A Geological Survey of Western Australia Newsletter

APRIL 2020 NUMBER 94

Fieldnotes

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

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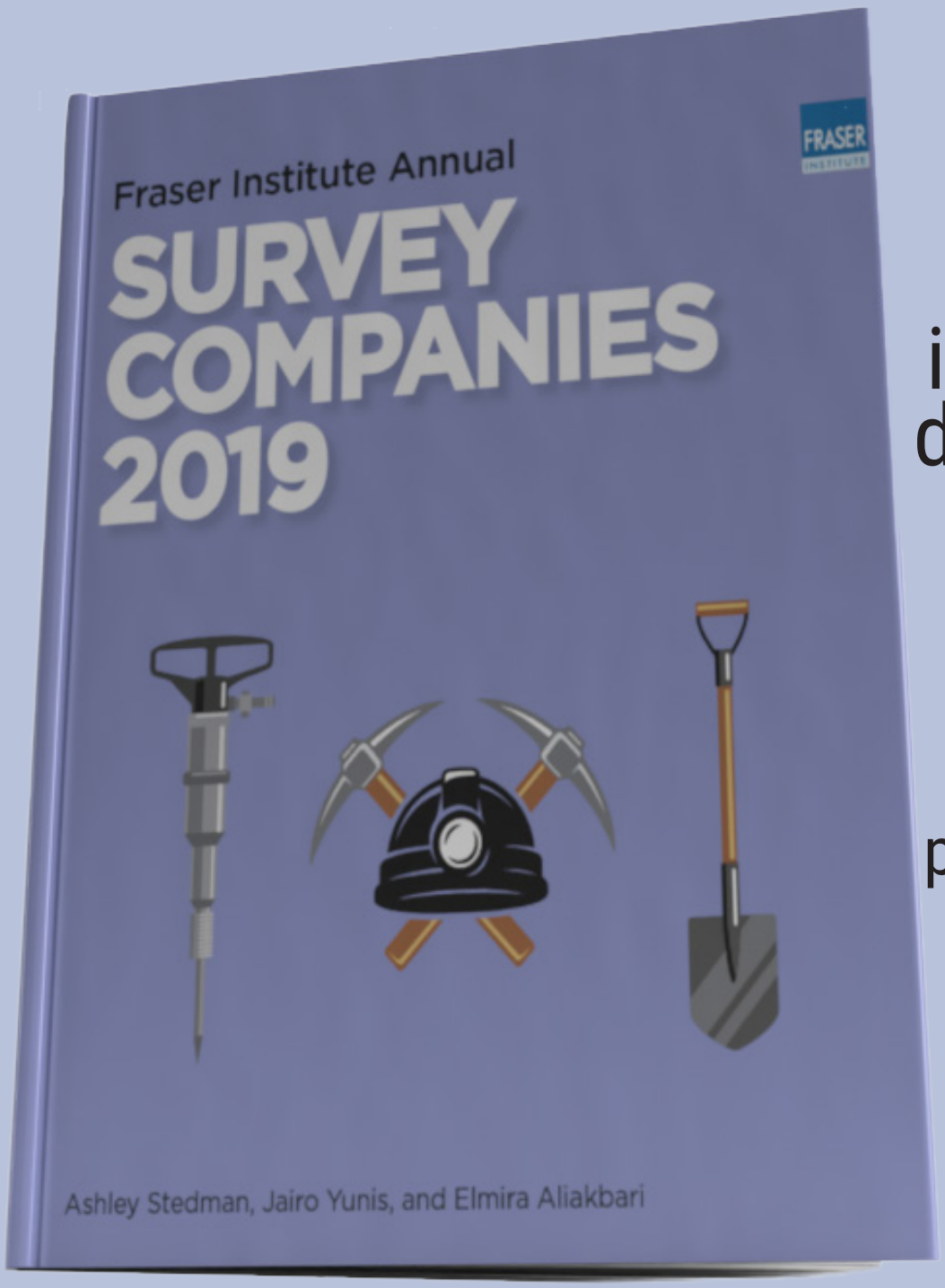

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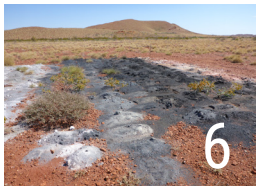

EDITORIAL TEAM

Editor

Robin Bower, Manager Editing and Publishing

Design and layout

Bec Hitchings, Desktop Publisher

Graphics

Michael Prause, Graphics Manager

Contributors to this issue

Heidi Allen
Peter Haines
Simon Johnson
David Martin
Sarah Martin
Jenna Meehan
Ruth Murdie
Stephen White

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Fieldnotes

Fieldnotes is a free digital-only quarterly newsletter published by the Geological Survey of Western Australia (GSWA). The newsletter provides regular updates to the State's exploration industry and other geoscientists about GSWA's latest work, programs, products and services.

Access Fieldnotes by:

- subscribing to the **GSWA eNewsletter** – there will be a Fieldnotes page with a link to the latest issue
- browsing previous issues from the **eBookshop**.

GSWA eNewsletter

The GSWA eNewsletter is an online newsletter delivered roughly once a month that contains information on workshops, field trips, training, events and the latest releases of maps, books and digital data packages. If you would like to stay informed about new products, services and other news, please **subscribe**.

GSWA publishes a vast amount of pre-competitive geoscience information on the State, contributing to billions of dollars' worth of resources for exploration and development. To find more information about publications and maps we publish, go to our **website**.

Cover image: Cover of the Fraser Institute's Annual Survey of Mining Companies 2019

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Western Australia ranks top investment destination in the world

The Fraser Institute, a Canadian public policy think tank (ranked in the top 20 think tanks in the world), annually publishes its global 'Survey of Mining Companies' which ranks the investment climates of mining jurisdictions around the world. The ranking is based on the opinions of mining industry executives and managers, and in 2019, the survey was circulated to 2400 individuals. It received 263 responses which provided sufficient data to rank 76 jurisdictions.

