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Fieldnotes

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Geological Survey of Western Australia

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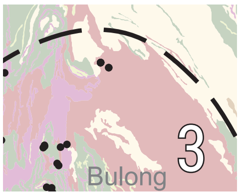

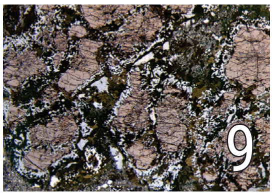

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Fieldnotes

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: Kalgoorlie in the Goldfields. Photograph courtesy of Imagevixen, Adobe Stock

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A geochemical approach to understanding greenstone stratigraphy and evolution

A new dataset of ~2800 high-quality whole-rock geochemical analyses of subvolcanic, volcanic, and volcaniclastic rocks from the Kalgoorlie Group is used to construct chemostratigraphic barcodes within the broader Ora Banda – Kambalda region, encompassing most of the previously defined domains of the Kalgoorlie Terrane as well as the Bulong complex area of the Kurnalpi Terrane (Fig. 1). Twenty-six distinct mafic compositional units are identified based on combinations of major and trace element variation diagrams, and in particular, on bivariate plots using strongly incompatible trace elements. These distinctions highlight the controls that various fundamental igneous processes and source compositional variations exerted on evolving magma compositions. There are broad trends in compositional change common to the chemostratigraphy in most areas throughout the region. As described in numerous previous studies, the three commonly identified regional stratigraphic levels (basaltic lower, komatiitic/basaltic middle, and basaltic upper) correspond to changes in tectonomagmatic processes, and in particular, a general increase in the degree of mantle partial melting, an increase in the amount and/or effect of crustal contamination, and an increase in overall magmatic compositional diversity.

According to the new barcode data, individual established lithostratigraphic units, typically comprise at least two distinct geochemical units (Fig. 2). In addition, most of these geochemical units occur in several stratigraphic units, and in most regional stratigraphic columns. Thus, the individual greenstone stratigraphic formations comprise overlapping flow fields, each representing the products of a discrete eruptive event and/or eruptive centres that tapped genetically unrelated magma sources. This potentially makes some stratigraphic formation boundaries somewhat arbitrary reflections of changing source eruptions. Although complex, this diversity ensures that, in most cases, the position of stratigraphically unknown geochemical samples can be uniquely established as long as enough samples are taken over a continuous stratigraphic interval that also incorporates the overlying and underlying units.

Because of the greater continuity of low-viscosity flows that characterize its basalt-dominated stratigraphy, the application of chemostratigraphic barcoding is more reliable or appropriate for the Kalgoorlie Group than for the overlying Black Flag Group. Geochemical characteristics and relationships within the felsic-dominated Black Flag Group, nevertheless, provide broad stratigraphic information and significant insight into crustal architecture and regional geological evolution.

The regional distribution of the mafic chemostratigraphic associations is distinctly asymmetric, in many cases ignoring previously established domain boundaries. However, a broadly north-trending structure incorporating segments of (from south to north) the Zuleika Shear Zone, Abattoir Fault, and the Bardoc Shear Zone (ZAB) does appear to separate the 'western domains' (Coolgardie and Ora Banda) from the 'eastern domains' (Kambalda, Boorara, Parker, and the Bulong complex) (Figs 1, 3).

