)
- Preliminary estimate of potential greenstone reservoirs for CO₂ sequestration and anthropogenic geothermal energy generation (Report and database)

PART TWO

Exploration Incentive Scheme
– detailed work programs

ES20 Government Co-funded Exploration Drilling

Manager: Charlotte Hall

Team member: Monique Brouxhon

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

The program is preferentially funding high-quality, technical and soundly based projects that promote new exploration concepts and technologies. Proposals from applicants are assessed by an independent panel based on geoscientific and exploration targeting merit and data generated.

An advisory committee, chaired by the Deputy Director General of the Resource and Environmental Regulation Group in DMIRS, and consisting of representatives from the main industry representative groups and research sector, provides advice to the department on program guidelines and feedback from industry. The committee, which meets twice yearly, also ensures that the program is relevant to the exploration industry.

The Co-funded Exploration Drilling Program also undergoes a transactional and probity audit on the co-funding twice a year by an external auditor. The probity audit ensures the selection process is transparent, impartial and defensible for any round. The transactional audit reviews the process and control in the administration of the refund payments for previous rounds made in the previous six months. The external auditor prepares a final report on the transactional and probity results every six months, which is then presented to the DMIRS Internal Audit branch for further oversight.

The program refunds up to 50% of direct drilling costs capped at \$30 000 for genuine prospectors, \$150 000 for multi-hole projects, and \$200 000 for deep single-hole projects.

Figure 7 shows the number of offers made in a financial year and in the number of projects completed. Successful applicants are required to complete the proposed drilling project within 12 months. Final drilling reports with assay results and diamond core, where cored drilling is undertaken, are submitted to DMIRS. Final reports and core are released to open file after a six-month confidentiality period.

From Round 23, the 12-month drilling period was shifted by one month to avoid a round finishing on either a) the end of the financial year or, b) the Christmas – New year period. Going forward the drilling would start on 1 June to 31 May the following year, or 1 December to 30 November the following year.

Planned work program

During 2021–22, drilling from three rounds will be undertaken by exploration companies. These are Rounds 22, 23 and 24.

Other work will include:

- Final closure of Round 21 including receipt of all final reports to WAMEX, issue of final payments and receipt of diamond core if drilled. Applicants have three months after the drilling period ends to complete analytical and scientific data acquisition to allow inclusion in the final report
- Completion of Rounds 22 and 23 drilling periods, including receipt of interim and final reporting requirements
- Release of co-funded drilling reports, not confidential, to DMIRS online WAMEX open-file database
- Call for submissions for applications for Round 24 (August 2021) and Round 25 (February 2022)
- Audits by an external auditor on the probity of the selection process for Rounds 24 and 25 and transactions for the last 12 months
- Summary of 2020–21 co-funded drilling for inclusion in the Geological Survey Annual Review 2020–21.

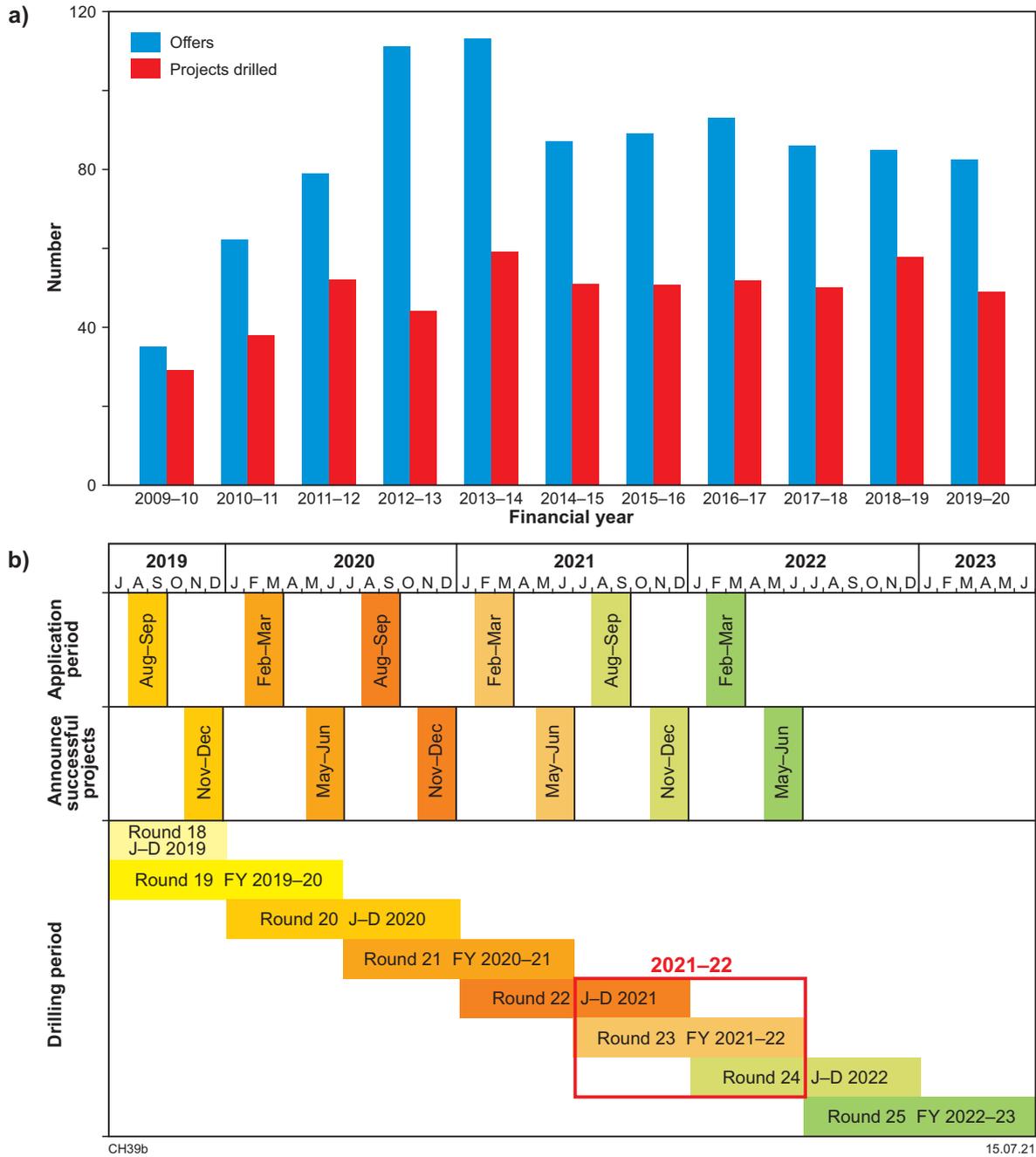


Figure 7. EIS Co-funded Drilling Program statistics. Number of projects offered funding vs project actually drilled, by financial year

ES23 Government–Industry Co-funded Energy Analysis

Manager: Charlotte Hall

Team member: Monique Brouxhon, Louisa Dent

A new co-funding initiative, the Energy Analysis Program (EAP), has been designed to encourage exploration of petroleum and geothermal resources in Western Australia.

The program will make funding available for analysis of existing State resources (core, sidewall core, cuttings, and oil, condensate, water, and gas samples) and to allow re-analysis or reprocessing of existing digital data. By studying existing material, it will avoid the requirement of ground access and allow for completion of a project within 12 months. Analysis of material and data will be limited to that acquired within regions that are under Western Australian legislation, excluding Commonwealth regions (offshore) which are likely to require additional approvals.

The program was developed in the second half of 2020, in response to the State Government COVID-19 recovery plan. It was modelled on the successful co-funded Exploration Drilling Program. A total pool of \$250 000 has been apportioned from the annual EIS funding of \$10 million. Individual project refunds will be up to 50% of the analysis costs to a maximum of \$50 000 (ex GST). The funds will not be for company staff to do the research, but for a third-party expert business that will invoice the successful applicant for the work undertaken. This is similar to the drilling refund, where the third party is the drilling company. In both co-funding programs, the third-party invoices provide auditable documentation that the work has been completed.

The first call for applications was co-incident with Round 23 of the co-funded drilling. This call is referred to as a 'Series' to avoid confusion with 'Round' in the drilling. Series 1 had 12 applications, with eight successful applications announced on 21 April 2021. Find more details, documents, guidelines and schedules for the [EAP](#).

Planned work program

During 2021–22, Series 2 and 3 will open for application on 2 August 2021 and 7 February 2022, respectively. Successful applicants of Series 1 will be required to submit their completed project reports by 30 April for acceptance by 31 May 2022.

Products planned for release

- The first data release of final reports and results from Series 1 are not due until August 2022–23

ES30 Airborne and Ground Geophysical Surveys

Manager: David Howard

Team member: John Brett

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

Western Australia currently boasts complete coverage of the State with medium-resolution aeromagnetic and radiometric surveys (with 200–400 m line-spacing), and 5–8 km wavelength resolution ground and airborne gravity surveys (with 2500 m station or line-spacing). The current focus is on completion of broad-reconnaissance airborne

electromagnetic coverage at a line spacing of 20 km – the AusAEM20–WA program (Fig. 8).

Planned work program

In 2021–22, we will see completion of Stage 1 of AusAEM20–WA that began in 2020–21. SkyTEM surveys over the Southwest and Murchison blocks are expected to be completed by October 2021 to complement the already completed coverage of the eastern blocks surveyed with the TEMPEST system. The remainder of the southern part of Western Australia and the small area in the northern Kimberley will be surveyed in later stages.