Western Australia ranked the world's top destination for investment based on the Investment Attractiveness Index, moving up from second place in 2018 (Fig. 1, Table 1). The Investment Attractiveness Index is constructed by combining the Best Practices Mineral Potential Index, which rates the geological attractiveness of a region, and the Policy Perception Index, a measure of the government's attitude towards exploration investment. Individually, Western Australia ranked second in the Best Practices Mineral Potential Index and fifth in the Policy Perception Index. Western Australia has remained in the 'top 5' world rankings, and within the 'top 2' rankings within Australia for investment attractiveness for the past nine consecutive years – a major achievement (Tables 1 and 2).

The survey also rates the quality of the 'Geological Database'. Western Australia recovered slightly to 11th from 13th place in 2018, slowly continuing its recovery from an unexpected drop from 1st place in 2016 to 17th place in 2017 (Fig. 1). Western Australia's steady rise in 'Geological Database' ranking prior to 2017 is attributed to the rapid rise in the volume of pre-competitive geoscience data and knowledge produced with funding assistance from the Exploration Incentive Scheme. The Geological Survey of Western Australia (GSWA) believes that the reason for the dramatic fall and slow recovery in the quality of 'Geological Database' ranking is that jurisdictions around the world have been learning from Western Australian systems, and that the rankings of those jurisdictions jump dramatically when they release their improved systems. Western Australia currently lies behind the likes of Queensland, the Republic of Ireland, Finland and Alberta which ranked the first in the world. However, GSWA is in the process of defining a five-year data strategy, which will transform the collection, storage and delivery of all pre-competitive geoscience and statutory datasets, ensuring that the data are FAIR (Findable, Accessible, Interoperable and Reusable).

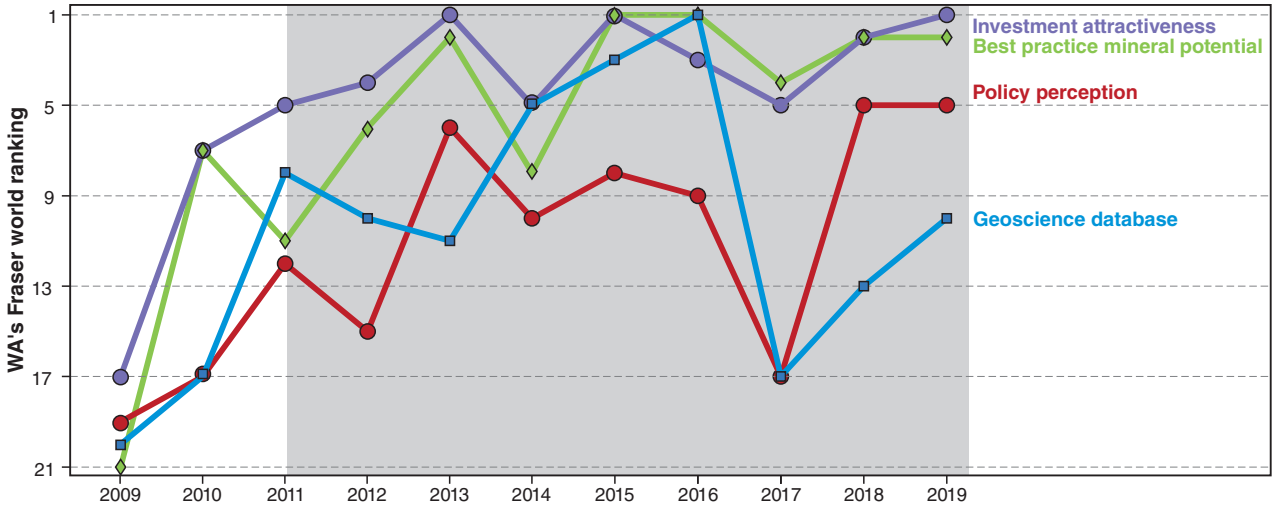


Figure 1. Western Australia's Fraser world ranking

Table 1. A comparison of Western Australia's performance relative to other Australian jurisdictions

Fraser index	WA's world ranking									WA's Australian relative ranking								
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of jurisdictions surveyed	93	96	112	122	109	104	91	83	76	7	7	7	7	7	7	7	7	7
Best practice mineral potential	11	6	2	8	1	1	4	2	2	1	1	1	1	1	1	2	1	1
Investment attractiveness	5	4	1	5	1	3	5	2	1	1	1	1	1	1	1	1	1	1
Policy perception	12	15	6	10	8	9	17	5	5	1	1	1	1	1	1	1	1	1
Geoscience database	8	10	11	5	3	1	17	13	11	3	4	3	2	1	1	5	3	2

Table 2. Several of the survey's key measures since 2009–10

Fraser Institute's Policy Perception Index — Australian States only

Ranking	2009–10	2010–11	2011–12	2012–13	2013	2014	2015	2016	2017	2018	2019
1	SA	SA	NT	WA	WA	WA	WA	WA	WA	WA	WA
2	NT	WA	SA	SA	SA	SA	SA	SA	SA	SA	SA
3	WA	NSW	NSW	NT	NT	Tas	NT	NT	Qld	Qld	NT
4	NSW	NT	Tas	Vic	Qld	NT	Qld	Tas	Tas	Tas	Qld
5								Qld	NT	NT	Tas
6								Vic	Vic	Vic	Vic
7								NSW	NSW	NSW	NSW

The Fraser Institute also includes an assessment of the mining industry's perceptions of the exploration permitting process in Canada, and a few other jurisdictions around the world including Australia and the United States. Western Australia ranked well within the jurisdictions surveyed, and ranked top for Australian States and Territories. The survey respondents indicated that within Western Australia relevant permitting took less than six months, that most of the time permitting decisions were made within prescribed timelines, that applicants were confident that permits would be approved, and that the permitting process was not a deterrent to investment. Significantly, though, respondents generally had perceived little change in permit approval times over the past decade.

Despite the highly positive outlook for Western Australia over the past number of years, GSWA is not resting on its laurels. GSWA aims to continue the collection of new, cutting-edge, high-quality pre-competitive geoscience datasets, while modernizing its data delivery systems, and streamlining and reducing the time of permitting approvals.