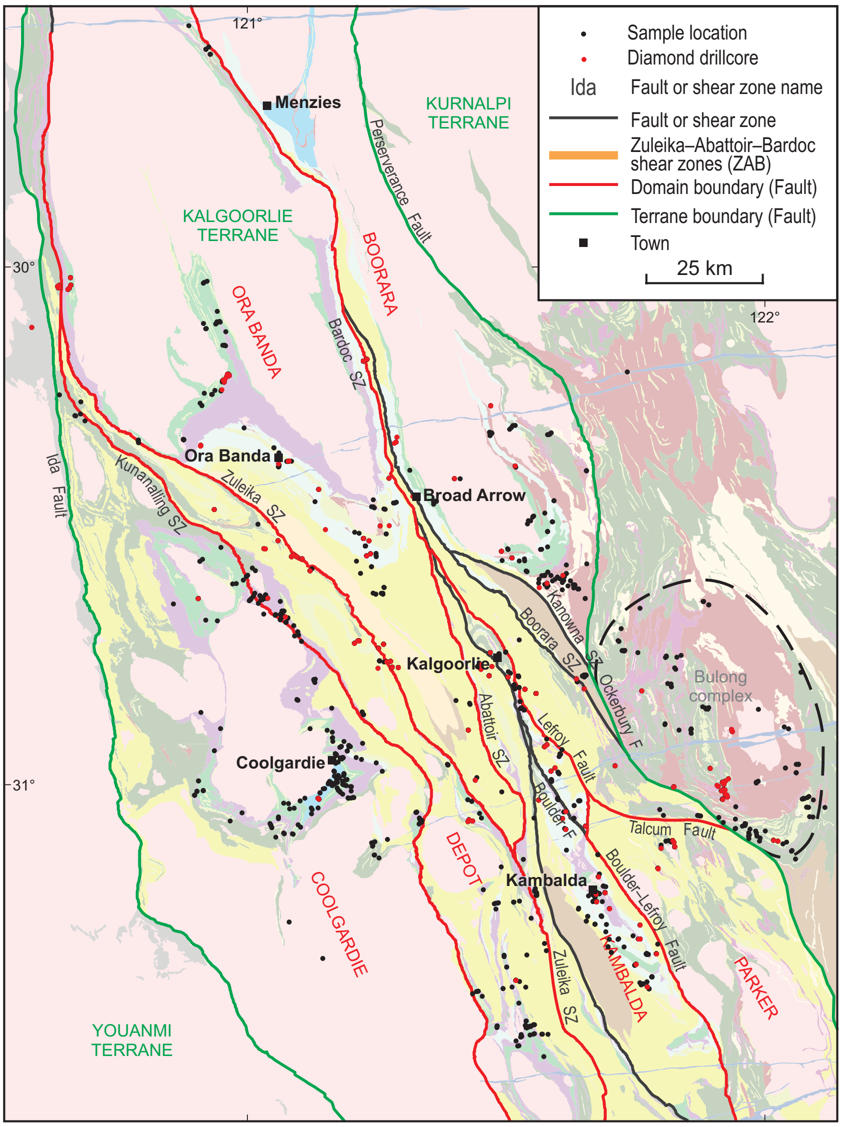


Figure 1. Geological map of the study area within the Kalgoorlie Terrane, showing the distribution of sites where greenstones have been sampled for whole-rock geochemical data, including the locations for diamond drillcore. Diamond drillcore locations are typically the sites of multiple (up to 55) individual samples