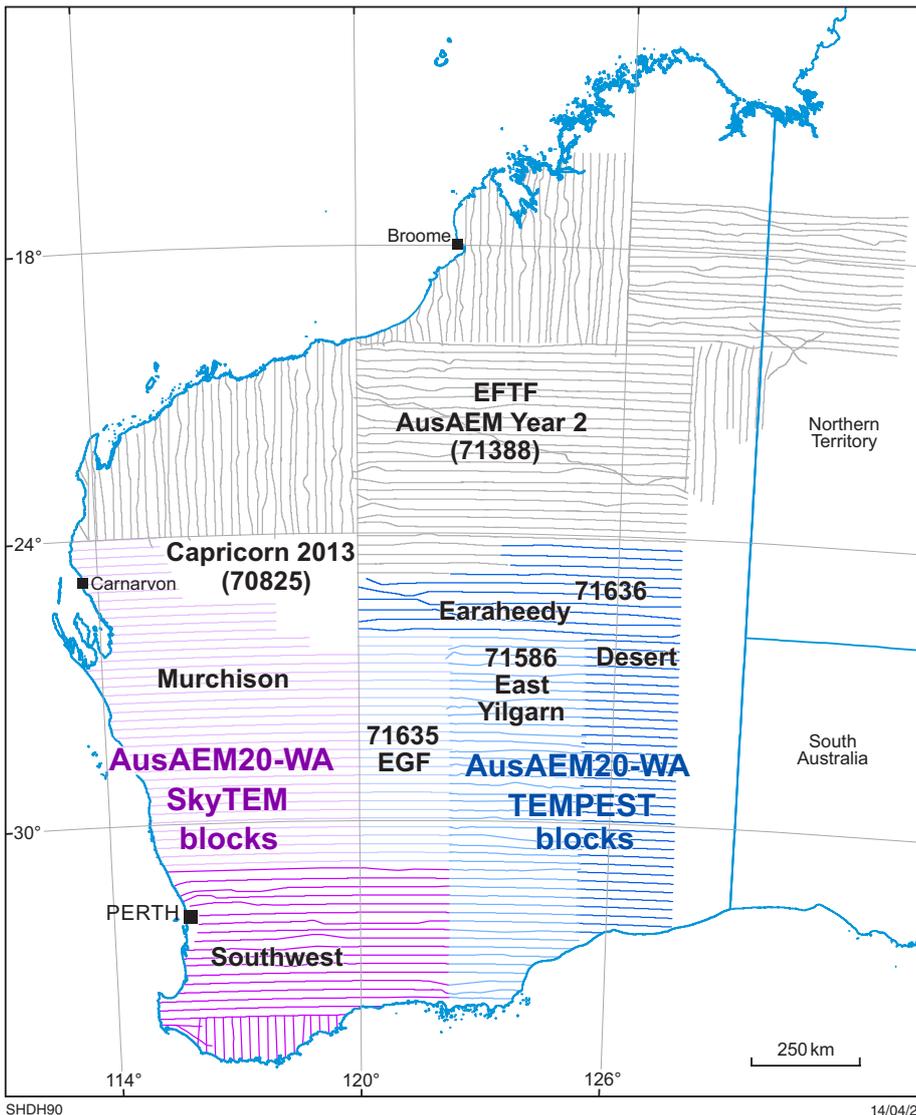


Figure 8. Location of AusAEM20–WA survey areas. Numbers refer to dataset registration numbers in MAGIX data repository

SHDH90

14/04/21

ES31 Active and Passive Seismic, and Magnetotelluric Surveys

Manager: Simon Johnson

Team members: Lucy Brisbout, Richard Chopping, Klaus Gessner, Ruth Murdie

The aim of the Deep Earth Imaging program is to obtain a variety of geophysical data that underpins the understanding of the geological evolution of the lithosphere in Western Australia over some four billion years of Earth's history. The program's objective is to acquire, process, analyse and publish data that allow GSWA to integrate geophysical and geological information across the West Australian, North Australian and South Australian Cratons and the intervening Neoproterozoic and Phanerozoic basins. These data also contribute to understanding the localization of mineral systems within the upper crust. In addition to collaborating with GA on the active source seismic acquisition, GSWA engages with Macquarie University, Australian National University (ANU), UWA and the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS) in the acquisition of passive source seismology and magnetotelluric surveys. GSWA activities that derive from the data acquired and processed in ES31 are also described in the GS62 3D Geoscience and ES42 3D Lithosphere Visualization Project sections.

Planned work program

Passive source seismic and magnetotelluric data from the Eastern Goldfields acquired in a collaborative project with UWA led by Mike Dentith are being finalized. This three-year research project commenced in July 2018 to complement the high-resolution seismic survey in the Eastern Goldfields.

Additional high-resolution magnetotelluric surveys were also completed by Mike Dentith of UWA in the Eastern Goldfields which are currently undergoing data processing.

GSWA is also in the planning stage of coordinating future acquisition of passive source seismic and magnetotelluric data with GA under the Australian Passive Seismic Array project (AusARRAY) and the Australian Lithospheric Architecture Magnetotelluric project (AusLAMP) initiatives. Funds are committed to provide logistical and cultural heritage clearance for acquisition sites in the east of the State.

Australian Research Council (ARC) project LP180101118 Enhanced 3D seismic structure for southwest Australia with ANU, GA and the Department of Fire and Emergency Services (DFES) is currently in the data collection phase which will run until October 2022.

A new passive seismic project in collaboration with Macquarie University, UWA and IGG-CAS will commence in 2021 for two years of field deployment in the Pilbara.

GSWA is working with GA in augmenting the Australian National Seismic Network with the installation of 20 long-term passive seismic monitoring sites spread between the Canning Basin, to look at lithospheric architecture, and in the Eastern Goldfields, to investigate the current stress fields.

ES34 Regolith and 3D Paleosurface Mapping

Manager: Richard Chopping

*Team members: Nadir de Souza Kovacs, Sara Jakica,
Jennifer Porter (MinEx CRC Embedded Researcher)*

This program funds collaborative research with leading research institutions that complement GSWA's capabilities in regolith, surface and landscape mapping, including data acquisition, analysis and modelling under the GS64 Geoscience Mapping Through Cover and ES36 Participation in MinEx CRC projects. In addition to collaborating within the MinEx CRC, GSWA engages with other research institutions such as CSIRO.

The detailed work program is presented under GS64 Geoscience Mapping Through Cover and ES36 Participation in MinEx CRC, with the ES34 Regolith and 3D Paleosurface Mapping Project funding the following collaborative research program:

- Interpreting regolith geochemistry results for the West Arunta region acquired using the CSIRO Ultrafine process.

ES36 MinEx CRC Program 3

Manager: Richard Chopping

Team members: Nadir de Souza Kovacs, David Kelsey, Fawna Korhonen, Sara Jakica, Chris Phillips, Jennifer Porter (MinEx CRC Embedded Researcher)

This program commenced 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. It represents a 10-year investment in the next generation of mineral system discovery research. The CRC, which commenced in January 2019, comprises three programs:

1. Drilling Technologies
2. Data from Drilling
3. The NDI.

GSWA is a participant in Program 3, the NDI and Project 6, automated 3D modelling.

Research in the three programs in MinEx CRC includes:

- Developing more productive, safer and environmentally friendly drilling methods to discover and drill-out deposits, including coiled tubing drilling technology
- Developing new technologies for collecting data while drilling and bringing forward mine production
- Implementing the NDI – a world-first collaboration of geological surveys, researchers and industry that will undertake drilling in underexplored areas of potential mineral wealth in Australia.

Find more information on the [MinEx CRC website](#).

MinEx CRC Program 3

The NDI is designed to maximize the benefits of collaborative work across the geoscience research community, CSIRO, GA and geological survey organizations across Australia. The NDI vision is to drill multiple holes using new technologies developed by the MinEx CRC to map the regional geology and architecture of greenfields regions, and define the potential for mineral systems in 3D. The NDI will generate a large amount of new data and add value to existing data. There are three projects that encompass the NDI:

Project 7 – maximizing the value of data and drilling through cover

Project 8 – geological architecture and evolution

Project 9 – targeting mineral systems in covered terranes.

The aims of **Project 7** are to:

- Develop a web platform and data management system that can operate in near real time
- Develop advanced mineral system data analytics so that the maximum amount of geoscientific information can be extracted from the legacy and NDI drilling programs
- Maximize the efficiency and value of drilling by developing algorithms and tools that can optimize drill program design and provide drill target rankings relative to the key science questions.

This streamlined approach to managing and integrating the many layers of complex drilling data will enable objective analysis and result in significant efficiency gains as well as the ability to modify drilling programs in real time.

The aim of **Project 8** is to provide new pre-competitive geoscience data in the NDI case study areas to increase data confidence and improve geological understanding. An understanding of the relationships between regolith, basin cover and basement, through new knowledge of mineralogy, geochemistry, petrophysics, hydrology and geochronology, will be used to reconstruct landscape evolution through time and to map the depths to key boundaries and cover thickness. Determination and development of the most rigorous methods for characterizing and mapping buried geology will be a key feature, and will enable predictions of buried geology through novel drilling techniques, and by understanding its expression in cover sequences and geophysical data.

The aim of **Project 9** is to develop methodologies to detect and understand the footprints of buried mineral systems using the extensive datasets generated through Project 8. This will involve establishment of a new generation of multiscale (province, district and links to deposit scale) exploration targeting models for selected mineral systems that represent and quantify the spatial variations in architectural/structural, stratigraphic, geophysical, geochemical, mineralogical and isotopic (collectively geological) characteristics of each mineral system type.

Project 9 will provide advice on the most valuable data types, sampling media and densities to map footprints of relevant mineral systems. It will also integrate temporal and spatial geoscientific data for specified regions with existing understanding of ore-forming processes to create maps of mineral potential, using improved knowledge- and data-driven prospectivity mapping techniques, and test exploration targeting models and mineral potential maps by using MinEx CRC drilling technology and research.

Project 6

Project 6 of the MinEx CRC is developing tools to support the automatic creation of 3D models. This project sits within data from the drilling program of the CRC. It aims to develop algorithms and software that enable the integration of drillhole and other data to create first-pass 3D models that are reproducible, provide uncertainty estimates, and draw upon a broad range of datasets. Project 6 is also related to the international [Loop consortium](#).

The NDI in Western Australia

Although resource rich, Western Australia contains much of Australia's most remote and underexplored regions, particularly those that lie under regolith and basin cover. Increasingly, geological surveys will be expected to undertake mapping in covered terranes using drilling technologies. The NDI in Western Australia will focus on how to undertake such mapping programs efficiently and effectively. Focus will be on the region that underlies the Canning Basin, including the Officer and Amadeus Basins, and basement rocks of the Paterson and West Arunta Orogens, the far eastern edge of the Yilgarn Craton (Yamarna Terrane), and the Warri–Anketell Gravity Ridge, which appears to form a link between the Paterson Orogen and Musgrave Province. This area is informally defined as 'The Gap'. This work will align with other project work including GS64 Geoscience Mapping Through Cover, GS65 Proterozoic Margins, GS10 Energy Geoscience and Carbon Strategy and external collaborative projects through the Minerals Research Institute of Western Australia (MRIWA).

Planned work program

Two drilling campaigns will be conducted under the NDI in Western Australia. The first is currently aimed for late 2021 or potentially early 2022 pending field access and access to the coiled-tube drill rig. This first campaign will focus on the eastern margin of the Yilgarn Craton and its undercover extension; the second campaign will focus on another exploration frontier within The Gap. Under the AGP, a Geological Exploration Package (GEP) was compiled for the Eastern Yilgarn providing a solid framework for the drilling campaign. This year, the work program will be made towards logistical planning and implementation of the first drilling campaign and data compilation and mineral systems analysis for The Gap to narrow down possible drilling locations for the second program.

