A Geological Survey of Western Australia Newsletter

July 2019 NUMBER 91

Fieldnotes

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

www.dmp.wa.gov.au/GSWA

EIS CO-FUNDED EXPLORATION DRILLING

ROUND 19 SUCCESSFUL APPLICANTS ANNOUNCED

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Geological Survey of Western Australia

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REGULARS

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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.

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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: Drilling at Eucla (image by Gunson Resources)
(see article on page 3)

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Results for Round 19

EXPLORATION INCENTIVE SCHEME

A list of 45 successful applicants for Round 19 of the Exploration Incentive Scheme's (EIS) Co-funded Exploration Drilling program was announced by the Minister for Mines and Petroleum, Bill Johnston on 22 May 2019. Nearly one-third of successful applicants in the latest round hope to discover battery commodities needed for Western Australia's fast-growing battery industry. Applicants searching for battery minerals are predominantly targeting nickel with others seeking lithium, cobalt, rare earth elements (REE) and graphite.

A total of $5.12 million in grants has been offered to companies and prospectors. In addition to the battery commodities, other projects are targeting traditional metals such as gold, copper, silver and base metals, diamonds and petroleum. The project locations match the diversity of commodities, ranging from the South West to the east Kimberley, Goldfields and remote regions of Western Australia's eastern border (Fig. 1).

Since it commenced in 2009, the EIS Co-funded Drilling program has offered funding to more than 900 projects, resulting in more than 745 500 m of drilling across the State. The proportion of percussion drilling to diamond drilling is approximately 2:1, which has resulted in significant amounts of diamond core being submitted to one of two State core libraries. The EIS core becomes publically available for viewing on request once a six-month confidentiality period ends. Following viewing, and with subsequent approval from the Geological Survey of Western Australia (GSWA), core may be sampled for additional geoscientific studies.

EIS success stories from recent completed rounds of co-funded drilling include the following:

- significant shallow oxide gold intersections at Lefroy Exploration Limited Lucky Strike project southeast of Kalgoorlie
- Buxton Resources Double Magic project (Merlin prospect) delivering high grade Ni–Cu–Co +/-PGE sulfide intercepts at multiple targets within the Ruins Dolerite intrusive suite
- Bellevue Gold Limited continued to find deeper 'Bellevue-style' gold mineralization 150 m below the historical underground mine north of Leinster.

The next round of co-funded drilling (Round 20) will open for applications in late August 2019, and will be open for six weeks. Round 20 will be for drilling from 1 January to 31 December 2020. Advice, guidelines and a copy of the co-funding agreement can be found on our **website**.

The Co-funded Drilling program is subject to probity and financial audits, for each round, to ensure a fair and transparent process.

For more information, contact **Charlotte Hall**.

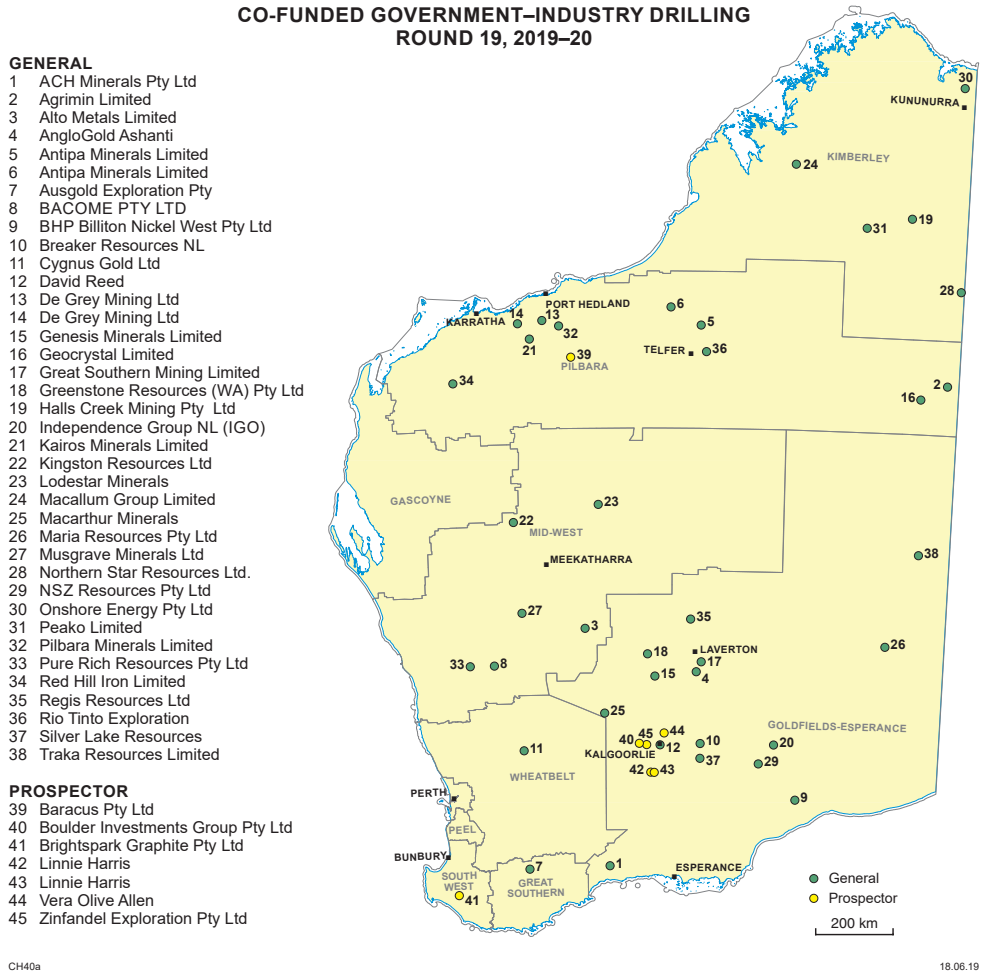


Figure 1. Locations and names of successful applicants, Round 19

Western Australia ranks in the top two

The Fraser Institute, an independent, non-partisan Canadian policy think tank annually surveys mining companies worldwide, with 83 jurisdictions surveyed in 2018.