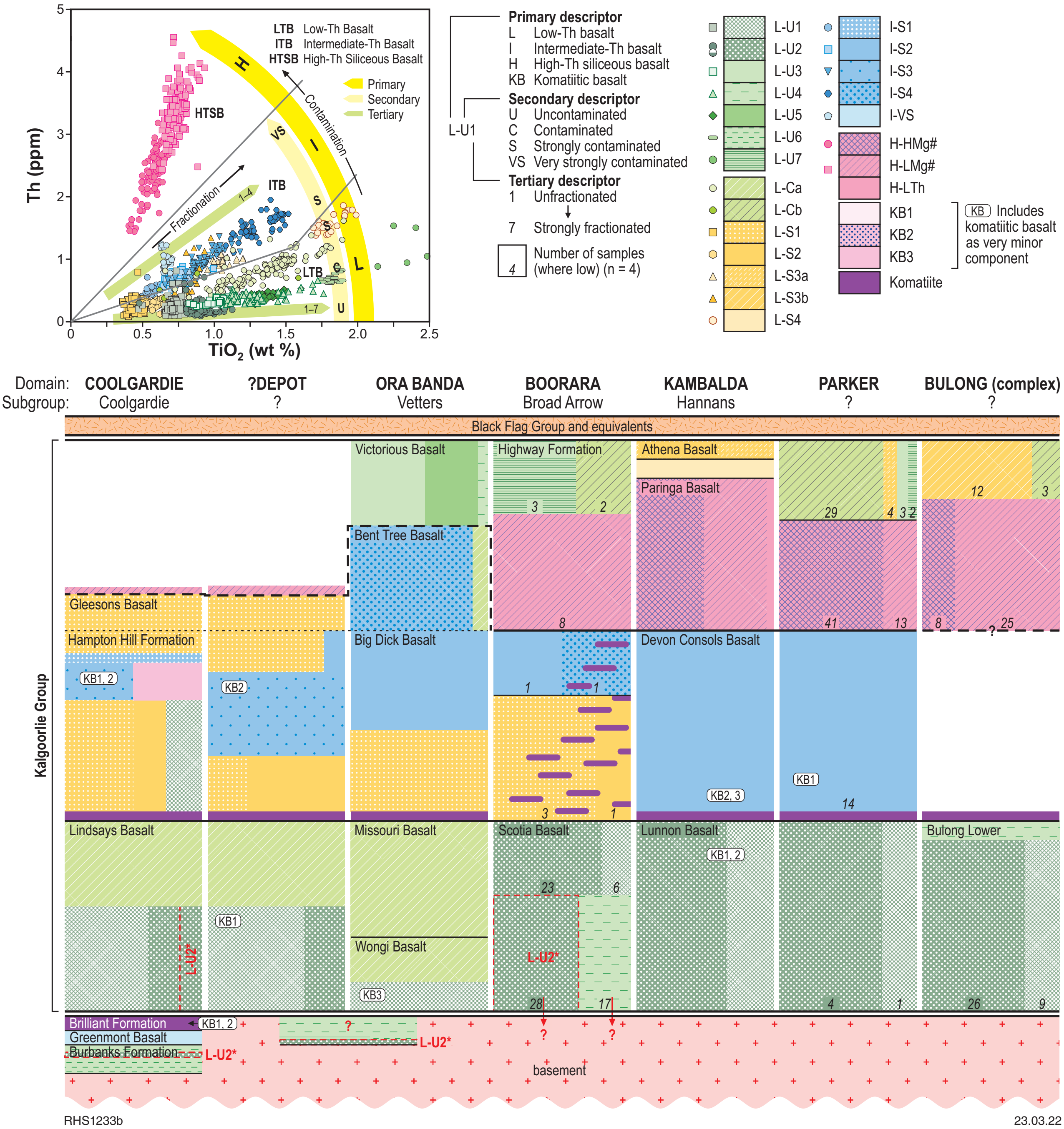


Figure 2. Chemostratigraphic columns representing each of the domain regions within the area studied. The plot of Th with TiO_2 is one of several geochemical variation diagrams used for classification and the rationale used to give unique codes to each specific mafic geochemical unit is also shown