ES38 Proterozoic Margins

Manager: Fawna Korhonen

Team members: David Kelsey, Chris Phillips, Jennifer Porter (MinEx CRC Embedded Researcher)

This program funds collaborative research with leading research institutions that complement GSWA's mapping and analytical capabilities under the GS65 Proterozoic Margins project. In addition to collaborating within the MinEx CRC, GSWA engages with other institutions including Curtin University and CET at UWA.

The detailed work program for the 2021–22 financial year is presented under GS65 Proterozoic Margins with the ES38 Proterozoic Margins project funding the MRIWA M521 project (CET), focusing on basin evolution, geophysical data interpretation and numerical modelling for the Paterson Orogen.

ES39 Petrophysics

Manager: Charlotte Hall

Team member: Lucy Brisbout

Acquisition and dissemination of petrophysics data has been identified as a target in the GSWA Geoscience Strategy 2021–25 and ranks high in the list of focus areas in the Uncover Roadmap. In 2020–21, GSWA initiated pilot projects to acquire a suite of petrophysical measurements on some 3500 samples from selected drillcores in various geological provinces. The measurements were made on samples from drillholes in the Eucla, West Arunta, Paterson, and the Eastern Goldfields areas. The objective of the pilot projects was to assess the 'value proposition' for systematic petrophysical data acquisition as a complement to regional geophysical survey data, and as an input for constraining interpretation models from those data.

Planned work program

In 2021–22, GSWA will conduct an assessment of the process and results of the pilot projects in consideration of a regular ongoing EIS program for the provision of a 'regional petrophysical coverage' of major type-lithologies, alteration patterns, and mineralization styles.

Additional acquisition campaigns may be undertaken in new areas and to expand the coverage of areas already sampled.

Products planned for release

Petrophysical data and reports will be released from work completed in 2020–21 and new work in 2021–22. This will include results from mineralized core through the Kalgoorlie Super Pit, and stratigraphy and nearby core that represents a 'near-miss' through the same stratigraphy.

ES42 3D Lithosphere Visualization Project

Manager: Ruth Murdie

Team members: Lucy Brisbout, Klaus Gessner, Huaiyu Yuan (Macquarie University)

This program funds collaborative research with leading research institutions that complement GSWA's capabilities in data acquisition, analysis, and modelling under the GS53 State Geoscience work program. The emphasis is on 3D visualization, hypothesis testing, numerical modelling and verification using all available datasets. The detailed work program for 2021–22 is presented under GS53, with the ES42 Lithosphere Visualization Project funding the following collaborative research programs:

- ARC project LP170100985 Enabling 3D stochastic geological modelling (3D-LOOP)
- Tectonic evolution of the Canning Basin (IGG-CAS)
- Deep imaging of the Eastern Pilbara (IGG-CAS).

Models being developed include:

- 3D model of the Kalgoorlie region of the Eastern Goldfields
- 3D model of the Yalgoo–Singleton Dome
- 3D model of the Southwest Yilgarn Craton (Fig. 9)
- 3D model of the State of Western Australia
- 3D model of the Capricorn Orogen.

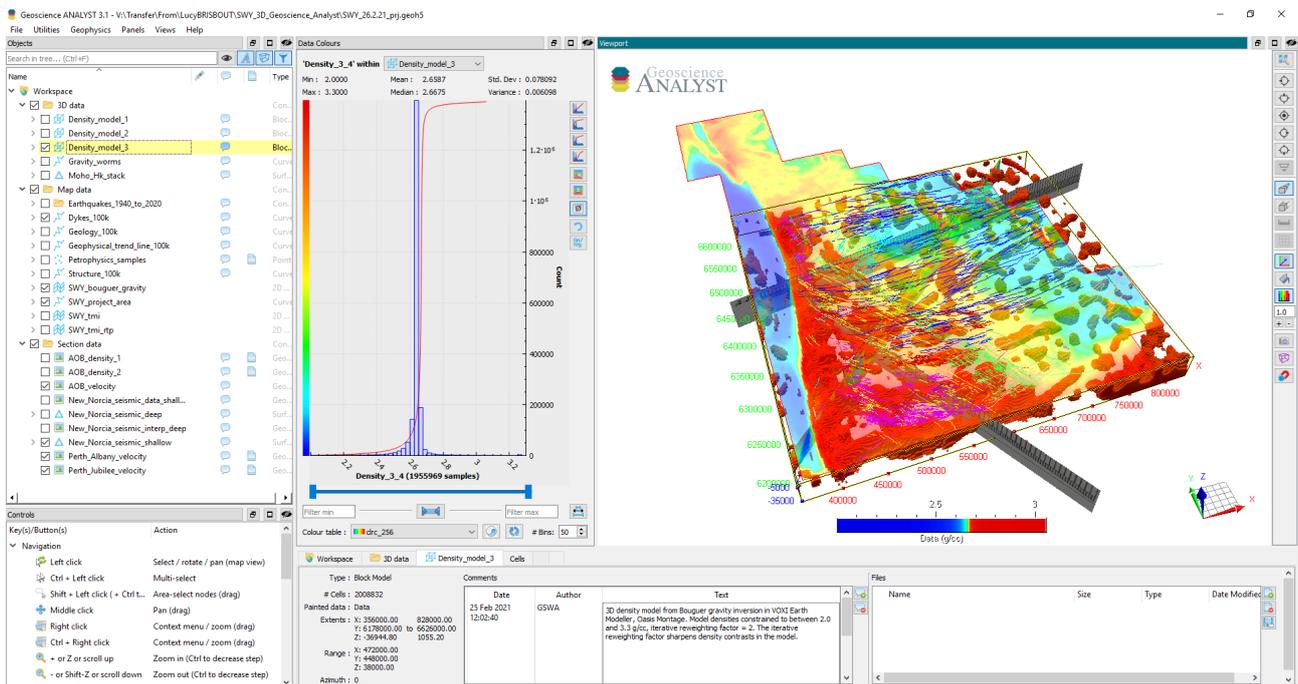


Figure 9. Screenshot of the Southwest Yilgarn 3D geomodel from the Geoscience Analyst Viewer

ES43 Mineral Systems

Manager: Warren Ormsby

Team members: Olga Blay, Paul Duuring, Lena Hancock, Sidy Morin-Ka, Michael Wingate

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

Projects underway or pending completion in 2021–22 include:

- Pilbara gold fingerprinting
- MRIWA M532 – Geology, mineralogy and metallurgy of eMaterial resources in Western Australia (\$50 000 per annum over two years)
- Rare earth resource potential of northern Australia (\$20 000 per annum over three years)
- Critical metals (Li, Ta, Nb, W, REE) in the western Yilgarn Craton (\$100 000 for one year). This project is a component of GSWA's 2020–21 AGP.

Planned work program

The Pilbara gold fingerprinting project aims to characterize the provenance and metallogenesis of gold mineralization across the Pilbara Craton, using morphometry, microstructure, associated minerals and trace element composition of bedrock-hosted and placer gold grains/nuggets. Gold-bearing specimens provided by industry partners are visually inspected, then mounted in resin, cut and polished, and analysed quantitatively for a suite of trace elements using LA-ICP-MS and energy dispersive X-ray spectroscopy (SEM-EDX), and calibrated using certified gold standards. With the assistance of John Watling (TSW Analytical), this project will provide a world-first database of gold trace element chemistry. Results are expected to assist in identifying the type and origin of basement-hosted gold deposits, the sources of paleoplacer gold in Fortescue Group rocks, and an evaluation of the prospectivity of the Pilbara for significant undiscovered gold deposits. This project was substantially delayed in 2020–21 due to COVID-19 related constraints. During 2021–22, the geochemical database will be developed, and the final Report will be published.

GSWA is also sponsoring MRIWA project M532 – Geology, mineralogy and metallurgy of eMaterial resources in Western Australia – in collaboration with Curtin University, Lithium Australia NL, Rio Tinto Limited and AXT Pty Ltd. The project is largely operated by the John de Laeter Centre at Curtin University, and is intended to provide a comprehensive understanding of the geology and mineralogy of Western Australian lithium–caesium–tantalum (LCT) pegmatite-hosted lithium deposits, develop practical geometallurgical models to optimize the sustainable development of these

deposits, and verify the suitability of field portable analytical devices for determining lithium abundance and distribution during exploration.

The project comprises three modules:

1. Classification and geology of LCT pegmatites
2. Mineralogy and deportment of economic and deleterious elements
3. Physical and chemical processing behaviour.

GSWA is collaborating most closely with Module 1, assisting with the development of a database documenting the geological setting of LCT pegmatite mineral systems in Western Australia (age, isotope geodynamics, degree of mineral fractionation, petrological, geochemical variations, post-emplacement histories), and comparing Western Australian eMaterial deposits with global counterparts. The project will be completed by mid-2021 with the report due in 2021–22.

GSWA will also be a collaborator in the ARC Linkage project 'LP190100635 – Realising Australia's rare earth resource potential', with the University of Adelaide, ANU, GA, the Geological Surveys of New South Wales and Queensland, and several REE-focused resource companies. University researchers propose to combine experimental petrology, numerical modelling of lithosphere architecture and magma evolution, and petrological and geochemical studies of prospective or known areas of unconformity-related and peralkaline volcanic REE mineralization across Australia, to develop comprehensive metallogenic models and exploration tools. Case studies will include the Browns Range and John Galt REE deposits in the East Kimberley – West Tanami region of northern Western Australia, and it is with these studies that GSWA will be most closely affiliated. Commencement of this project was delayed until early 2021 due to the pandemic.

In 2019–20, GSWA commissioned CSIRO to re-analyse approximately 3200 laterite samples from the western Yilgarn Craton using modern analytical techniques to determine Li and several other critical metals (i.e. Sn, W, REE) that could not be reliably measured in previous analytical campaigns using older technologies. The study combines conventional geochemical analysis, indicator mineral chemistry, and studies of regolith characteristics and deportment of critical metals in primary critical mineral deposits. The intent is to understand the formation of critical metal anomalies in the regolith, and their significance as indicators of the size and quality of potential underlying mineralization, hence assess critical metal potential value in the region, and provide a tool that might be applied to critical metals exploration at the regional scale. The results of this study are now anticipated to be made available in 2021–22.