Western Australia's ranking on the survey's Investment Attractiveness Index — a composite of policy perceptions and minerals potential — rose to second in 2018 from fifth in 2017. Nevada was rated as the most attractive jurisdiction for mining investment in 2018, with Saskatchewan, Quebec and Alaska making up the top five.

Western Australia has maintained its position as one of the five most attractive jurisdictions for eight consecutive years. At second in 2018, Western Australia remains the highest ranked Australian jurisdiction for investment attractiveness, followed by Queensland (13th), Northern Territory (23rd), South Australia (24th), New South Wales (42nd), Victoria (54th) and Tasmania (55th).

The Policy Perception Index is a composite measure of the attractiveness of mining policies in a jurisdiction. Western Australia's recovery in its Policy Perception Index score and ranking from 17th to 5th reflects mid-term political stability after a change in government, with approvals for planned uranium mines kept in place, and no changes to gold royalty arrangements.

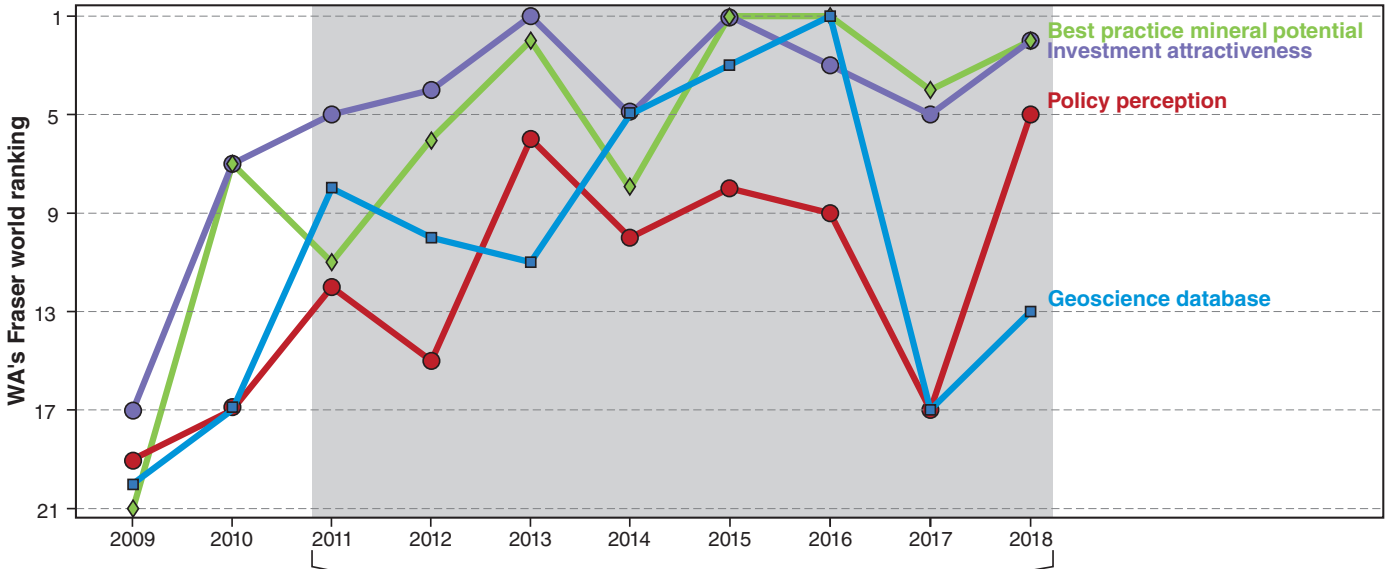
The State's ranking for the Best Practice Mineral Potential Index (which reflects perceptions of underlying geological prospectivity) rose to second in 2018, behind Nevada.

This is up from fourth in 2017, and back above Queensland (12th).

Western Australia's ranking for its geological databases recovered slightly in 2018, rising to 13th from 17th in 2017. This follows the dramatic fall from first in 2016, considered to reflect, in part, having to access online web-based platforms, including GeoVIEW.WA, via the unsupported MS Explorer web browser rather than readily available internet web browsers, such as Chrome. This is currently being fixed, but there is also a perception that historic exploration data within WAMEX and the drillhole and geochemical database are difficult to extract and interpret using modern geophysical and geochemical targeting techniques. This will require more time and resources for an extensive upgrade and QA/QC of the databases.

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

For more information, contact **Ian Tyler**.



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

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Figure 1. Western Australia's global ranking and comparison to other Australian states and territories

Magnetotelluric survey provides 2D and 3D conductivity models

Magnetotelluric soundings at 163 locations across the east Albany–Fraser Orogen have provided 2D and 3D conductivity models of the crust and uppermost lithospheric mantle beneath four regional transects (Fig. 1). Dimensionality and geoelectric strike analysis on these data reveal complex and variable strike directions both laterally and with depth, highlighting the need for 3D modelling, although locally 2D models can still be reliable.

In general, the models reveal a resistive upper crust that is crosscut by several near-vertical, low resistivity zones. In some instances, the low resistivity zones can be correlated with the locations of major shear zones or tectonic unit boundaries, or the effects of these structures. A conductive zone in the lower crust below the Northern Foreland and the Biranup Zone coincides with a non-reflective lower crustal zone observed in seismic reflection data, and with a region of thicker crust determined from passive seismic data (Figs 1, 2). This, and other regions of conductivity variation in the deep crust and mantle, are locally oblique to surface geological strike.