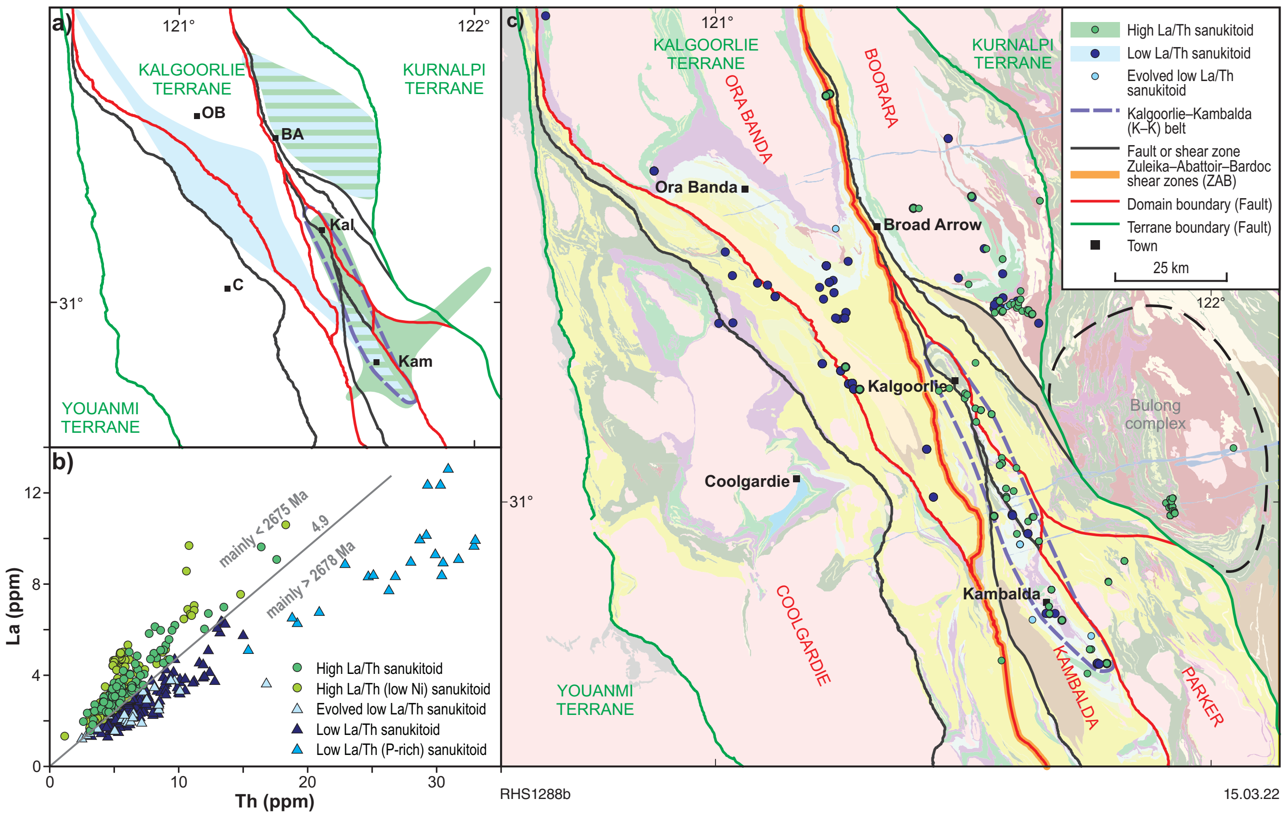


Figure 3. Geological map showing the distribution of samples of the various sanukitoid types and a broad outline of sanukitoid distribution

These domain groups have distinctive chemostratigraphic variations (Fig. 2) that probably reflect a fundamental crustal architectural control and potentially provide some basis for re-assessing the present domain boundaries. In particular, the mafic units in the western domains probably reflect melting of a more depleted source beneath thicker lithosphere. The Ora Banda Domain is clearly a part of the western domains throughout evolution of the lower and middle greenstone stratigraphy, but it also appears transitional to the eastern domains in terms of its diversity of fractionated layered sill-derived magmatism in its upper stratigraphy. The chemostratigraphic differences between the western and eastern domains extend to the felsic units of the Black Flag Group.

The subvolcanic, volcanic, and volcaniclastic rocks of the Black Flag Group have the composition of sanukitoids, which are likely derived from a metasomatically enriched lithospheric mantle source. They show a wide range in La/Th ratios, which broadly correlates with crystallization age, source composition, and location (Fig. 3). Low La/Th sanukitoid is typically older (>2678 Ma), derived from a source with less radiogenic Nd (i.e. is more crustal) and is more common west of the ZAB. High La/Th sanukitoid is typically younger (<2675 Ma), has more mantle-like isotopic compositions and is virtually restricted to east of the ZAB. The simplest explanation for the regional compositional variations in the mafic and felsic rocks is that the ZAB is the exposed trace of a structure separating compositionally contrasting translithospheric domains. Northern and southern extensions of that trace should be entirely identifiable based on geochemical and isotopic data.

The interpretations of data presented here have been significantly influenced by a wealth of field and laboratory experience and expertise from government, industry and university investigators. The interpretations, nevertheless, remain heavily based on geochemical trends and their validity or applicability needs to be carefully considered on a case-by-case basis in light of local geological context. However, the data do show clear, persistent and systematic composition variations that should be highly informative on a number of levels. It is hoped that the geochemical barcodes provide an accurate and useful stratigraphic tool from the mine site to the regional scale. The applicability of the barcodes to greenstone stratigraphy outside of the study area has not been tested yet, although it is clearly expected to decrease.

Report 226 Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag Groups – Ora Banda to Kambalda region will be available on the DMIRS eBookshop.

For more information, contact **Hugh Smithies**.

New Reports complement EIS drilling

The Geological Survey of Western Australia (GSWA) has commenced a regional petrophysical data acquisition project to improve understanding of the links between geophysical datasets and significant geological units. This project is funded by the Exploration Incentive Scheme (EIS) and complements both the EIS Co-funded Drilling Program and GSWA's regional geophysics acquisition.