Products planned for release

- Pilbara gold fingerprinting study (Report)
- Cobranded GSWA–MRIWA Report for Project M532
- Other results from the REE (ARC Linkage) and LCT pegmatite (MRIWA) projects will be published in external publications
- Western Yilgarn laterite geochemistry database, including element abundance maps; joint CSIRO–GSWA Report describing the results of the Western Yilgarn laterite geochemistry study

ES46 Enhanced Geochronology and Isotopic Mapping

Manager: Michael Wingate

Team members: Sarah Gain, Imogen Fielding, Dominique Harmer, Frances James, Yongjun Lu, Marlene Papiccio, Sandra Romano, Tom Scillieri, John Williams

This project complements GSWA's geochronology studies (see GS54) with the addition of Lu–Hf and oxygen isotope and trace element analysis of zircons, Sm–Nd isotope analysis of whole-rock samples, and additional isotope-related techniques (such as whole-rock Lu–Hf and Pb isotopes) conducted in collaboration with university research groups.

Variations in radiogenic isotope compositions (mainly Sm–Nd and Lu–Hf) provide information on the nature of the sources of magmatic rocks, allowing magmatic rocks derived from the mantle to be distinguished from those derived by reworking of older crust. Knowledge of crustal evolution is also important for understanding mineralization because the addition of juvenile material from the mantle into the crust is commonly associated with mineralizing events. Stable isotopes, mainly oxygen, are used to distinguish material derived from near-surface or supracrustal environments from mantle-derived material. These techniques enable the 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.

Three new statewide isotope map layers, Sm–Nd, zircon Lu–Hf, and zircon oxygen, are available via GeoVIEW.WA and the Data and Software Centre. Isotope maps play an increasingly important role in exploration targeting at regional scales, and we expect them to generate significant interest from explorers in 2021–22. The layers will be maintained with addition of new data as they become available. Another new map layer is the McNaughton Legacy SHRIMP Mount Collection. GSWA was a supporting partner, with the John de Laeter Centre, AuScope, Australian Research Data Commons (ARDC) and UWA, in a 2018–20 project to secure, digitize and make publicly available 25 years' worth of geochronology sample materials and associated data records in the McNaughton Legacy SHRIMP Mount Collection. GSWA is the custodian of physical specimens which are available to the research community and public.

The ES46 project also includes measurement of whole-rock geochemical and zircon and apatite trace element compositions of granitic rocks in Western Australia, to understand water content, pressure, temperature and oxidation state of magmas, all of which control magma fertility for ore formation and can be used as exploration indicators in remote or covered terrains.

The ES46 project is funding the work for GS54. Accordingly, the work program for GS54 is included below. Most analytical work under ES46 and GS54 is conducted at the

John de Laeter Centre at Curtin University, the Centre for Microscopy, Characterisation and Analysis (CMCA) at UWA, and by several other university laboratories.

Planned work program

The GS54 program will generate U–Pb zircon, baddeleyite and monazite ages in support of GSWA geoscience programs across Western Australia. The timely release of geochronology results will be maintained, through both rapid, brief, in-house reports and the Geochronology Record series, published online via GeoVIEW.WA, eBookshop and the Data and Software Centre. The laboratory will process samples for geochronology, whole-rock geochemistry and isotope geochemistry as required by GSWA geoscience programs. The Greenstone Geochemical Barcoding Project (ES49) is the largest single user of whole-rock geochemistry, with >1000 samples analysed each year.

The ES46 program will continue analyses of Lu–Hf, Sm–Nd, and oxygen isotopes in 2021–22. Isotope data generated by this program will be checked for accuracy and consistency, provided to GSWA projects, and used to update statewide isotope maps available in GeoVIEW.WA (Fig. 10). The results will be integrated with geological and geochemical data and gravity, aeromagnetic, seismic and magnetotelluric datasets, to advance our understanding of crustal architecture, geological evolution and mineralization. Syntheses will be published as Reports or Records and will inform other GSWA and external publications.

A three-year ARC Linkage project 'New tools for old rocks: first cycle provenance information' is continuing and will enhance stratigraphic understanding of sedimentary sequences through novel provenance fingerprinting using K-feldspar (Pb isotopes) and apatite (U–Pb, Sr isotopes and grain chemistry). This statewide project already involves case studies in the Pilbara and Yilgarn Cratons and the Canning and Northern Carnarvon Basins.

GSWA contributed to the recent success of an ARC Large Infrastructure and Equipment Fund (LIEF) grant to establish facilities at Curtin and Melbourne Universities that incorporate next-generation, multicollector mass spectrometers and ultraclean gas line systems, capable of revolutionizing $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. The installation at Curtin will be optimized to analyse ultrasmall and potassium-poor samples, such as tiny inclusions in ore minerals and feldspars and pyroxenes in mafic igneous rocks, which cannot be dated by other methods.

GSWA is an ongoing participant in the NCRIS-sponsored AuScope National Argon Map (NAM) program, which aims to

generate an open-source locational $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology database for the Australian crust to support resource exploration and increase our geological understanding of the Australian continent. GSWA has already submitted samples and nominated a wide variety of additional samples for analysis under this program.

Development of a new geochronology, isotopes, mineral chemistry and metamorphic history database application (WAGIMS) is continuing. The application will organize and deliver geochronology, isotope and mineral chemistry, and metamorphism data. New Geochronology Records will be produced 'on-the-fly', together with the most up-to-date geological context information, by a module in the Explanatory Notes System (ENS) within GeoVIEW.WA. The WAGIMS database will also facilitate publication of 'external' geochronology data, via a dedicated layer in GeoVIEW.WA.

Products planned for release

- Geochronology Records and U–Pb datasets released to online applications (GeoVIEW.WA)
- Whole-rock geochemistry analyses released to online applications (GeoChem Extract and GeoVIEW.WA)
- Sm–Nd, Lu–Hf and oxygen isotope datasets released to online applications (GeoVIEW.WA)
- Mineral chemistry datasets released to online applications (GeoVIEW.WA)
- New isotopic constraints on the crustal architecture of basement beneath the Canning Basin (Report)
- Geochronology of metasedimentary and igneous rocks in the Lamboo Province, Kimberley region: re-assessing collisional geodynamic models (Report)

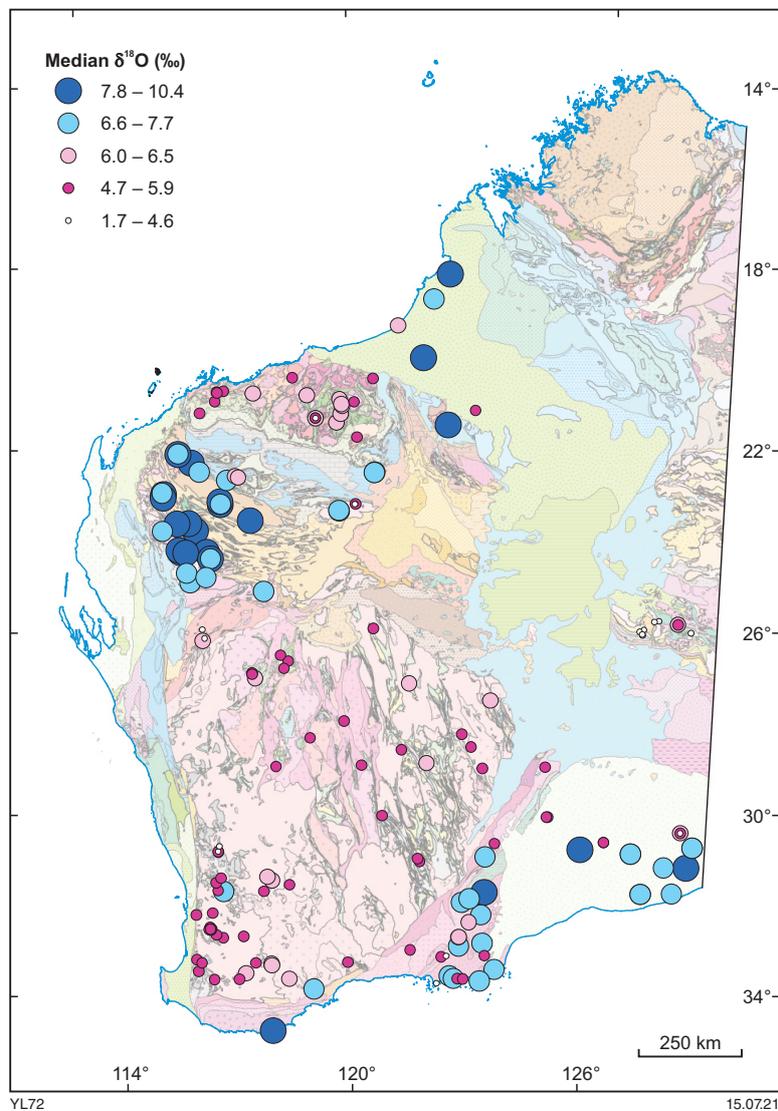


Figure 10. Zircon oxygen isotope map for igneous rocks in Western Australia. Median $\delta^{18}\text{O}$ values of primary magmatic zircons from each igneous rock sample are presented on top of the 1:2 500 000 interpreted bedrock geology map

ES47 Petroleum Systems

Manager: Deidre Brooks

Team members: Norman Alavi, Richard Bruce, Louisa Dent, Ameer Ghori, Peter Haines, Arthur Mory, Leon Normore, Charmaine Thomas, Yijie (Alex) Zhan

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 several distinct subprograms.

During 2019–20, an EIS-funded project to assess the parameters influencing reservoir quality in the Permian sandstones of the northern Perth Basin was finalized and included ichnology, XRD, petrography, HyLogger spectral analysis, influence of temperature and depositional environment on distribution of clays and detailed core logging. The results have been incorporated into a Report which was released in 2020–21.

Geophysical projects that continue from the previous financial year into 2021–22 incorporate pre-competitive data which was funded through the EIS in 2018. These projects aim to improve the structural and stratigraphic definition of the Canning, Perth and Carnarvon Basins and include:

- Seismic interpretation of Kidson Sub-basin and Crossland Platform, using the EIS co-funded acquisition of the Kidson Seismic Survey and EIS-funded, reprocessed 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and northwestern Canning Basin
- Seismic interpretation of the Southern Carnarvon and northern Perth Basins, using EIS-funded, newly reprocessed 2D seismic lines in the Southern Carnarvon Basin and the Coolcalalaya Sub-basin of the northern Perth Basin, and incorporating results from the EIS-funded Carnarvon Basin SEEBASE product.