An overview of Western Australia's global ranking, together with a comparison of its performance relative to other Australian jurisdictions, on several of the survey's key measures since 2009–10 is provided in Figure 1 and Tables 1 and 2.

For more information, contact **Simon Johnson**.

Overdue recognition for microbialites in new handbook

Microbialites represent one of the oldest forms of life on Earth, and the most abundant form of early life available for scientific study. Their role in generating oxygen in Earth's early atmosphere was pivotal in establishing conditions that encouraged the rise of all other complex life on the planet and, as such, these fossils have long been used to better understand the origins and evolution of life, and changes in the planet's early environments. Western Australia is unique in hosting a diversity of microbialites, extending from what are widely accepted as the world's oldest fossils located in the Pilbara, through to internationally renowned living analogues in Shark Bay, Lake Thetis and Lake Clifton. It is for this reason that the State has been at the forefront of microbialite study and research for many years.

Geological Survey of Western Australia (GSWA) Bulletin 147 formally standardizes the terminology and approaches used in studying microbialites. Condensing nearly 50 years of research and practical experience into a single volume, the authors provide a comprehensive guide to the methods for describing and interpreting fossil and recent microbialites, thereby facilitating consistent communication between workers within this field.

This book is the latest in the GSWA Bulletin series and will attract worldwide interest in the scientific community. It will be a key text for researchers in the fields of paleontology, sedimentology, stratigraphy, resource exploration, astrobiology, and the origin and evolution of life.

Major features

The handbook aims to be a highly practical guide for both experienced and new microbialite workers by:

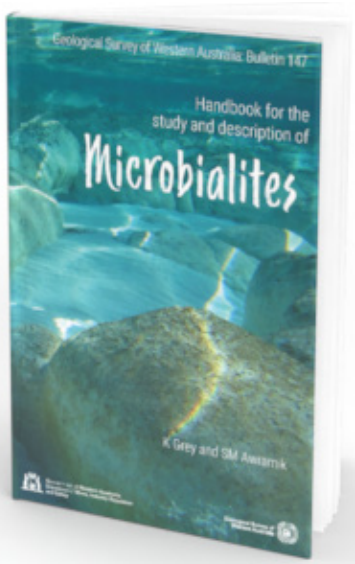
- its extensive use of conceptual diagrams and large format colour photos to illustrate the key features of microbialites
- showcasing microbialites in the field, and in the extensive collections of GSWA, University of California Santa Barbara, and other institutions
- collating and distilling worldwide expertise across many geographic and stratigraphic settings for microbialites, ancient and modern
- proposing a Code of Microbialite Nomenclature to resolve a serious disadvantage to existing and future microbialite systematics.

Bulletin 147 Handbook for the study and description of microbialites by Dr Kathleen Grey, retired GSWA Chief Paleontologist, and Prof. Stanley Awramik, University of California Santa Barbara is available for download as a PDF from the DMIRS eBookshop and as a casebound book.

For more information, contact **Heidi Allen**.

Figure 1. Compound biostrome of nested, subspherical, thrombolitic bioherms; Holocene; Lake Clifton, Western Australia (photo by SM Awramik)

Figure 2. Linked-conical stromatolite; Neoarchean; Tumbiana Formation, Fortescue Basin, Western Australia (photo by SM Awramik)



Implications for the northern Capricorn Orogen

The Hardey Syncline in the southern Hamersley province preserves a number of critical field relationships that provide important insights into understanding the geological evolution of the northern margin of the Capricorn Orogen, and the tectonic history of the Ophthalmia Orogeny, in particular. The significance of the area stems from its near complete stratigraphic record of the Mount Bruce Supergroup and overlying strata, and the relative and absolute age of Ophthalmian deformation events that can be determined by reference to well-preserved field relationships and the presence of isotopically dated rock units. These relationships, as well as definition of a revised stratigraphy of the uppermost Mount Bruce Supergroup, are described in a new Report on the geology of the Hardey Syncline and have important implications for mineral prospectivity in the region.

Geological Survey of Western Australia (GSWA) Report 203 establishes formal stratigraphic names and definitions for some previously un-named units within the Turee Creek Group and revises the stratigraphic nomenclature of the lower part of the overlying Wyloo Group (Fig. 2). In particular, part of the lower Wyloo Group is formally named as the Shingle Creek Group, and the Wooly Dolomite is revised as a separate entity and redefined as the Wooly Formation. These revisions have resulted from new GSWA mapping in the area and an increased awareness of the importance of the Turee Creek Group which preserves the stratigraphic record of the Great Oxidation Event and Huronian glaciation, both currently the subject of global research interest.

The formal recognition of eight unconformity/disconformity bound sequences (Fig. 2) and their relationship to the newly named Balgara Dolerite allows tighter time constraints on the folding that produced the Hardey Syncline during the Ophthalmia Orogeny. The Ophthalmia Orogeny is recognized to be the product of five discrete coaxial west-northwest – east-southeast fold events, and one later northwest–southeast fold event.

A potentially important economic consequence of these revisions is the recognition of the regional extent of the revised Wooly Formation, which new mapping indicates hosts the Mount Olympus gold deposit. Moreover, the Wooly Formation consists predominantly of siliciclastic sedimentary rocks, including large thicknesses of pyritic, carbonaceous shales (Fig. 1) which are prospective for stratabound and hypogene mineralization.

GSWA Report 203 Geology of the Hardey Syncline — the key to understanding the northern margin of the Capricorn Orogen and a **Preliminary map of the Fortescue and Hamersley Basins** are available as free downloadable PDFs from the DMIRS eBookshop.

For more information, contact **David Martin**.