To date, GSWA has acquired and published petrophysical datasets from the Paterson Orogen, West Arunta and Eucla basement. The most recent petrophysical report releases are from the Kalgoorlie Terrane (Report 224) and Yamarna Terrane (Report 225). These Reports describe the petrophysical methods used, and provide an analysis of the eight physical properties acquired from the Kalgoorlie and Yamarna Terrane drillcore samples.

To illustrate how this data can be used, physical property measurements from mineralized Kalgoorlie Superpit drillcore SCGD 007D (Fig. 1a) have been processed using CSIRO's free **Data Mosaic Web App**. Univariate and multivariate tessellation methods have been used to determine major boundaries in the petrophysical dataset. For the magnetic susceptibility data, major boundaries occur at mineralized lodes within Unit 9 of the Golden Mile Dolerite (Fig. 1b). When this method is applied to all seven physical properties (magnetic susceptibility, dry bulk density, porosity, P-wave velocity, chargeability, conductivity and galvanic resistivity), the strongest boundaries occur within the Black Flag Group and at the contact between the Black Flag Group and the porphyritic unit (Fig. 1c).

How to access

Report 224 Regional petrophysics: Kalgoorlie Terrane 2020–21 and **Report 225 Regional petrophysics: Yamarna Terrane 2020–21,** both by M Markoski, J Trunfull and B Bourne, are available as free downloadable PDFs from the Department of Mines, Industry Regulation and Safety (DMIRS) eBookshop.

For more information, contact **Lucy Brisbout**.