As with other geophysical datasets (e.g. seismic reflection, passive seismic, gravity), it is apparent that the lower crust, and perhaps parts of the middle and lower crust, may have different geological trends to the upper crust. This likely reflects significant detachment and perhaps rotation during Proterozoic magmatism and deformation. A lack of evidence of the northwesterly trending Yilgarn Craton terrane boundaries below the orogen are consistent with this, and suggests that these boundaries are now cryptic due to Proterozoic modification. As with the 2D profiles, there is some evidence for a more conductive Proterozoic mantle in the vicinity of the zone of increased crustal thickness compared to the Archean mantle, with less variation to the southeast.

Download a free PDF of **GSWA Report 189**
A magnetotelluric survey across the east Albany–Fraser Orogen, Western Australia
by J Spratt, MC Dentith and CV Spaggiari from the DMIRS eBookshop.

This work was a collaborative project with CET and Moombarriga Geoscience.

For more information, contact **Catherine Spaggiari**.

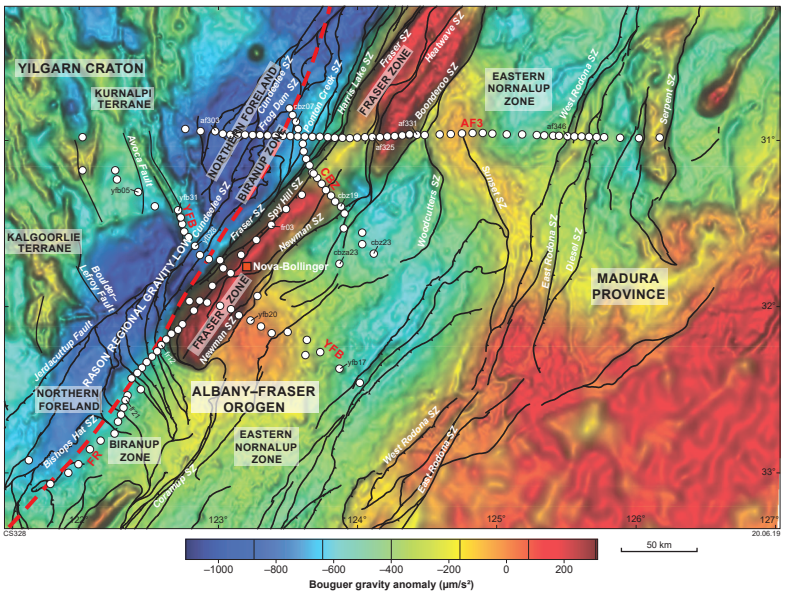

Figure 1. Bouguer gravity image showing the locations of the magnetotelluric (MT) survey lines and selected MT stations, the Fraser Zone, the Rason Regional Gravity Low, and major structures. The red dashed line shows the approximate axis of the zone of thickened crust, derived from passive seismic data and receiver function analysis (Sippl et al., 2017, GSWA Report 177). Abbreviation: SZ, Shear Zone

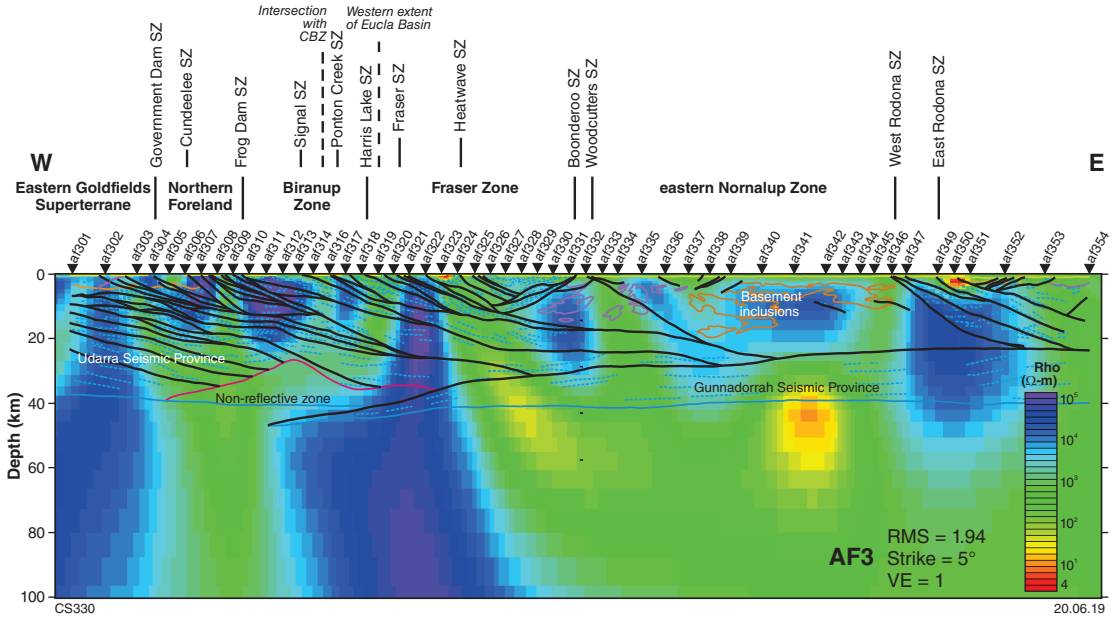

Figure 2. Selected 2D model from the AF3 transect overlain with interpretation linework of seismic reflection profile 12GA-AF3 (Spaggiari et al., 2014, GSWA Record 2014/6). Warm colours represent areas that are conductive and blue colours represent areas that are resistive

Mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton

The Youanmi Terrane hosts voluminous mafic–ultramafic magmatic rocks, which yield an extensive rock record between 3.01 and 2.72 Ga in the western Yilgarn Craton. The terrane is unique globally in that it preserves a high proportion of these rocks as intrusions (often layered), forming 40% of greenstone belt units.