Figure 1. Drillhole intersection south of Urandy Creek Outcamp of a thick, pyritic, carbonaceous shale interval typical of the revised Wooly Formation

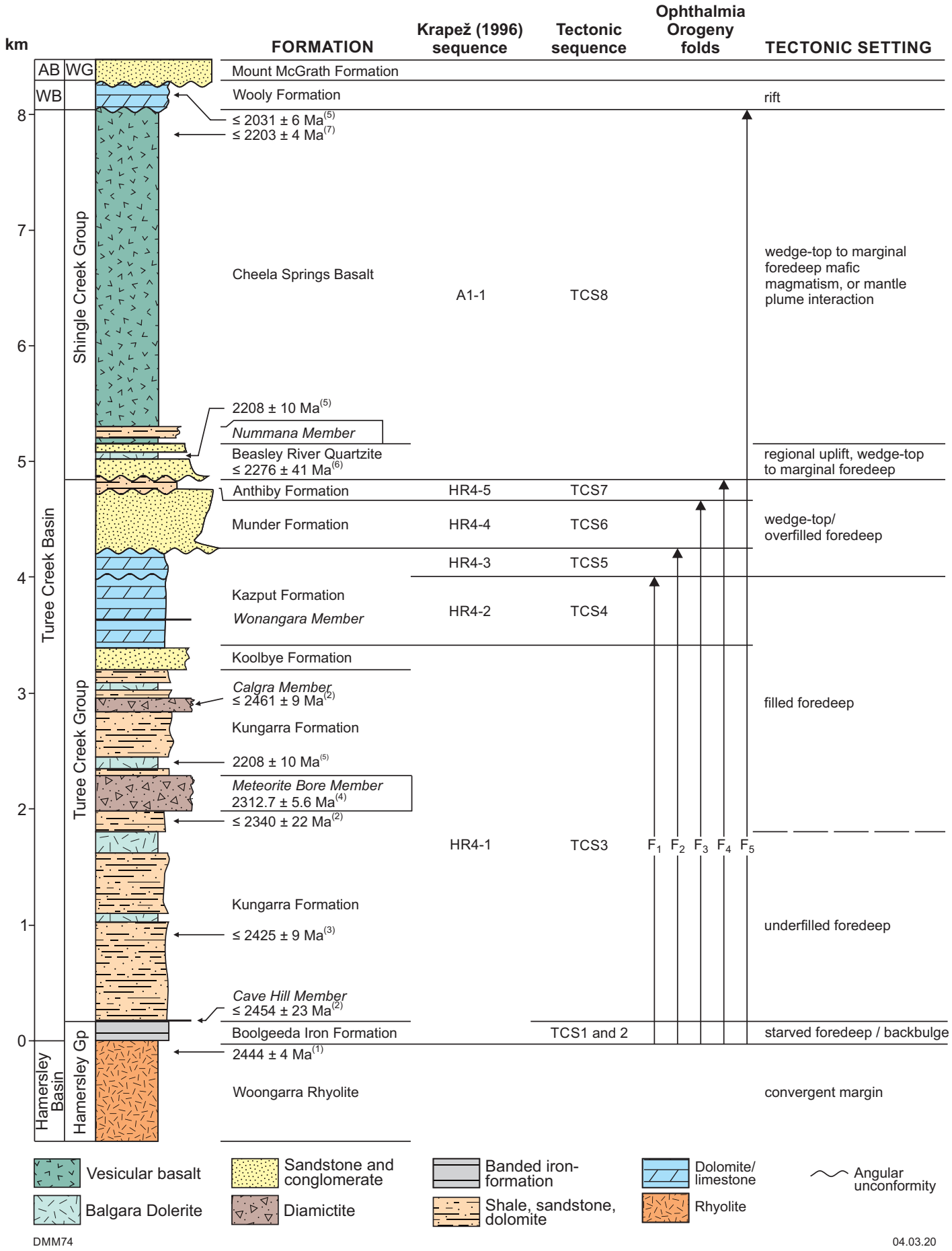


Figure 2. Revised stratigraphic nomenclature of the upper Mount Bruce Supergroup in the Hardey Syncline. See Report 203 for details

Recent 3D geomodels

In the past year, three new Geological Survey of Western Australia (GSWA) 3D geomodels have become available through the Data and Software Centre. All models are available as SKUA-GOCAD projects, or as Geoscience Analyst files. Geoscience Analyst, distributed by **MIRA Geoscience** is a free 3D visualization and communication software for integrated, multidisciplinary Earth models and data. Geoscience Analyst files include all the data, metadata, interpretations and associated documents.

The East Albany–Fraser Orogen 3D model documents magmatic underplating along the boundary between the Proterozoic East Albany–Fraser Orogen and Archean Yilgarn Craton. The craton margin's structure is interpreted from deep reflection seismic, receiver functions from passive seismic (Fig. 1) and 3D gravity forward modelling. Specifically, the constraints on the model include an interpreted bedrock geology map, Moho depth points from the ALFREX passive seismic survey (see **GSWA Report 177**) and the interpretations of the 12GA-AF1, 2 and 3 deep crustal reflection seismic lines (see **GSWA Record 2014/6**). The Moho model shows a zone of thickened crust oriented parallel along the entire length to the Albany–Fraser Orogen. 3D gravity forward modelling suggests that this zone of thickened crust contains dense material in the lower crust, coincident with a large non-reflective zone imaged in reflection seismic data. This zone is interpreted to represent a Proterozoic mafic underplate that formed in the lower crust of the Yilgarn Craton. Some of the possible tectonic settings for the emplacement of this voluminous mafic underplate include Paleo-Mesoproterozoic extension that occurred along the Yilgarn Craton margin or Mesoproterozoic crustal shortening during the Albany–Fraser Orogeny.

The Lawlers Anticline 3D model (Fig. 2) was built as part of a detailed mineralization study into the Archean gold deposits within the Agnew Gold Camp by N Thébaud and J Miller of the Centre for Exploration Targeting, The University of Western Australia. A field investigation delineated the structural framework and paragenesis associated with the mineralization of each of the individual deposits at Songvang, Crusader, Waroonga and New Holland – Genesis. The Lawlers Anticline is located in the southwest corner of the Agnew–Wiluna belt in the Kalgoorlie Terrane, which is part of the Eastern Goldfields Superterrane within the Yilgarn Craton. It consists of a moderately to tightly folded greenstone belt bounded to the west by the Waroonga Shear Zone, a 2 km-wide, dextral strike-slip zone separating the greenstones from a granite–gneiss terrane. Regional east–west contraction resulted in a folding event that led to the formation of the Lawlers Anticline, which plunges 50–60° to the north in the core of the Agnew Gold Camp. On the western limb of the Lawlers Anticline, the contact with metasedimentary rocks of the Scotty Creek Formation is faulted along the north- to northeast-trending Emu Shear Zone, which hosts, or is close to, the majority of existing high-grade gold deposits. Mineralization in each of the deposits is associated with vastly different alteration styles.