Following the Kidson Sub-basin seismic acquisition, stratigraphic drilling of Barnicarndy 1 was undertaken in late 2019 in the western Canning Basin. This is located on the new seismic line and will improve understanding of the stratigraphy and petroleum potential of the Barnicarndy Graben and the underlying basement. The drilling costs were not funded by the EIS; however, the post-well analysis for Barnicarndy 1 was largely performed in 2020–21 and was funded by the EIS. These analyses results will be incorporated into the Barnicarndy 1 Digital Core Atlas and will include CA-ID TIMS geochronology, ichnology, sequence stratigraphy, chemostratigraphy, image log analysis, organic and inorganic geochemistry, seal capacity, biostratigraphy, reservoir analysis, core gamma, HyLogger image and spectral data. A Record comparing the velocity data from Barnicarndy 1 and the resulting synthetic seismic trace to tie to the Kidson Sub-basin Seismic Survey will be published in 2021–22.

Planned work program

EIS-funded regional geological and geophysical studies for the Canning, Perth and Carnarvon Basins will continue.

Canning Basin

The planned studies in the Canning Basin are to:

- Incorporate the results of the interpretation of the new 2D regional deep crustal seismic line across the Kidson Sub-basin into a regional mapping project
- Continue interpreting the 2018 EIS-funded newly reprocessed 2D seismic lines in the Kidson Sub-basin, Cobb Embayment and the northwest portion of the Canning Basin
- Compile the Barnicarndy 1 Digital Core Atlas.

Southern Carnarvon Basin

Planned studies in the northern Perth and Southern Carnarvon Basin include continuation of interpretation of the 2018 EIS-funded, reprocessed 2D seismic lines and to incorporate the results, along with the 2018 EIS-funded Carnarvon SEEBASE product, into a wider interpretation project to improve the definition of the stratigraphy and structure of the basins. The results of this project will be included as new pre-competitive data supporting future acreage releases.

Products planned for release

- Barnicarndy 1 Digital Core Atlas (digital product)
- Geophysical analysis of Barnicarndy 1: velocity, out-of-plane, and seismic correlation (Record)

ES49 Greenstone Geochemical Barcoding Project

Manager: Hugh Smithies

Team members: Lauren Grech, Jack Lowrey

The Greenstone Geochemical Barcoding Project (Fig. 11) is an initiative under the EIS that aims to geochemically characterize greenstone stratigraphy throughout the EGST. This project will continue to substantially increase the amount of high-quality, multi-element, geochemical data for greenstones, targeting available diamond drillcores that sample the most geologically well-constrained, or best-understood, parts of various greenstone belts. Extensive sampling has already been undertaken in the Kalgoorlie–Kambalda region, as well as in several other smaller regions throughout the EGST, and will ultimately extend throughout the EGST. Through detailed geochemical sampling of diamond drillcore, we hope to establish a geochemical ‘barcode’ of the stratigraphy (including local variations) in these better-known sections of greenstone belts. The ultimate goals of this project are to:

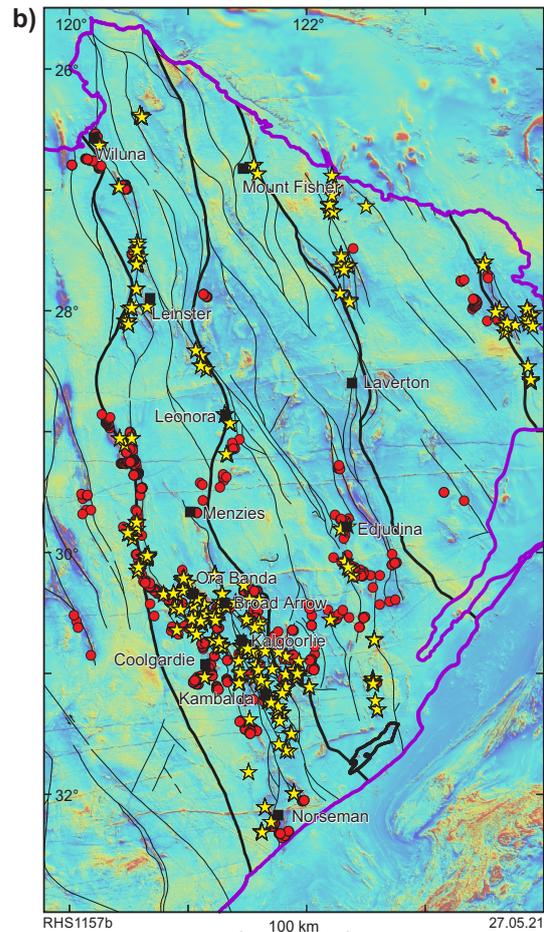
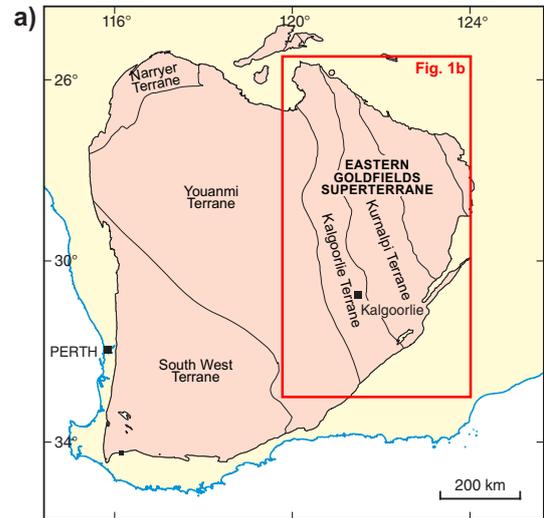
- Establish whether local and/or regional greenstone stratigraphies are geologically valid, and understand the geological reasons for any local and regional stratigraphic variations
- Provide a reasonable geochemical proxy for stratigraphy that will allow users to better establish where a particular lithology or lithological association fits in a local or regional stratigraphy
- Provide a data-rich, high-quality geochemical dataset regionally representative of all magmatic rock types that will help develop our understanding of petrogenetic processes in greenstone evolution and associated mineralization.

Planned work program

Work within this project will concentrate in the southern and eastern parts of the EGST, but also support other regional Yilgarn Craton geoscience programs.

Products planned for release

- Greenstone Geochemical Barcoding project data release (Record)
- Eastern Goldfields greenstone geochemical barcoding project: geochemical characterization of igneous units from the Ora Banda – Kambalda region (Report)



- Geochemistry site
- Diamond drillhole site
- Town
- Fault
- Terrane boundary
- Yilgarn Craton

Figure 11. Eastern Goldfields greenstone geochemical barcoding project area overview and sample localities

ES50 Strategic Industry Research Program

Manager: Charlotte Hall

Team members: MRIWA

This program supports the Minerals Research Institute of Western Australia (MRIWA) under the MRIWA project theme of **Find more viable resources**. Under a 2019 MoU, the EIS contributes \$350 000 per annum. The selection of projects submitted under the theme to receive support is at the discretion of the MRIWA board. This funding is in addition to projects where GSWA is a partner in a project such as M0554 and M0470a.

All projects sponsored under **Find more viable resources** can be found on the [MRIWA website](#).



ES51 Yilgarn Granite Project

Manager: Hugh Smithies

Team members: Dominique Harmer, Jack Lowrey

The Yilgarn Granite Project (Fig. 12) is an initiative under the EIS that aims to provide complete and detailed coverage of the Yilgarn Craton in terms of modern, high-quality, major- and trace element data (including Li) on granitic rocks, and at the same time, expand the coverage of whole-rock Sm–Nd isotope data. We hope also to identify, within this new dataset, potential proxies for crustal source composition, melting conditions and for fertility in terms of producing precious and strategic mineral deposits. An extension of this project will involve the trace element and isotopic study of apatite crystals from samples of ‘mafic’ granites (sanukitoids) and lamprophyric rocks from across the craton to identify regional compositional variation in lithospheric source regions (i.e. map the lithospheric mantle). The project will provide interpretation (digital data, GIS layers,

Reports) that attempts to place these data within the context of crustal-scale structure, source regions and economic mineral fertility.

Planned work program

Work within this project will concentrate on re-analysing about 3000 granite samples collected by and currently archived with GA and then the re-analysis of legacy samples from GSWA.

Product planned for release

- Yilgarn Granite Project data release (Record)