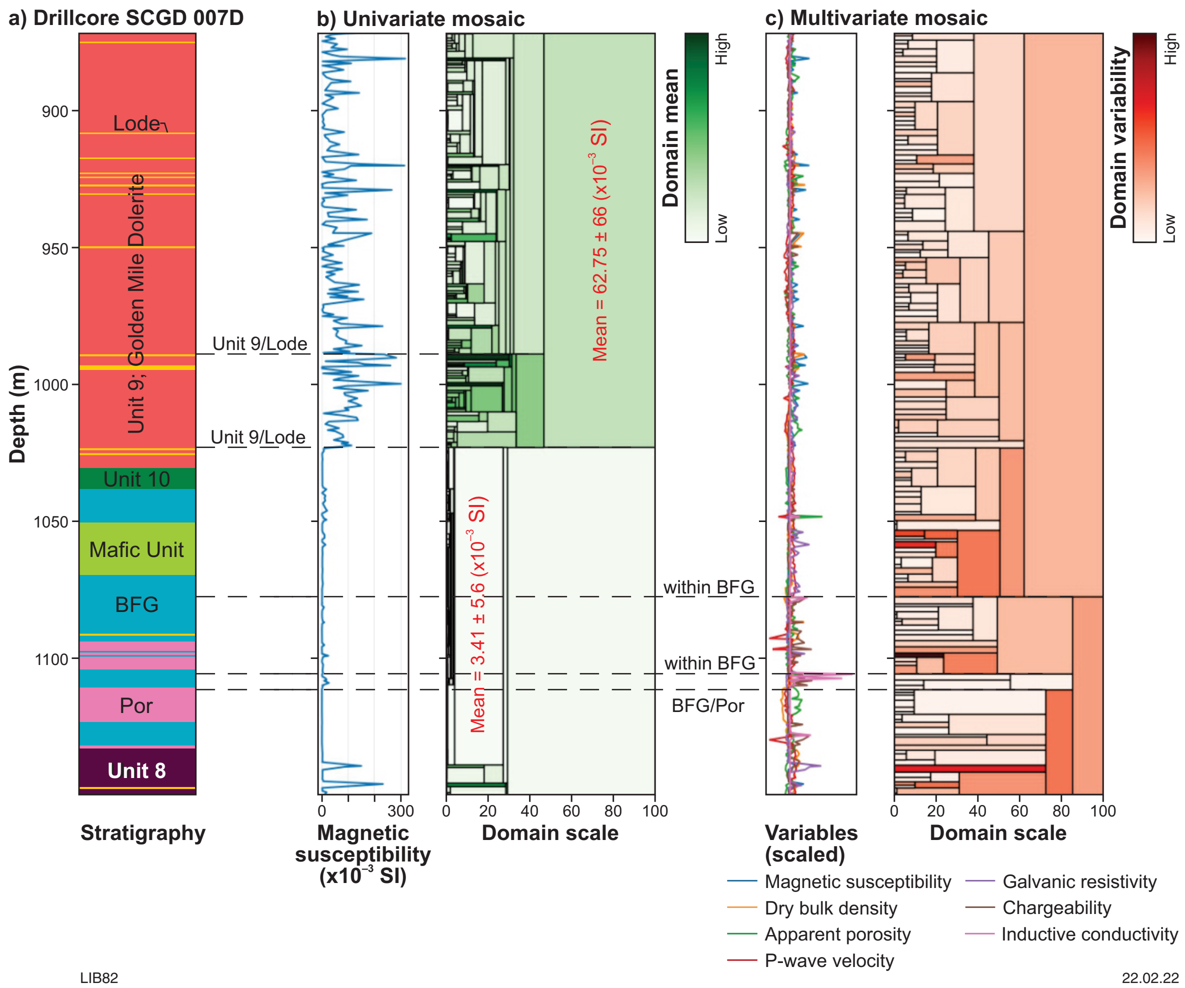


Figure 1. Petrophysical data from drillcore SCGD 007D, processed in CSIRO's Data Mosaic software. SCGD 007D intersects Units 8 to 10 of the Golden Mile Dolerite, the overlying (but down core) Black Flag Group (BFG) and intrusive mafic (Mafic Unit) and porphyritic units (Por). Data from SCGD 007D was originally acquired by Terra Petrophysics for Newmont, and has been donated to this project by Northern Star: a) stratigraphic log for sampled intervals (logged by Newmont geologists); b) boundaries/domains for downcore magnetic susceptibility data; c) boundaries/domains for all downcore petrophysical data

Characterizing cover in hard rock environments

Ever wondered how deep the regolith is on your tenement? The Geological Survey of Western Australia (GSWA) has sponsored a Master's thesis that investigates various seismic methods, and the use of other than primary (P) waves, to characterize the cover in the hard rock environments at the Ravensthorpe mine site, Western Australia (Fig. 1). The study deployed Reflection, Refraction, and Multichannel Analysis of Surface Wave (MASW) along a pre-selected transect. Three different source types were used:

- 45 kg weight drop
- shear plate
- Betsy gun.

Each source was recorded by three different receiver types:

- three-component geophones with spikes
- single component nodal geophone acting as buried receiver
- optical fibre.

Although the results show that the reflection survey with 45 km weight drop shows significant depth of penetration over 400 m, the combination of all methods greatly exceeded the value of each individual technique.

How to access

GSWA Report 220 Depth to basement estimates form seismic data – a comparative study by A Yang is available as a free downloadable PDF from the Department of Mines, Industry Regulation and Safety (DMIRS) eBookshop.

For more information, contact **Sara Jakica**.