Between 2009 and 2015, 1:100 000-scale regional mapping by the Geological Survey of Western Australia (GSWA) covered the majority of mafic–ultramafic intrusions of the Youanmi Terrane. A 1:200 000-scale geological map covers the largest layered intrusions — Windimurra, Youanmi, Atley and Narndee igneous complexes (see the map **Layered intrusions of the Youanmi Terrane, Yilgarn Craton**). Through accompanying geochronological work, a stratigraphic–magmatic framework was established. Integrated geochronology, geochemistry, stable isotope data and geophysical data has provided the basis for categorizing these intrusions in terms of chronostratigraphic context, 3D geometry, chemical suites and mantle source characteristics.

GSWA Report 192 Mafic–ultramafic intrusions of the Youanmi Terrane, Yilgarn Craton details field observations, contact relationships and structural observations with four suites identified at 2.81, 2.80, 2.79 and 2.72 Ga, these being the Meeline, Boodanoo, Warriedar and Yalgowra suites, respectively. There are eight large layered 'igneous complexes' (at formation level), which are commonly subdivided into zones based on cumulate mineral assemblages (Figs 1, 2). There are ten named 'gabbros' (at member level), which are locally layered, but are not readily categorized into zones. Hundreds of smaller sills associated with the Warriedar and Yalgowra suites typically have minor, coarse lithological layering and are unnamed. There is an accompanying field guide, which covers the key sections of outcrop (**GSWA Record 2016/6 A field guide to the mafic–ultramafic layered intrusions of the northern Youanmi Terrane** and **Virtual tour of the mafic–ultramafic intrusions of the Youanmi Terrane**).

Samples from these suites yielded an array of petrographic textures, some present in all suites and some unique to individual intrusions, which are summarized in the 'Suite descriptions' section. The Report describes the lithogeochemistry of these samples and shows that there are distinct chemical trends associated with each suite. This allows for the correlation of intrusive suites to particular volcanic portions of the Murchison Supergroup stratigraphy, forming a new perspective on the progression of magmatism from 2.82 to 2.72 Ga (Fig. 3). The distribution of the Warriedar and Yalgowra Suites is strongly correlated with coeval mafic volcanic rocks in the Youanmi Terrane, indicative of their subvolcanic intrusive setting.

Stable and radiogenic isotope work has allowed for an assessment of the nature and extent of mantle vs crustal input into the intruded magmas, which has implications for the geodynamic development of the Youanmi Terrane (summarized in **GSWA Record 2016/6**). The isotopic and geochemical data from the intrusions in this study indicate that at 2.81 Ga, a mantle plume was focused on the juvenile 'Cue isotopic zone' of weak, 2.95 Ga lithosphere, resulting in the Meeline Suite and parts of the basaltic stratigraphy of the Norie Group. This was followed by a more widespread, chemically diverse, locally subduction-related, series of mafic–ultramafic magmas during the deposition of varied basaltic rocks of the Polelle and Glen Groups from 2.80 to 2.72 Ga.

Potential field data have been used, in combination with surface mapping, to model the geometry of a few of the larger igneous complexes (**GSWA Record 2015/12 The Windimurra Igneous Complex, Yilgarn Craton: an Archean layered intrusion revealed by seismic data and 3D modelling** and **Windimurra, 2015: 3D Geomodel Series**), showing that, for example,

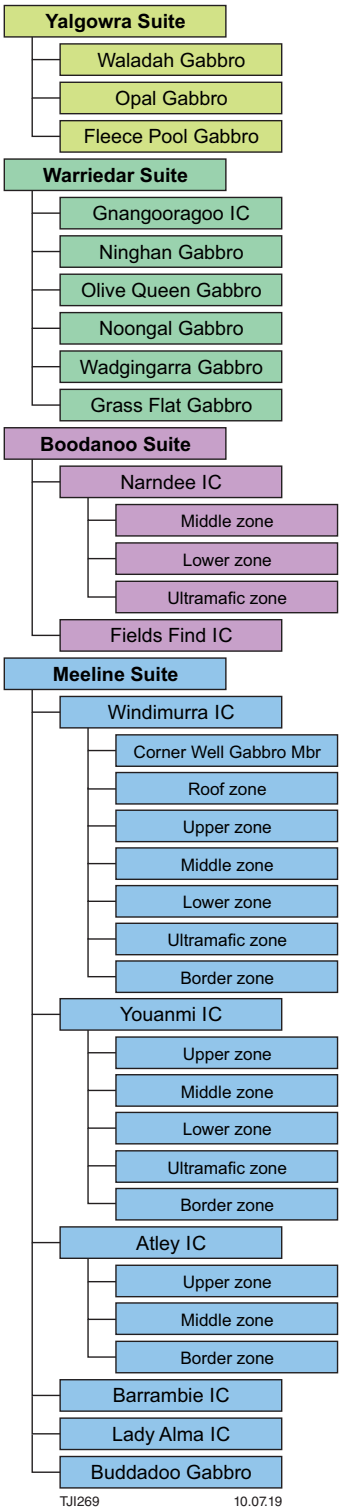

Figure 1. Summary of named mafic intrusive units in this study. Abbreviation: IC, igneous complex

the Windimurra Igneous Complex is 26 000 km^3 and 11 km deep, and is thus the thickest documented layered intrusion on Earth. The geometric relationships within intrusions have augmented understanding of magma chamber processes. The Windimurra Igneous Complex is a multi-lobed and highly discordant body with a crosscutting upper zone sheet, with similarities to the Bushveld Complex. Documentation of the volume of magma involved has shown that the Meeline Suite is the fourth most voluminous suite of such rocks on Earth (Fig. 4).