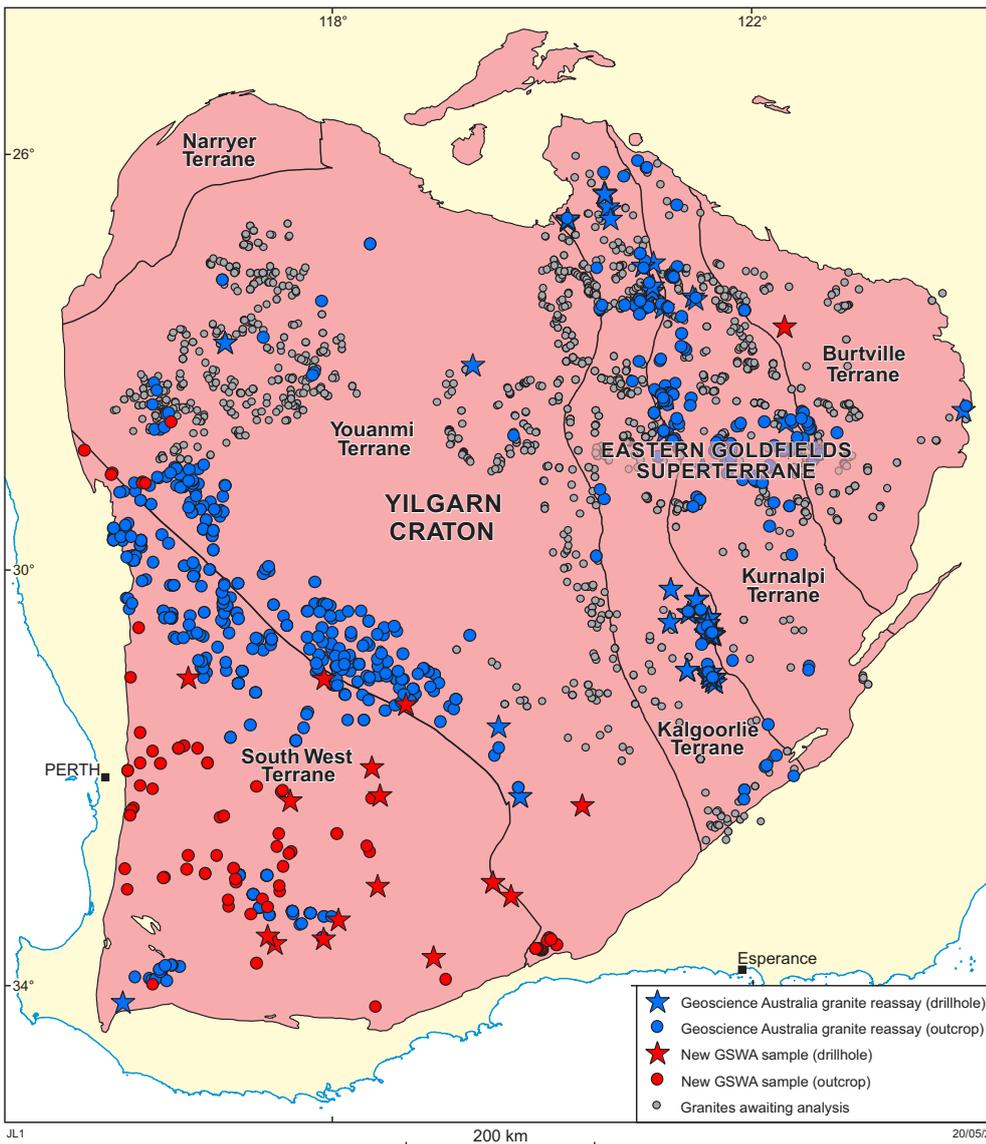


Figure 12. Yilgarn Granite Project area overview and sample localities

ES53 Core Scanning and Machine Learning

Managers: Hugh Smithies, Richard Chopping

Team members: ad hoc as required

This program commenced in 2020–21 to understand, enhance and promote the role of machine learning or other data analytical techniques in providing additional and detailed geological context around GSWA-managed drill samples, e.g. from EIS core (Fig. 13). This work is to assist with the ES49 Greenstone Geochemical Barcoding Project and would integrate new, non-destructive analyses with more traditional geochemical analyses through the use of modern data analytical techniques.

Planned work program

Pending funding, the work program of this project is to acquire non-destructive geochemical analyses on core from a key mineralized region such as the Eastern Goldfields.

Products planned for release

No products are planned for release in 2021–22.



Figure 13. The HyLogger spectral scanner

SPECIAL PROJECTS

TF70 Hydrogen Storage Potential of Depleted Oil and Gas Fields

Managers: Deidre Brooks, Sunil Varma

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

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

The proposal is to take a two-stage approach. Stage 1 is a literature review and scoping study to take no more than three months between 1 June and 31 August 2021. Stage 2 consists of 3D static and dynamic compositional modelling of selected depleted oil and gas fields for storage capacity estimation, containment and contamination risks. Stage 2 is expected to commence in September 2021 and take between 12 and 18 months to complete.

The main outcomes/products of the project will be:

- 3D models for public release (through WAPIMS) to aid in future hydrogen storage projects

- Publication of the results as GSWA Record(s)/Report(s)
- External presentations and publications, as appropriate
- Discussion of options for further work
- Standalone reports on Stages 1 and 2
- Integrated final report (Stage 2).

Planned work program

The literature review will be conducted on the geological underground storage of hydrogen in depleted oil and gas fields and saline aquifers, and other examples of underground geological storage of hydrogen. The scoping study will review depleted fields in the northern Perth Basin and onshore Carnarvon Basin within Western Australia to identify which fields should be modelled in Stage 2 of the project. A report will be written detailing the findings from the review of literature and include technical advice derived from the scoping study to assist in planning the Stage 2 (modelling) part of the project.

Stage 2 will commence when Stage 1 is completed and will extend into 2022–23.

Products planned for release

- Report or Record on the results of Stage 1 (literature review and scoping study)

APPENDIX

GSWA active collaborative research projects

ARC collaborative agreements



ARC Centre of Excellence for Core to Crust Fluid Systems — CE11E0070

Project manager: Suzanne O'Reilly (Macquarie University)

Partner researchers/institutions: Simon Wilde (Curtin University), Campbell McCuaig (CET, UWA), Chris Kirkland (CET, Curtin), Huaiyu Yuan (Macquarie University, CET)

GSWA contacts: Simon Johnson, Klaus Gessner, Michael Wingate

Duration of project: 2011–17 (extended to 2025)

Project description

A world-leading **Centre of Excellence** driving innovative interdisciplinary research towards a new understanding of Earth's origins, fluid budgets and evolution, and delivering outcomes of tangible benefit to society.

GSWA sponsored projects

- 3D crustal architecture of Western Australia
- Zircon Lu–Hf constraints on Precambrian crustal evolution in Western Australia

Outputs — planned or actual

- Co-branded GSWA Reports and international journal papers; GSWA geochronology records

ARC Discovery project DP200101104 — Deciphering the tectonic record of the early Earth

Project manager: Fawna Korhonen

Partner researchers/institutions: Curtin University

GSWA contacts: Fawna Korhonen, Simon Johnson

Duration of project: 2020–25 (delayed due to COVID-19) commencing in 2021

Project description

This project aims to decipher how and why plate tectonics emerged, and how any precursor tectonic system modulated planetary heat loss. The project expects to generate new knowledge regarding the tectonic record of the early Earth using pressure–temperature–age constraints from truly ancient (2.8 – 4.0 billion years old) metamorphosed rocks in the Pilbara Craton and the Narryer Terrane, as well as other localities worldwide. Expected outcomes of this collaborative international project include the development of a conceptual geodynamic model for the early Earth. This should provide significant benefits in permitting a better understanding of the where and why of Australia's natural resources, in training a new generation of Earth system scientists, and in broadening public awareness of fundamental Earth science.

Outputs — planned or actual

- Metamorphic History Records for each metamorphic sample (once these are published)

ARC Linkage project LP130100722 — Earth's best-preserved Archean boninites: do they finally resolve the Archean mantle plume–plate controversy?**Project manager:** Derek Wyman (University of Sydney)**Partner researchers/institutions:** Jack Lowrey (PhD candidate, University of Sydney / GSWA)**GWSA contact:** Tim Ivanic**Duration of project:** 2014–18 (extended to 2021)**Project description**

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

Outputs — planned or actual

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

**ARC Linkage project LP170100985 — Enabling 3D stochastic geological modelling (LOOP)****Project manager:** Klaus Gessner**Partner researchers/institutions:** Monash University**GWSA contact:** Klaus Gessner**Duration of project:** 2018–22**Project description**

We will develop a new open-source 3D implicit geostructural simulator and modelling platform that will address the entire 3D geological modelling workflow, from guiding efficient observations and field sampling to the production of a series of consistent 3D geological models with uncertainty assessment and characterization.

Outputs — planned or actual

- Open-source 3D geological simulator and modelling software package

**ARC Linkage project LP180100199 — New tools for old rocks: first cycle provenance information****Project managers:** Simon Johnson, Michael Wingate and Hugh Smithies**Partner researchers/institutions:** Chris Kirkland (Curtin University)**GWSA contact:** Simon Johnson, Hugh Smithies**Duration of project:** 2020–23**Project description**

The aim of this research is to enhance stratigraphic understanding of sedimentary sequences in Western Australia through application of novel provenance fingerprinting tools in K-feldspar (Pb isotopes) and apatite (U–Pb, Sr isotopes and mineral chemistry). While much stratigraphic characterization has been based on detrital zircon ages and their correlation to basement sources, two major limitations are apparent:

a) zircon may be multicycle, blurring source–sink relationships; b) zircon may be absent in mafic lithologies thus biasing investigations.

In this work, K-feldspar and apatite provenance investigation will be undertaken on a statewide basis and include case studies in the Yilgarn Craton and Canning and northern Carnarvon Basins.

Outputs — planned or actual

- Johnson, SP, Kirkland, CL, Evans, NJ, McDonald, BJ and Cutten, HN 2018, The complexity of sediment recycling as revealed by common Pb isotopes in K-feldspar: *Geoscience Frontiers*, v. 9, p. 1515–1527, doi:10.1016/j.gsf.2018.03.009.

- Numerous high-quality, open-access journal articles at various stages throughout the project, some probably published six months to one year after project end



ARC Linkage project LP180101118 — Enhanced 3D seismic structure for southwest Australia (SWAN)

Project manager: Klaus Gessner

Partner researchers/institutions: ANU, GA, DFES

GSWA contact: Klaus Gessner

Duration of project: 2020–23 (delayed and extended for additional six months due to COVID-19)

Project description

The objective of this work is to delineate the 3D structure of the crust and lithosphere located in the southwestern part of Western Australia, using a full range of seismic imaging techniques.

Outputs — planned or actual

- External publications, Report

ARC Linkage project LP190100146 — Evolution of Proterozoic multistage rift basins – key to mineral systems

Project manager: Mark Jessell (UWA)

Partner researchers/institutions: UWA, Monash, University of Sydney, CSIRO, Independence NL, BHP Billiton, Anglo American PLC, MRIWA

GSWA contact: Klaus Gessner

Duration of project: 2020–24 (four years from signed agreement)

Project description

This project will deliver a new quantitative and integrated exploratory framework for the mineral industry in Australia's frontier sedimentary basins by integrating the latest advances in laboratory experimental tectonics with thermo-mechanical numerical, surface process and geophysical modelling. The project will use northern Australian basins as a natural laboratory to address the fundamental processes involved in the development of sedimentary ore systems. The project will investigate how they can be detected by modern exploration techniques using a multidisciplinary approach with a team of experts with backgrounds in mineral and petroleum systems.



ARC Linkage project LP190100635 — Rare earth resources of northern Australia

Project manager: Trevor Beardsmore

Partner researchers/institutions: Adelaide University, GA, GSNSW, GSQ, resource companies

GSWA contacts: Trevor Beardsmore, Sidy Morin-Ka

Duration of project: 2020–22

Project description

Combine experimental petrology, numerical modelling of lithosphere architecture and magma evolution, and petrological and geochemical studies of prospective or known areas of unconformity-related and peralkaline volcanic REE mineralization across northern Australia, to develop comprehensive metallogenic models and exploration tools. Case studies will include the Browns Range and John Galt REE deposits in the East Kimberley – West Tanami region of northern Western Australia. It is with these studies that GSWA will be most closely affiliated.

Outputs — planned or actual

- External publications

ARC Grant (DP200103208) — Testing continental growth models with calcium and strontium isotopes**Project manager:** Tony Kemp (Chief Investigator, UWA)**Partner researchers/institutions:** Simon Wilde (Curtin University), Martin Van Kranendonk, (UNSW), Tim Elliott (University of Bristol), Matilda Boyce (PhD candidate)**GSWA contact:** Tim Ivanic (co-supervisor to PhD)**Duration of project:** 2020–22**Project description**

Testing the relationship between atmospheric and magmatic records in Ca and Sr isotopes during Mesoarchean crustal growth. Fresh plagioclase and calcite will be collected from the best preserved Eo-mesoarchean layered mafic intrusions and stromatolites to provide a window into the crust–mantle–atmosphere system in early Earth history.