The Murchison 3D model (Fig. 3) covers highly mineralized granite–greenstone domains in the northwestern part of the Yilgarn Craton. The region covered includes the northwestern Youanmi Terrane (Mesoarchean to Neoarchean), the Paleoarchean to Neoarchean Narryer Terrane and their boundaries with the Capricorn Orogen, and the northwestern part of the Neoarchean Eastern Goldfields Superterrane.

The aim is to provide fundamental constraints on the first-order, 3D geometrical architecture of the network of synorogenic structures within the northwestern part of the Yilgarn Craton. The interpretations presented here are based on integrating deep reflection seismic surveys that were acquired in 2010 and 2011 (see **GSWA Record 2013/6**) with aerial magnetic and ground gravity surveys compiled by GSWA and the mapping campaigns of GSWA within that region.

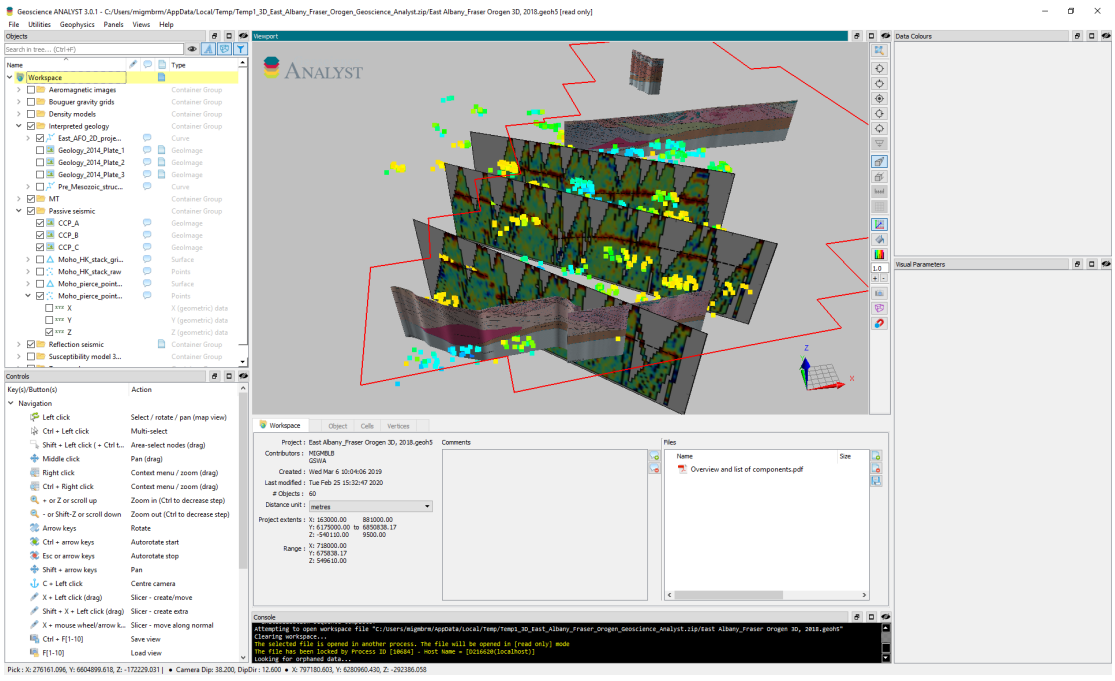


Figure 1. Seismic constraints on the East Albany–Fraser Orogen 3D model

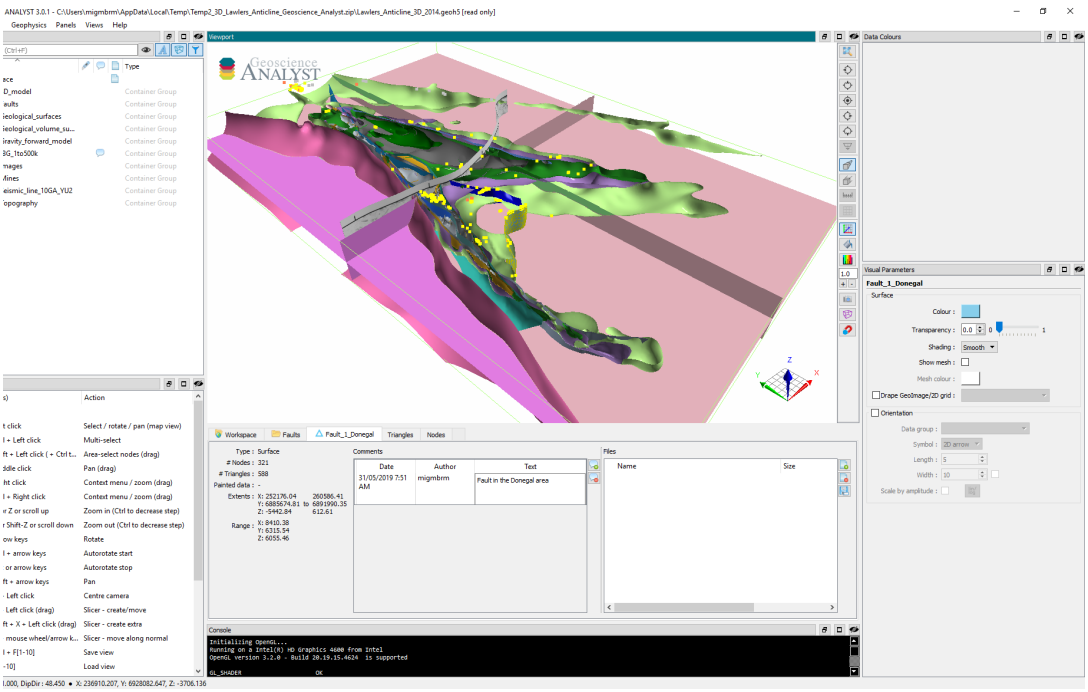


Figure 2. Surfaces and sections of the Lawlers Anticline 3D model

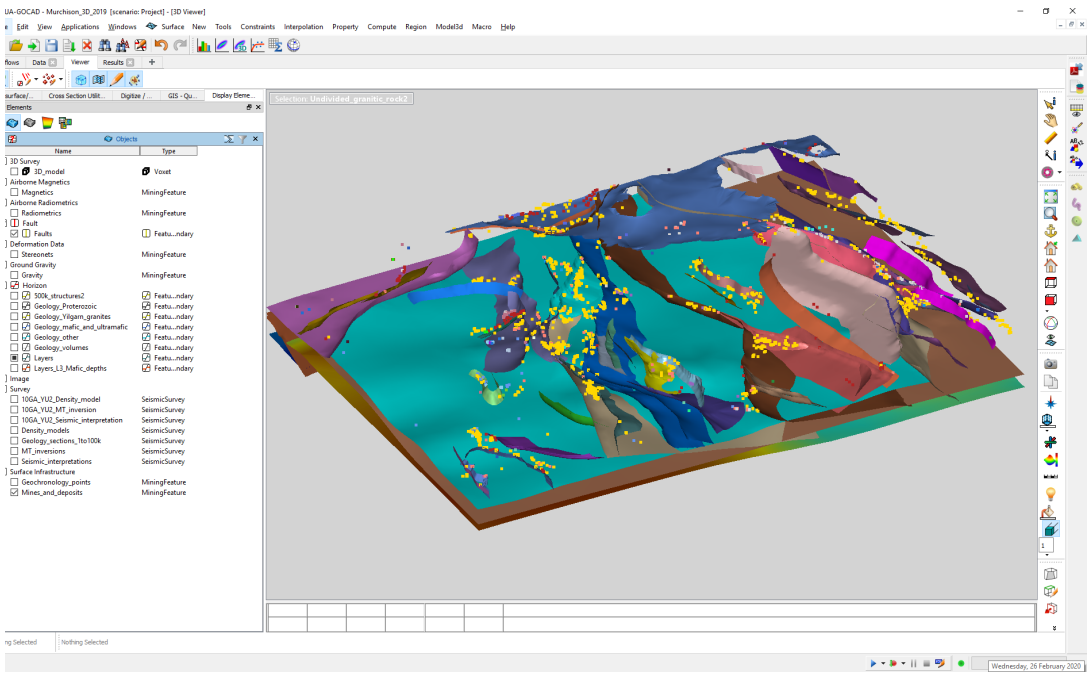


Figure 3. Screen capture of the Murchison 3D model in SKUA-GOCAD

There is a high degree of symmetry in the fault network that can be observed in map view, which is in striking contrast to the profoundly asymmetric crustal architecture present in all the seismic profiles acquired across the Yilgarn Craton. This observation is probably the most significant outcome of this study. The dominantly east-dipping pervasive fabric described in association with some studied faults represents a craton-scale feature that is developed throughout the crust of the Yilgarn Craton. In contrast, west-dipping structures are typically restricted to the upper crustal levels, systematically truncating the east-dipping structures and fabrics.

This model is a visualization that extrapolates outwards the 3D fabrics and structures from the images generated by the seismic lines and provides some fundamental constraints for the development of a kinematic model for the synorogenic fault network of the Yilgarn Craton. This is particularly applicable when considering the resource potential of the area and the mineral system concept.