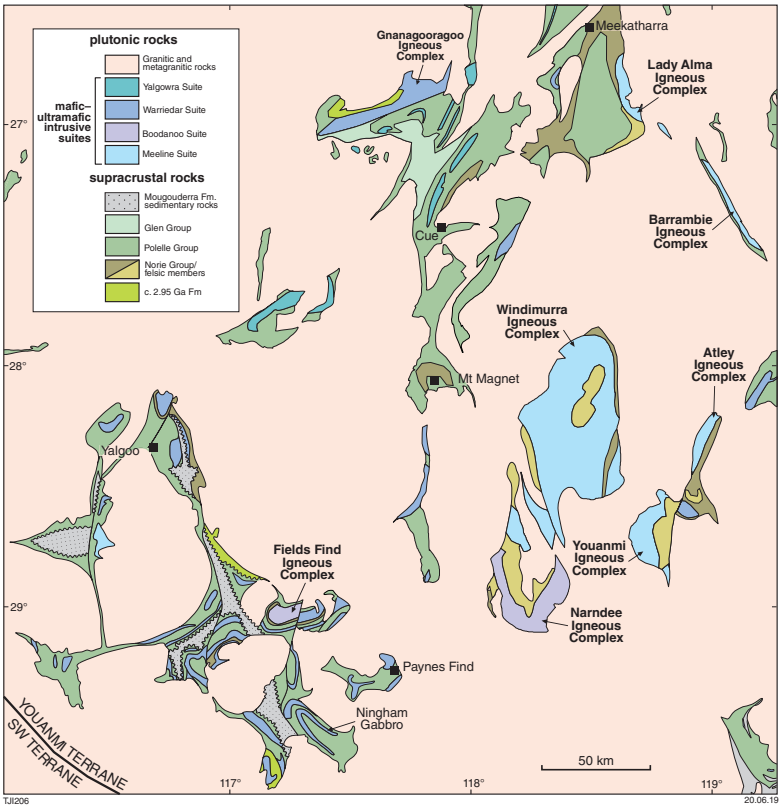

Figure 2. Simplified geological map showing mafic–ultramafic intrusive suites of the northern Youanmi Terrane

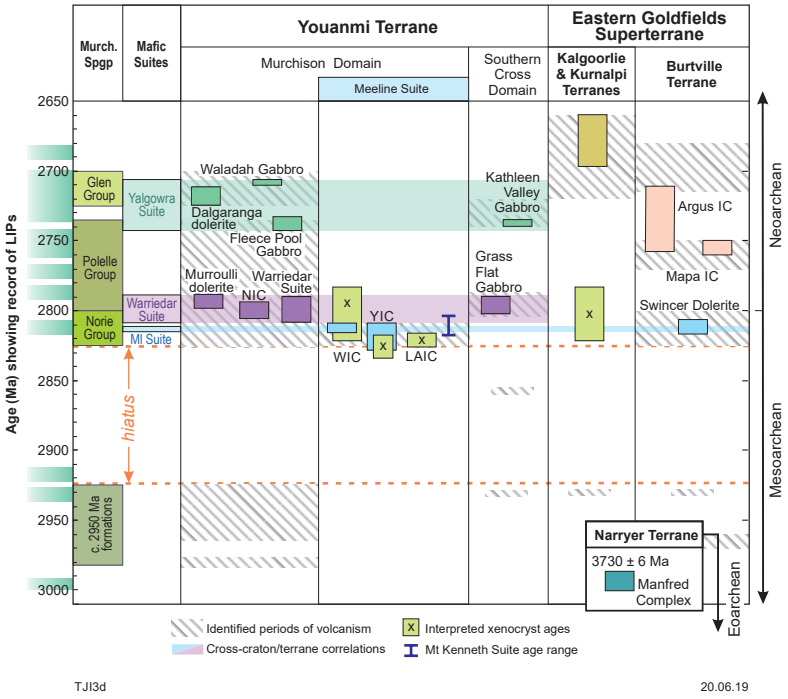

Figure 3. Time–space plot of dated mafic intrusive events (uncertainties shown as 2σ) across the Yilgarn Craton, showing relation to episodes of volcanic activity and the record of global large igneous provinces