Outputs – planned or actual

- Journal articles

***ARC Grant (LP190100635) — Realising Australia's rare earth resource potential*****Project manager:** A/Prof Carl Spandler (University of Adelaide)**Partner researchers/institutions:** A/Prof John Mavrogenes (ANU), Dr Rhodri Davies (ANU), Dr Teresa Ubide (UQ), Dr David Huston (GA), Prof Nicholas Rawlinson (U of Cambridge), Dr Phillip Blevin (GSNSWA), Dr Helen Degeling (GSQ), Mr Robin Wilson (Northern Minerals Ltd)**GSWA contact:** Sidy Morin-Ka**Duration of project:** 2020–23**Project description**

This project aims to reveal the potential for undiscovered economic deposits of rare earth elements within the Australian continent. Future supply of these elements underpins society's transition to clean energy and embracing of high-tech applications. The project expects to greatly enhance our knowledge of Australia's endowment of rare earth element resources using an array of traditional and innovative geological research methods. Expected outcomes of this project include a greater understanding of how, where and when rare earth element orebodies form in the Earth's crust. This should provide significant benefits to exploring for – and discovering – new orebodies that are required to secure global critical metal supplies.

Outputs – planned or actual

- Journal articles

MinEx collaborative agreements



MinEx CRC Program 3: National Drilling Initiative (NDI)

Project manager: Richard Chopping

Partner researchers/institutions: Multicollaborative project

GSWA contact: Richard Chopping

Duration of project: 2018–28

Project description

MinEx CRC will create new opportunities for mineral discovery by delivering more productive, safer and environmentally friendly drilling methods and new technologies for collecting data while drilling, and exploration data on never-before-sampled rocks that are hidden but prospective for minerals. A key component of this CRC is the NDI, linking state and federal geological surveys with researchers in drilling and deriving meaning from data to develop new methodologies to map under cover. The NDI will focus on drilling in each partner state, and will conduct three major research streams:

- Project 7: Maximizing the value of data and drilling through cover
- Project 8: Geological architecture and evolution
- Project 9: Targeting mineral systems in covered terranes.

The GSWA involvement in MinEx CRC includes additional involvement in Project 6 (discussed below). GSWA will house an embedded researcher from the University of South Australia in 2019–22 who will contribute to this research.

Outputs – planned or actual

- Compilation of geoscientific data for ‘The Gap’ region (Paterson Orogen – Canning Basin – west Arunta Orogen – west Musgrave Province)
- New geological, geochemical, geochronological and petrophysical samples/data obtained through MinEx CRC drilling techniques

MinEx CRC Project 6 — Automated 3D Geology Modelling

Project manager: Mark Jessell (UWA)

Partner researchers/institutions: Mark Lindsay (Supervisory), Raneer Joshi (PhD candidate) / UWA

GSWA contact: Tim Ivanic (co-supervisor to PhD)

Duration of project: 2019–22

Project description

Integrate multiscale datasets into one model wherein data could be subsampled and dynamically visualized in a particular scale optimal for solving multiple multiscale geologic problems. To answer this, existing subsampling methodologies are tested against different types, dimension and resolution of geological data. The specific aim of building a multiscale model in the Yalgoo–Singleton area is to combine multiscale datasets to take advantage of the full value of the data available and provide new knowledge of the stratigraphy, crustal architecture and underlying geodynamic process that may have led to today’s 3D geometry of the region. Since the modelling will be performed as an iterative process, we expect to find new geologic indications, point to areas that need more detailed modelling or data and raise new geological questions as the model is upscaled and downscaled. The type of data considered in this research focuses on lithological, structural and geophysical vector and grid data with publicly available data from GSWA to emphasize maximizing available pre-competitive datasets and consequentially assess the ease-of-access of the existing data formats.

Outputs – planned or actual

- Joshi, R, Lindsay, M and Jessell, M 2019, Multiscale 3D Geological Model of the Yalgoo-Greenstone Belt Area through Subsampling of Stratigraphic Vector Maps, Oral presentation at SGTSG Biennial Meeting, Port Lincoln, South Australia, 22 November 2019.
- Joshi, R, Jessell, M and Lindsay, M 2019, Going Multiscale and Estimating Uncertainty on 3D Geological Models, Oral presentation at GeoCon 2019: Geoscience for a resilient and sustainable Philippines, Manila, Philippines, 4–5 December 2019.

MRIWA collaborative agreements



MRIWA project M470a — A multiscale approach to controls on mineralization in the Fraser Zone, Western Australia

Project managers: Katy Evans, Chris Kirkland (Curtin University)

Partner researchers/institutions: MRIWA, Independence Group NL, MG Creasy, Curtin University

GSA contact: Raphael Quentin de Gromard

Duration of project: Originally 2020–23 but was put on hold because of the delayed arrival of PhD students in Australia due to COVID-19 travel restrictions. Project has resumed in 2021 and is extended to 2024.

Project description

This program of research will focus on the partially covered and highly prospective Fraser Zone, Western Australia.

The project will consist of four modules:

1. Architecture and stratigraphy: cutting-edge split stream LA-ICP-MS instrumentation and new mineral isotope systems will produce a reliable chronostratigraphic and tectonothermal framework, in the context of a well-constrained lithospheric architecture.
2. The tectonothermal evolution of the Fraser Zone: application of new thermodynamic models with high-resolution, high-throughput, element maps of mineralized and unmineralized samples to quantify variations in pressure, temperature, time and space in the Fraser Zone.
3. Controls on tenor: process-based conceptual models of crust–magma–fluid interactions based on detailed site data from our partner organizations. A data science approach will be necessary to optimize information from the large existing datasets. The outputs will be a quantitative understanding of the processes that control the grade of mineralization, and tools to recognize the presence of mineralization from indirect evidence.
4. Regolith from the Silver Knight deposit will be used to develop a gossan/alteration model for the Fraser Zone deposits with predictive capacity.

This MRIWA-funded research program will build on existing investment by GSA and Western Australia's research institutions to provide an exceptional value proposal.



MRIWA project M521 — Lithospheric and crustal-scale controls on multistage basin evolution: impacts on mineralizing systems

Project managers: Weronika Gorczyk, Mark Jessell (CET, UWA)

Partner researchers/institutions: MRIWA (UWA/First Quantum Minerals / Fortescue Metals Group)

GSA contact: David Kelsey

Duration of project: 2018–22

Project description

This project will use an integrated basin studies approach, combining interpretation of multiple regional datasets (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.

Outputs — planned or actual

- The project will produce six-monthly reports and comprehensive MRIWA reports



MRIWA project M532 — Geology, mineralogy and metallurgy of eMaterial resources in Western Australia

Project manager: Trevor Beardsmore

Partner researchers/institutions: John de Laeter Centre, Curtin University; AXT Pty Ltd

GSWA contact: Trevor Beardsmore

Duration of project: 2020–23

Project description

To develop a geometallurgical framework for Western Australian lithium pegmatite deposits that will lead to improved efficiencies in exploration, mineral beneficiation and processing techniques.

Outputs — planned or actual

- External publications, Report

Other collaborative agreements



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

Project manager: Trevor Beardsmore

Partner researchers/institutions: CSIRO

GSWA contacts: Trevor Beardsmore, Paul Duuring

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

Project description

CSIRO will re-analyse approximately 3200 laterite samples from the western Yilgarn Craton using modern analytical techniques, to determine lithium and several other critical metals (i.e. tin, tungsten and REE) that could not be reliably measured in previous analytical campaigns using older technologies. The study will combine conventional geochemical analysis with the UltraFine+ methodology, indicator mineral chemistry, and studies of regolith characteristics and deportment of critical metals in primary critical mineral deposits. The intent is to understand the formation of critical metal anomalies in the regolith, and their significance as indicators of the size and quality of potential underlying mineralization, hence assess critical metal potential value in the region, and provide a tool that might be applied to critical metals exploration at the regional scale.

Outputs – planned or actual

- Joint CSIRO–GSWA Report; western Yilgarn laterite geochemistry database; external publications



CSIRO Ultrafine+ soils Phase 2

Project manager: Richard Chopping

Partner researchers/institutions: Ryan Noble (CSIRO)

GSWA contact: Nadir de Souza Kovacs

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

Project description

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

Outputs – planned or actual

- Geochemical analyses in WACHEM, Records or Reports



CWAS Canning passive seismic deployment — Phase 3

Project manager: Klaus Gessner

Partner researchers/institutions: Huaiyu Yuan (Macquarie University)

GSWA contact: Klaus Gessner

Duration of project: 2021–23

Project description

The project will provide seismic velocity data for the active-source seismic model of the Kidson line and will provide depth information to constrain the architecture of the central Canning Basin, and its margins. The project will be essential to arrive at a better understanding of the basement of the Canning Basin and its potential for mineral systems.

Outputs – planned or actual

- Seismic models of the western margin and central part of the Canning Basin, including crustal thickness maps, crustal shear wave velocity model and body-wave tomographic model down to 400 km depth



Deep learning identification of anomalous data in geochemical datasets

Project manager: Trevor Beardsmore

Partner researchers/institutions: Vladimir Puzyrev (Curtin University)

GSWA contact: Paul Duuring

Duration of project: 2021–22

Project description

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

Outputs – planned or actual

- Digital versions of processes, Reports



Do the mineral systems in the southern Kalgoorlie Terrane have a camp-scale geophysical signature?

Project manager: Michael Dentith (UWA)

Partner researchers/institutions: UWA

GSWA contact: Klaus Gessner

Duration of project: 2018–19 (extended to 2022)

Project description

Geophysical data will be collected, processed and interpreted from the region between Kalgoorlie–Kambalda–Norseman. This experiment will research whether there is a distinctive crustal-scale geophysical signature of the mineral systems in this area, which is notable for its numerous large mineral deposits. Identifying such a signature will demonstrate a means for identifying other, as yet unknown, camps in Western Australia and hence encourage greenfields exploration in the State.