To access the models highlighted below and previous models, go to **Data and Software Centre**, under Datasets tab, tap on the Statewide spatial datasets tab. All models are found under the 3D geology tab. We encourage researchers to deposit their models in the GSWA archive if they wish to make their models available to the public.

For more information, contact **Ruth Murdie**.

Successful exhibition highlights State's geological work

Perth's geological community turned out in force to visit the Esplanade Hotel Fremantle in February to attend the Geological Survey of Western Australia (GSWA) Open Day 2020.

This premier geological event is a platform for the latest geological information and major activities undertaken by GSWA. Throughout the day there were geological presentations, an extensive poster display, and demonstrations of online systems and innovations in technology.

Round 21 of the Exploration Incentive Scheme's (EIS) Co-funded Drilling program was formally announced by Hon Bill Johnston, Minister for Mines and Petroleum. The program offers $5 million a year to encourage innovative drilling in greenfields and underexplored areas of the State. Thanks to funding through the EIS, GSWA has made tremendous strides in geoscience and mapping, helping explorers target new discoveries.

The Open Day featured 15 presentations by experts in the associated areas of geology and geoscience, covering a range of areas including the southwest Canning Basin, Amadeus and Officer Basins, Eastern Goldfields, West Kimberley, western Youanmi Terrane, Yilgarn Craton, and the northern Capricorn Orogen. Two of the standout presentations this year included a talk on the potential for a new world-class hydrogen and helium province below the world's oldest regional salt seal in the Amadeus and Officer Basins (**Haines and Allen, 2020**), and a talk by the Loop 3D consortium on improving the workflow for automatic extraction of geological map data to generate 3D models (**Jessell et al., 2020**).

The extensive poster display highlighted the results of ongoing GSWA work as well as the collaborative research programs funded by EIS, and by the Mineral Research Institute of Western Australia, including mineral exploration targeting with the CSIRO, the Centre for Exploration Targeting and Curtin University.

Staff also demonstrated a range of business systems including the latest updates for GeoVIEW.WA, GSWA's award-winning, state-of-the-art geoscientific web application that is continuously updated with the latest geoscience and resource information.