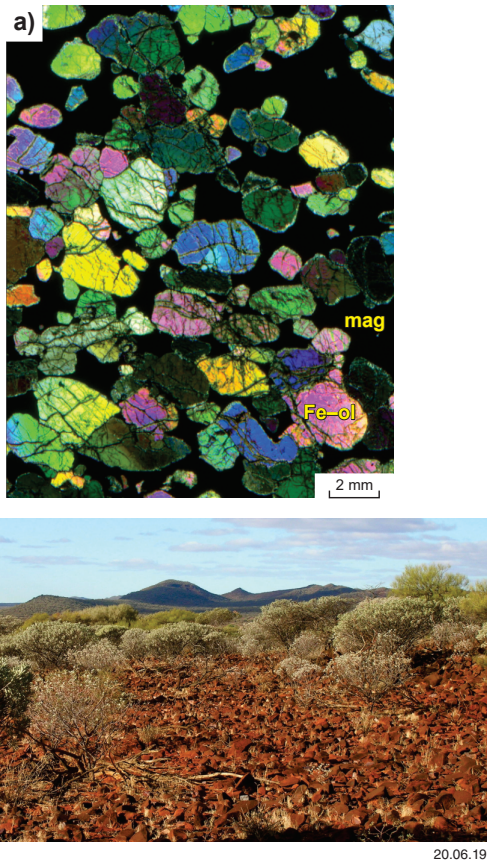

Figure 4. a) Photomicrograph in cross-polarized light of MNDD002-114 showing 4 mm cumulus fayalitic olivine crystals set in interstitial magnetite–ilmenite grains from the Canegrass prospect, upper zone, western lobe, Windimurra Igneous Complex; b) field photo of dolerite boulders belonging to the upper part of the Gnanagooragoo Igneous Complex forming wide ridges of the Weld Range, with the sharper ridges in the distance being composed of abundant rafts of banded iron-formation within dolerite

The voluminous magmatic systems identified in this Report have had far-reaching effects on the Yilgarn Craton lithosphere, such that they are a primary control for the distribution of orthomagmatically and hydrothermally derived metals within the Youanmi Terrane. Therefore, regional exploration for almost all metal commodities will benefit from an understanding of their geologic history and distribution.

Key orthomagmatic Cr–Cu–Ni–PGE and V–Ti–Fe mineralized sections have been placed into context within mineral zone stratigraphy of several intrusions described in this Report. A major separation of suites is evident where vanadiferous magnetite is present in the Meeline Suite and not others. Occurrences of chromite and Ni–Cu–PGE are found in all suites; however, possibly due to large portions of unexposed ultramafic rocks, not all Meeline Suite intrusions host these types of deposits.

For more information, contact **Tim Ivanic**.

Filling the data gap in Western Australia

The Kidson Sub-basin deep crustal seismic survey was released at the Brisbane APPEA conference on 27 May 2019. This seismic project was co-funded by the Commonwealth Government's Exploring for the Future program and the Western Australian State Government's Exploration Incentive Scheme.

Prior to the survey, a vast area of the southeastern Canning Basin was very poorly covered by seismic data compared to other parts of the Canning Basin, and consequently was one of the least geologically understood potential hydrocarbon provinces in onshore Australia. The nature of basement beneath the basin was also poorly understood. The main objectives of the survey were to:

- establish the subsurface geology of the Kidson Sub-basin and other components of the southern Canning Basin, including the extent and nature of sub-basin boundaries and troughs
- identify regional faults, folds and other structural elements
- image the structure of the basement below and adjacent to the southern Canning Basin, including the extent of major tectonic units such as the Centralian Superbasin, the west Arunta Orogen, the Paterson Orogen and the Pilbara Craton, and the nature of their boundaries.

In order to fill the data gap and investigate the tectonic architecture of the region, the Geological Survey of Western Australia (GSWA) in collaboration with Geoscience Australia (GA) acquired the deep crustal seismic survey along the road that links the Kiwirrkurra community in the east to Marble Bar in the west, with a total length of 872 km (Fig. 1). GA, as the project operator, contracted Geokinetics (now SAExploration) to carry out data acquisition and Velseis undertook the data processing.

The final data across the survey is of good quality, particularly in the Kidson Sub-basin, showing continuous parallel reflectors across the depocentre and faulting near the basin margins

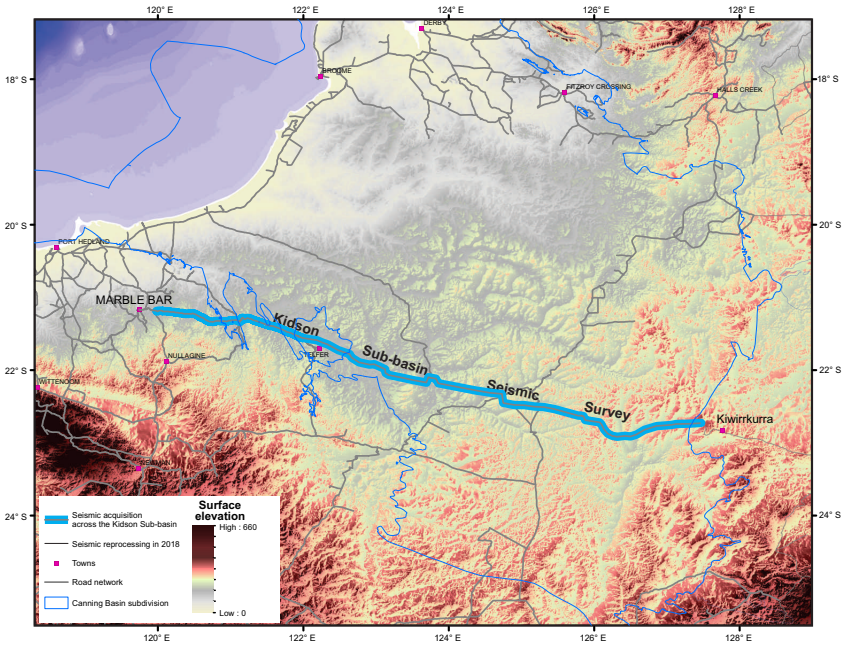

Figure 1. Location of the Kidson Sub-basin seismic survey (in blue)

(Fig. 2). Constraints from nearby petroleum exploration well Kidson 1, as well as projections from more distant offset wells including Frankenstein 1, Patience 2, Wilson Cliffs 1 and Contention Heights 1, will shed light on the Paleozoic stratigraphy and depositional history of the southeast Canning Basin during ongoing detailed interpretation.

Data from the Kidson Sub-basin seismic survey are available for download through GSWA's petroleum database, **WAPIMS**, including the seismic report, navigation, SEG-Y in time and depth domains and velocity profile.