Outputs – planned or actual

- Co-branded Reports and Records

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

Project partner: Chris Kirkland (Curtin University)

GSWA contact: Fawna Korhonen

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

Project description

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

Outputs – planned or actual

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

Interferometric processing

Project partner: Juerg Hauser (CSIRO)

GSWA contact: Klaus Gessner

Duration of project: March 2021 to August 2021

Project description

Develop and apply a methodology to:

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

Outputs – planned or actual

- Reports, white paper, seismic interferometric reconstruction method

K–Ar dating of fault rocks

Project manager: Huntly Cutten

Partner researchers/institutions: Horst Zwingmann (Kyoto University); Tonguc Uysal, Andrew Todd (ARRC, CSIRO)

GSWA contacts: Huntly Cutten, Michael Wingate

Duration of project: 2015–22

Project description

This project will involve K–Ar (and possibly Rb–Sr) dating of fault rocks, fault gouge and slickenside surfaces, to determine the ages of the most recent fault movements in low-grade rocks of the Edmund and Collier Basins, in which deformation events could previously be dated only indirectly. The project is planned to be expanded to include the eastern Capricorn Orogen basins, and additional Western Australian terranes.

Outputs – planned or actual

- Peer-reviewed journal papers; two Reports
- Cutten, HN, Johnson, SP, Thorne, AM, Wingate, MTD, Kirkland, CL, Belousova, EA, Blay, OA and Zwingmann, H 2016, Deposition, provenance, inversion history and mineralization of the Proterozoic Edmund and Collier Basins, Capricorn Orogen: Geological Survey of Western Australia, Report 127, 74p.
- Cutten, HN, Zwingmann, H, Uysal, T, Todd, A 2021, Dating Proterozoic fault movement using K–Ar geochronology of illite separated from fault gouge: Geological Survey of Western Australia, Report 214.

Narryer Terrane isotopes project

Project manager: Hugh Smithies

Partner researchers/institutions: Tony Kemp (UWA)

GSWA contacts: Hugh Smithies

Duration of project: 2012–ongoing

Project description

Field inspection/sampling of the Narryer gneisses, zircon isotope work (geochronology, oxygen isotopes and hafnium isotopes, both whole grain and laser ablation) and whole-rock hafnium, neodymium, and lead isotope studies.

Outputs – planned or actual

- Report and external papers
- Kemp, AIS, Wilde, SA and Spaggiari, CV 2019, The Narryer Terrane, Yilgarn Craton, Western Australia: review and recent developments, *in* Earth's Oldest Rocks, second edition *edited by* M van Kranendonk, V Bennett and E Hoffmann: Chapter 18, p. 401–433, Elsevier, doi:org/10.1016/B978-0-444-63901-1.00018-6.

- Rowe, ML 2016, Petrology and geochemistry of the Eoarchaeon Manfred Complex: origin and components: Geological Survey of Western Australia, Record 2016/22, 150p.

National Virtual Core Library — Western Australian node

Project manager: Lena Hancock

Partner researchers/institutions: AuScope with NCRIS funding, CSIRO

GSWA contact: Lena Hancock

Duration of project: Ongoing

Project description

GSWA houses, manages and operates a HyLogger-3 semi-automated core logging facility as part of the NVCL project. GSWA owns the HyLogger, maintains it and provides operational staff as a co-investment in the project. The aim is to systematically capture hyperspectral data for all mineral and petroleum drillcore in its Perth and Kalgoorlie core libraries. GSWA provides data and interpretations to the NVCL, GeoVIEW.WA and other third parties.

Outputs — planned or actual

- Geoscience publications using HyLogger data; procedural publications



Oxygen isotope analyses of zircons

Project manager: Michael Wingate

Partner researchers/institutions: UWA, CMCA

GSWA contact: Michael Wingate

Duration of project: Ongoing

Project description

This project will add value to zircon Lu–Hf analyses by using zircon oxygen isotopes to distinguish material derived from near-surface or supracrustal environments from material derived from the mantle.

Outputs — planned or actual

- Contributions to GSWA publications and journal articles



Paleoproterozoic mafic magmatism of the Kimberley Basin, Western Australia

Project manager: Fawna Korhonen

Partner researchers/institutions: Karin Orth (University of Tasmania)

GSWA contacts: Chris Phillips

Duration of project: 2012–15 (draft Report delivered late 2019, final in progress)

Project description

The main aims are to:

- Map the distribution and relationships of the extrusive mafic rocks and sedimentary interbeds
- Constrain the spatial and temporal relationships of the different magmatic phases within the Hart Dolerite Sill
- Search for the plumbing and drivers that lead to the eruption and intrusion of 300 000 km³ of magma
- Understand the role of mafic volcanism in the development of Australia and in particular the North Australian Craton.

Outputs — planned or actual

- Orth, K, The Hart–Carson Large Igneous Province, Kimberley Region, northwestern Australia: Report (planned; with a contribution from Susan Belford)



Pilbara gold fingerprinting

Project manager: Trevor Beardsmore

Partner researchers/institutions: TSW Analytical

GSWA contact: Lena Hancock

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

Project description

To characterize the provenance and metallogenesis of gold mineralization across the Pilbara Craton using morphometry, microstructure, associated minerals and trace element composition of bedrock and placer gold grains.

Outputs – planned or actual

- Records for donated gold samples from exploration and mining companies and a final Pilbara gold Report that will be released by June 2022

Seismic acquisition using distributed acoustic sensing in an urban environment

Project manager: Mike Dentith (UWA)

Partner researchers/institutions: UWA

GSWA contact: Klaus Gessner

Duration of project: 2017–20 (extended to 2022)

Project description

The project uses passive seismic, ambient noise-based methods to map large-scale structure, especially depth to basement. Concurrently, the seismic monitoring data will also be used as a comparative study that aims to demonstrate that instead of using seismic instruments, seismic monitoring can be undertaken using existing fibre-optic cable infrastructure. Distributed acoustic sensing is an emerging technology for seismic wavefield measurement that relies on conventional optical fibre cables to create 'virtual' strain-rate sensors at every few metres along the cable.

Outputs – planned or actual

- GSWA Report

National Collaborative Framework (NCF) agreements

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

Falls under the NCF CMCG40003A PA4

Project manager: David Howard

Partner researchers/institutions: GA

GSWA contacts: David Howard, John Brett

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

Project description

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

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

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

Outputs – planned or actual

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

Australia Minerals Project Agreement GA Ref: 003938

Falls under head agreement CMC G40003A – 000668-1

Project manager: Anthony Budd

Partner researchers/institutions: GA

GSWA contact: Executive Director, GSWA

Duration of project: 2018–21 (one option for extension of two years)

Project description

Australia Minerals is a collaborative group of Australian state and territory government geological surveys that is an outworking of the Geoscience Working Group (GWG) under the Energy Council of the Council of Australian Governments. Australia Minerals promotes minerals investment in Australia by participating in international and domestic conferences, mining trade shows and investment seminars. GA coordinates the participation of Australia Minerals at events.

The project:

- Promotes Australia to make it the preferred destination for minerals investment, particularly at the exploration stage
- Advocates opportunities in greenfields areas, mineral provinces and commodities revealed by new geoscience information or changes in market demand
- Targets all market segments responsible for guiding investment decisions in minerals
- Committees included: GWG.

Land access in Western Australia project agreement, GA Ref: 004637 (AUSLAMP and AUSARRAY)

Project managers: Klaus Gessner, David Howard

Partner researchers/institutions: GA

GSWA contacts: Klaus Gessner, David Howard

Duration of project: 2019–25 (six years initial term with option for two 12-month extensions)

Project description

The Australian Passive Seismic Array (AUSARRAY) is a collaborative national survey that acquires seismic waveform data. The moveable array of ~130 broadband seismic stations are arranged in a grid, spaced ~55 km apart and deployed for a 12-month period.

Australian Lithospheric Architecture Magnetotelluric Project (AUSLAMP) is a magnetotelluric survey acquiring long-period magnetotelluric data at ~3000 sites across Australia to map the electrical conductivity of the continent in 3D.

Management of National Offshore Petroleum and Greenhouse Gas Data Repository — National Offshore Petroleum Data and Core Repository CMCG4003A – P3

Open-file data

Partner researchers/institutions: GA (two-way agreement)

GSWA contact: Paul Duncan

Duration of project: 2020–23

Project description

NOPIMS manages both confidential and open-file data. Confidential data is restricted to NOPTA (CMCG4003A – P1) and GA. Open-file data (CMCG4003A – P3) is available to the public to query and download offshore petroleum data.

NCF Collaborative Head Agreement Ref: CMCG40003A – 000668-1

Project managers: Director Regional Geoscience; Executive Director, GSWA

Partner researchers/institutions: GA

GSWA contacts: Director Regional Geoscience; Executive Director, GSWA

Duration of project: 2017–22 (ongoing 2021–24)

Project description

The primary objective of this Head Agreement is to facilitate collaboration between governments through various projects for integrated service delivery in order to improve:

- Agency's delivery of services to customers
- Efficiency and effectiveness of government services.

This Head Agreement describes the process and limits for forming a project with GA under this agreement.

Committees include:

- Chief Government Geologist Committee
- Head Agreement Management Committee.

***NOPIMS — National Offshore Petroleum Information Management System Project Agreement
CMCG4003A – P4***

Information and communication technology (ICT) development

Partner researchers/institutions: NOPTA and GA (three-way agreement)

GSWA contact: Paul Duncan

Duration of project: Ongoing

Project description

Under the agreement, DMIRS provides services to the Commonwealth (GA and NOPTA) to deploy a petroleum information management system using DMIRS infrastructure with functionality comparable to WAPIMS.

This agreement is for the ongoing development and maintenance of the system with all costs associated related to ICT Common Use Agreement personnel.

***NOPTA — Offshore Petroleum and Greenhouse Gas Data Management Project Agreement – National
Offshore Petroleum Data and Core Repository CMCG4030 – P1***

Confidential data

Partner researchers/institutions: NOPTA and GA (three-way agreement)

GSWA contact: Paul Duncan

Duration of project: Ongoing

Project description

NOPIMS manages both confidential and open-file data. Confidential data is restricted to NOPTA (this agreement) and GA. Open-file data is available to the public to query and download offshore petroleum data including:

- Well activity and completion reports, and data
- Survey reports and data
- Titles reports and general study reports.

Some key aspects of the agreement are:

- DMIRS will host NOPIMS using DMIRS ICT infrastructure
- NOPIMS delivers capabilities for:
 - industry data discovery and delivery
 - data management
 - physical sample management
 - confidential information (CMCG4003A – P1) and open information (CMCG4003A – P3) metadata management.

NOPIMS will contain confidential and open information on wells, geophysical surveys and other related exploration and production data.

This Record is published in digital format (PDF) and is available as a free download from the DMIRS website at <www.dmirs.wa.gov.au/GSWApublications>.

Further details of geoscience products are available from:

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