Along with the displays and demonstrations of online systems, other highlights included the completion of two major State datasets now available on **GeoVIEW.WA**:

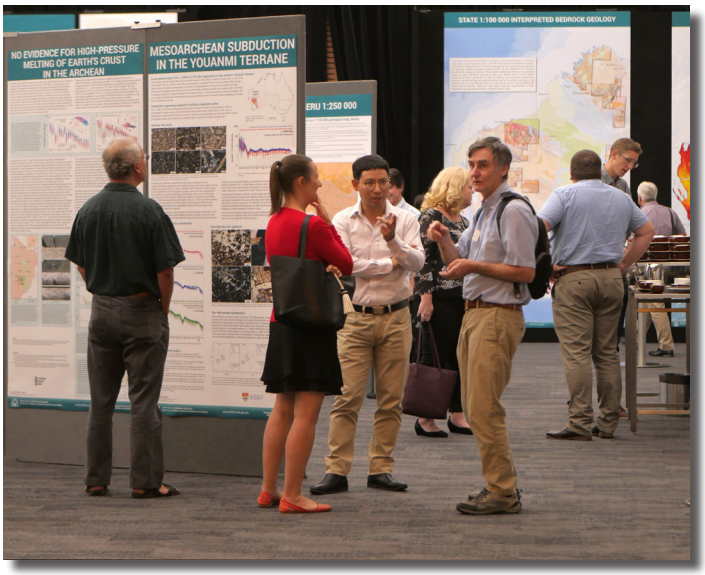
- release of the regolith–landform map for southern Western Australia to complete the 1:500 000 State regolith–landform map
- release of the Pilbara 2019 airborne gravity survey to complete the State gravity anomaly map.

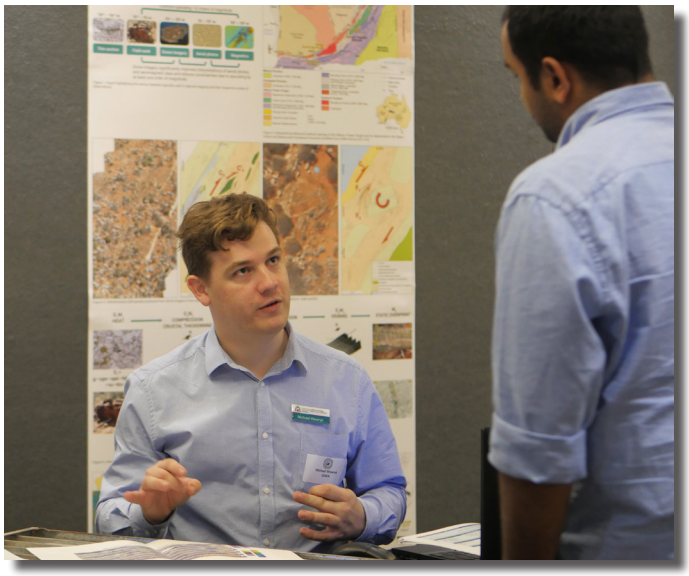
Full event details, including the presentations, extended abstracts and posters are available on the **DMIRS website**.

For more information, contact **Jenna Meehan**.

Photos: The Minister for Mines and Petroleum, Hon Bill Johnston, Director General, David Smith and Executive Director, Jeff Haworth presented and mingled with staff and industry representatives at this year's GSWA Open Day 2020

GSWA Open Day 2020





World's oldest regional salt seal has potential to trap subsalt hydrocarbons and helium

Thick salt deposits in sedimentary basins can form very effective seals over subsalt fluid traps. This has implications for the preservation of not only subsalt hydrocarbons, but also helium, particularly in old sedimentary basins where traps sealed by other lithologies such as shale tend to leak over geologically long time periods. Helium in the Earth's crust is a daughter product of radioactive decay of uranium and thorium, but this light, inert, and much in demand gas is difficult to trap. Helium is typically commercially extracted as a minor byproduct from commercial gas wells, with the United States being the main producer. Concentrations of helium in such wells are typically low, often of the order of 0.1%, but salt-sealed traps in old stable basins with long accumulation times can exceed 1%.

The Amadeus and Officer Basins, significant structural remnants of the former Centralian Superbasin, contain extensive deposits of Tonian (early Neoproterozoic) salt (Fig. 1). Older salt deposits are rare, and only of local extent, making these salt units of western and central Australia, dating from at least 800 Ma, or a little older, the oldest such deposits with basin-scale distribution worldwide. Younger (Ordovician–Silurian) salt deposits are also widespread in the Canning Basin.

Drilling beneath the salt seal in the eastern Amadeus Basin (Northern Territory) at Magee 1 and Mount Kitty 1 (Fig. 1) resulted in gas flows to surface, proving not only the existence of a subsalt gas-prone hydrocarbon system, but also recording exceptional helium contents of 6.2% and 9%, respectively. These wells were uneconomic due to poor reservoir at these locations. The thickness of subsalt sandstone (potential reservoir) and subsalt shale (potential hydrocarbon source) is inferred to thicken towards the unexplored Western Australian end of the basin. Subsalt wells in the Western Australian Officer Basin have not generally targeted subsalt traps, while drilling over the border in South Australia reported subsalt gas shows. The potential for subsalt hydrocarbons and helium in the Western Australian portions of these basins is considered high.

For a related recent publication on this topic, go to this **extended abstract** from GSWA Open Day 2020 which is available to download as a free PDF from the DMIRS eBookshop.

For more information, contact **Peter Haines**.