For more information, contact **Alex Zhan**, **Peter Haines** or **Deidre Brooks**.

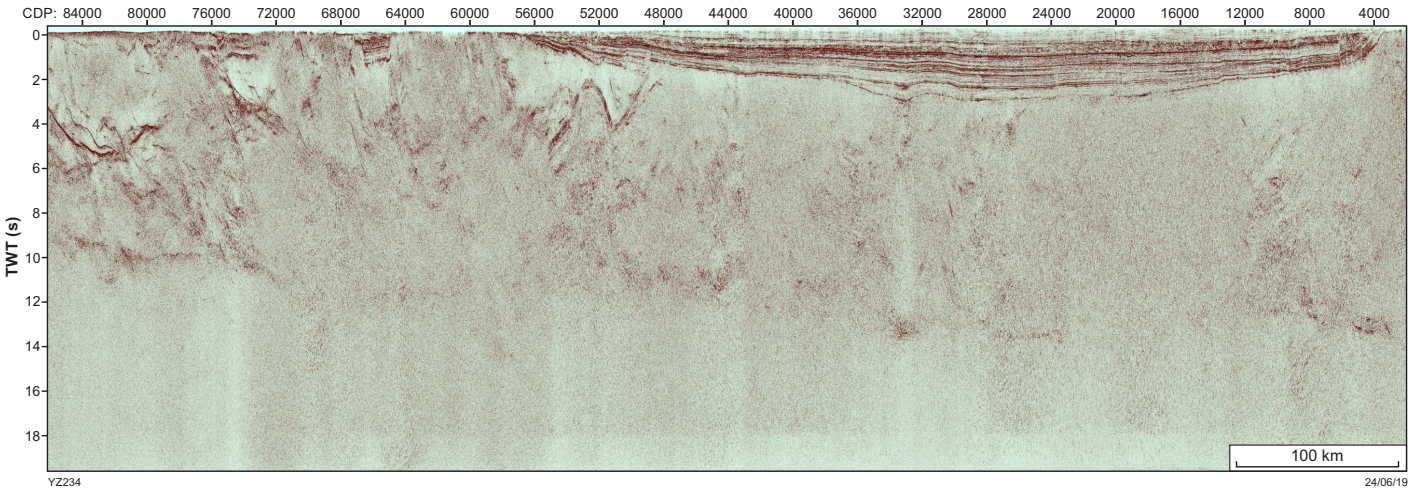

Figure 2. Snapshot of two-way time (TWT) profile across the Kidson Sub-basin seismic survey

Completion of second generation of Western Australia gravity coverage in sight

The data acquisition phase of a new airborne gravity survey over an area of 170 000 km^2 in the Pilbara region in northwest Western Australia (Fig. 1) is complete.

On 23 April 2019, Sander Geophysics' (SGL) airborne survey crews and two aircraft configured with the SGL AIRGrav system started flying the planned 70 000 line-km of survey along 2.5 km-spaced lines. Acquisition was completed eight weeks later on 17 June.

The survey data are now being processed.

The EIS-funded Pilbara survey is the final piece of a long-running collaborative program between the Geological Survey of Western Australia (GSWA) and Geoscience Australia (GA) to bring to completion a new generation of regional gravity coverage of Western Australia. The new coverage has up to 16 times higher resolution than the first generation gravity coverage of the Australian continent by GA's predecessor, the Bureau of Mineral Resources, between 1959 and 1975.

Final data should be publicly available during Q4/2019. Progress updates are posted on the Department of Mines, Industry Regulation and Safety **website** or you can subscribe to the **GSWA mailing list** for advance notice of the data release date when it has been set.