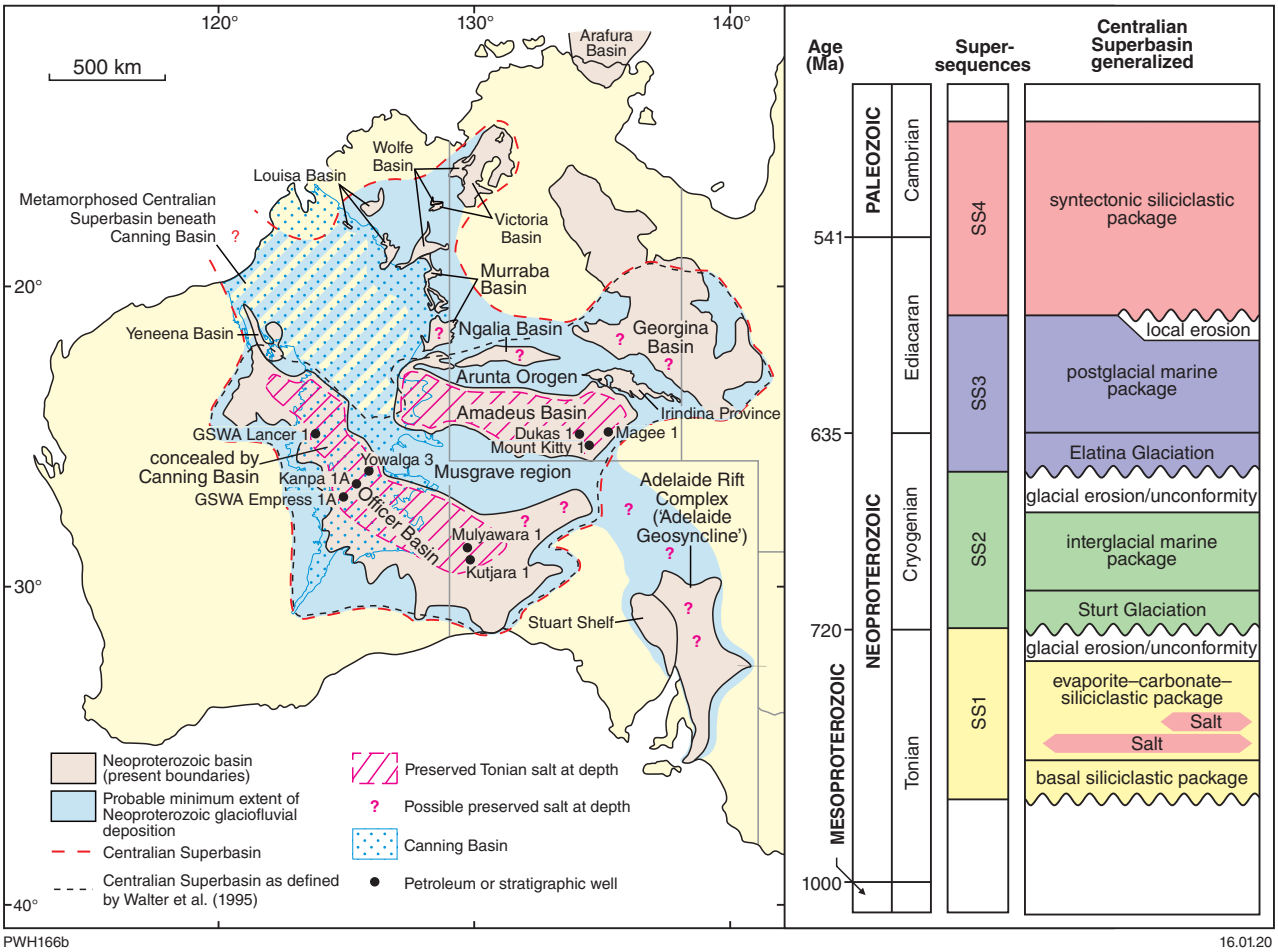


Figure 1. Map of the Centralian Superbasin and component basins, with generalized Neoproterozoic stratigraphy on the right indicating the stratigraphic position of the main Tonian salt units near the bottom of the succession. The known and inferred distribution of preserved subsurface salt in the Amadeus and Officer Basins is based on seismic data and drilling, where available, or extrapolated beyond. Subsalt petroleum exploration and stratigraphic wells in both basins are indicated

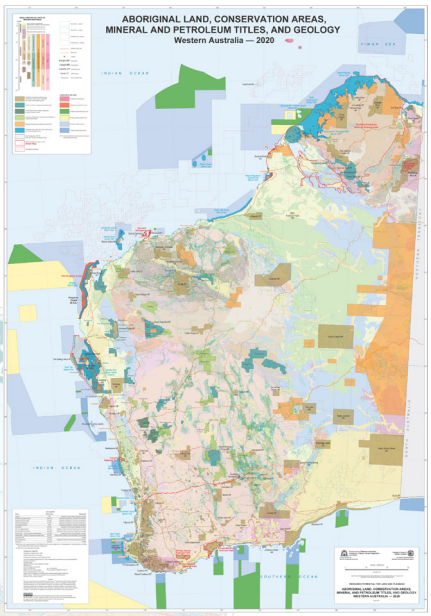
Product releases

• DIGITAL CORE ATLAS SERIES •

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

• MAPS •

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



Basement interpretation of the Kidson seismic survey 18GA-KB1
by Doublier, MP, Gessner, K, Kohanpour, F, Hickman, AH, Howard, HM, Martin, DMcB and Johnson, SP

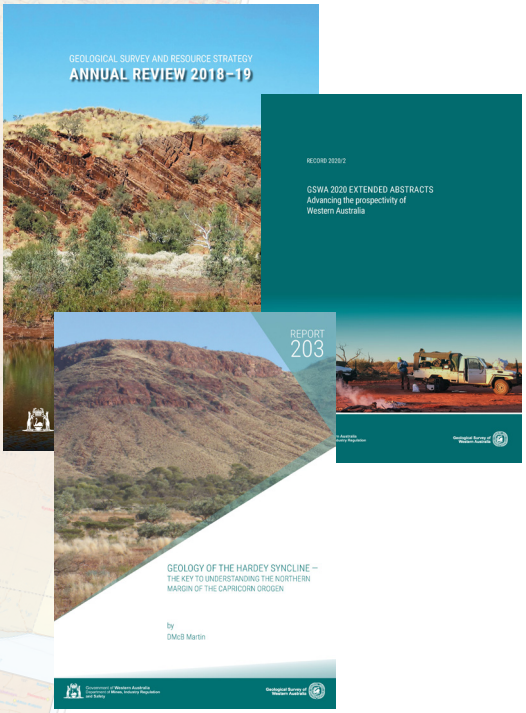
Mines – operating and under development, Western Australia – 2020
by Sargent, SN, Wyche, NL, D'Ercole, C, Jones, JA and Murray, SI

Major resource projects, Western Australia — 2020
by Sargent, SN

• TEXT PUBLICATIONS •

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

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



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

Geological Survey of Western Australia Annual Review 2018–19

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

• DATA PACKAGES •

1:500 000 State regolith geology of Western Australia, 2020
by Jakica, S and de Souza Kovacs, N

Kimberley, 2020: GIS

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

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