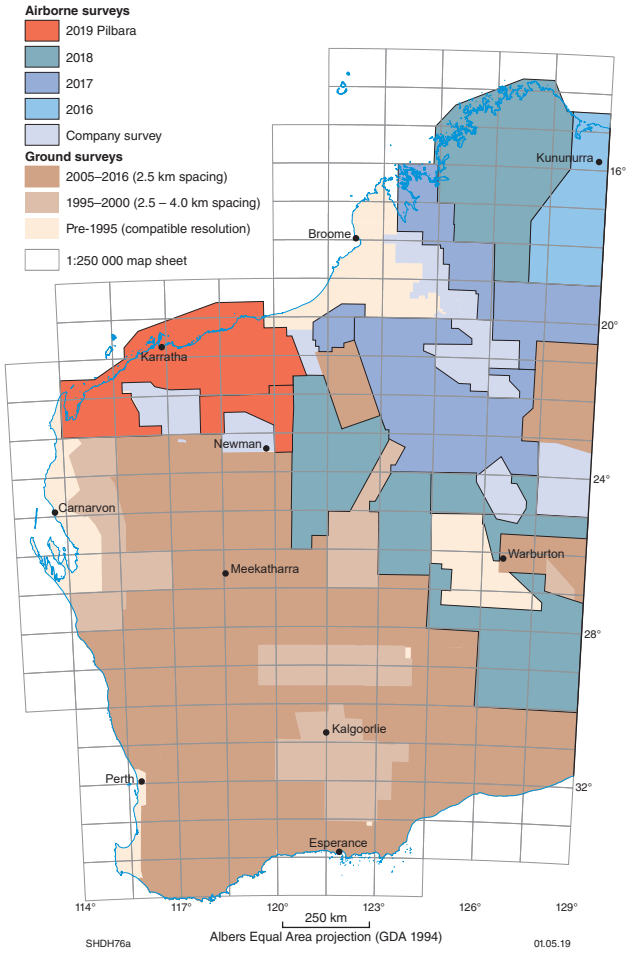

Figure 1. Progress of Western Australia 'second generation' gravity coverage

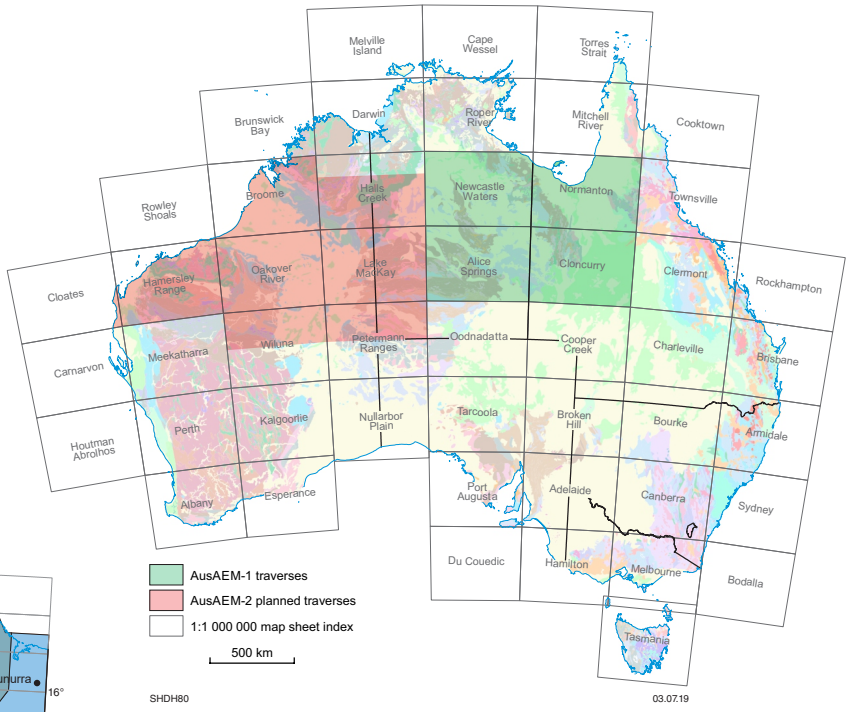

Figure 2. AusAEM traverses over GA Surface Geology of Australia

AusAEM-2

GSWA has entered into a National Collaboration Framework Agreement with GA for an extension of GA's Exploring for the Future AusAEM project into northern Western Australia (Fig. 2).

In the first stage of the AusAEM project during the 2017 and 2018 field season, GA, in collaboration with the Northern Territory Geological Survey and the Geological Survey of Queensland, acquired 60 000 line-km of data at a nominal 20 km line spacing covering an area of more than 1 000 000 km^2, spanning the Mt Isa and Tennant Creek mineral provinces. Data from AusAEM-1 are available from **GA**.

The new AusAEM-2 stage is even larger than AusAEM-1, with a planned 72 000 km of 20 km-spaced traverses covering a vast tract of 1.4 million km^2, extending from Western Australia's Pilbara to the Tanami of the Northern Territory. Data acquisition began on 22 May with CGG Aviation (Australia) flying its TEMPEST AEM system out of Derby in northwestern Western Australia.

For more information about Pilbara gravity, contact **David Howard** or for information about AusAEM-2 visit the **GA website**.

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Friday 13 September 2019

9.00 am – 4.00 pm

Followed by a Sundowner

Hyatt Regency Hotel Perth

99 Adelaide Tce Perth

Immediately following the GOOD OIL CONFERENCE

Find out what is going on with petroleum – now and in the future in Western Australia

This is a great opportunity to hear presentations and view posters showing the recent activities and information relevant to the Western Australian petroleum industry by staff from the Department of Mines, Industry Regulation and Safety, the Commonwealth as well as industry leaders.

Exhibits and staff from DIIS, Geoscience Australia, NOPTA, NOPSEMA, PESA, WA:ERA, Australian Marine Complex, PAWSEY and NERA are planned.

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by Fielding, IOH

Report 195 The cooling and exhumation of the Albany–Fraser Orogen, Western Australia, constrained by $^{40}Ar/^{39}Ar$, Rb/Sr and U/Pb thermochronology
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by Allen, JH and Haines, PW

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Mineral deposits and major petroleum projects, Western Australia — 2019
by Cooper, RW, Jones, JA, Wyche, NL, Strong, CA, Irimies, F and Dunbar, JR

Western Australia Atlas of mineral deposits and major petroleum projects 2019
by Cooper, RW, Jones, JA, Wyche, NL, Strong, CA and Irimies, F

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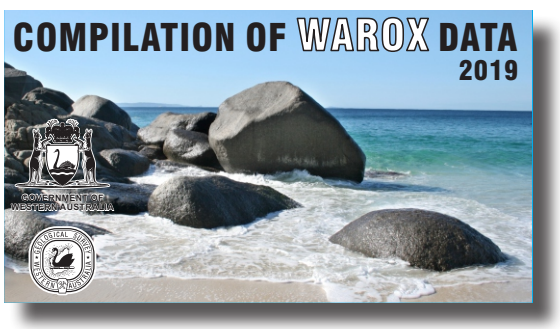

GSWA in the Goldfields — 2019

The Joe Lord Core Library in Kalgoorlie will be the venue for **GSWA in the Goldfields** to be held on **Thursday 28 November 2019**. There will be presentations with an introduction and welcome by Ian Tyler, Director, Geoscience, GSWA. Various core will be on display.

In the evening, the **Raglan Drilling Geology Lecture Series** will again be held at Hannans Club, 44 Brookman St, Kalgoorlie.

More information will follow in due course so make sure you save the date!