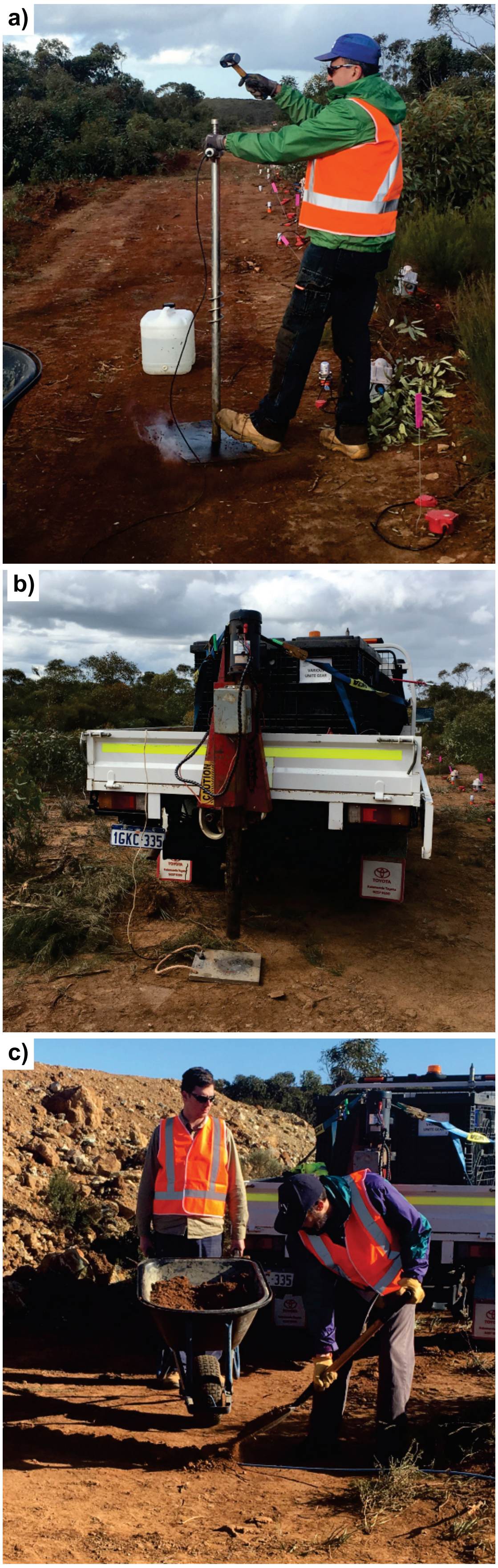


Figure 1. a) Betsy gun being used to generate P wave. Gun is planted in the shallow hole and triggered by hitting the firing pin using a small hammer;
b) 45 kg accelerated weight drop as a source to generate high power P-wave energy;
c) fibre-optic cable being buried in the ground for distributed acoustic sensing (DAS) acquisition

John de Laeter Centre

Curtin University

NGAANYATJARRA

New Ordovician basin margin succession discovered in the Cobb Embayment

The Cobb Embayment is a 140 km long and up to 40 km wide eastern extension of the Canning Basin overlying basement rocks of the Musgrave region. The embayment received very little attention and was assumed to be filled with upper Carboniferous – lower Permian glaciogenic rocks until recent field studies by the Geological Survey of Western Australia (GSWA) discovered Ordovician fish and trace fossils within the sparse outcrops now named the Cobb Formation (Fig. 1). Although Ordovician marine strata are widespread in the subsurface, and prospective for hydrocarbons, this is only the third known exposure of the Ordovician succession in the Canning Basin, the others being about 700 km to the north.

Under the new interpretations, the Cobb Embayment was initiated during the early history of the Canning Basin, controlled by late movements on the Woodroffe Thrust that coincides with the southern boundary of the embayment. The embayment is largely filled by a siliciclastic succession deposited under marginal marine, estuarine and lagoonal settings, with peripheral fluvial and alluvial fan deposits. Geophysics suggests the embayment is filled with a wedge-shaped package of strata up to 800 m thick against the thrust. Detrital zircon geochronology indicates the succession is a mixture of minor locally sourced sediment combined with a greater component washed landwards from the marine realm, as is typical of estuaries. The Cobb Formation shows similarities with other similar aged marginal marine siliciclastic units of the Canning Basin, including the outcropping Carranya Formation of the Billiluna Shelf, and the recently recognized subsurface Barnicarndy Formation of the Barnicarndy Graben. Similar Ordovician basin margin deposits may be more widespread in the subsurface, but the thin successions of the basin margin are rarely drilled.

How to access

GSWA Report 222 Cobb Embayment: Ordovician syntectonic siliciclastic deposition on the eastern margin of the Canning Basin, Western Australia by PW Haines, HJ Allen, MTD Wingate, Y Zhan, LM Dent and Y Lu is available as a free downloadable PDF from the Department of Mines, Industry Regulation and Safety (DMIRS) eBookshop.

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

Figure 1. Isolated sandstone outcrop in the Cobb Formation type area. Inset: Float blocks of sandstone displaying Cruziana arthropod trace fossils on soles

New multidisciplinary study unravels the 300 Ma-long tectonic evolution of the Ida Fault

The Yilgarn Craton exposes crustal-scale shear zones juxtaposing ribbon-like terranes that contain linear greenstone belts concordant with elongate granitic plutons. Report 227 focuses on the tectonic evolution of the Ida Fault, which is exposed in the central part of the craton, representing its most prominent tectonic boundary. The structural architecture of the area was mainly shaped during two major events of synmagmatic transpression, along the Ballard (Fig. 1) and Waroonga shear zones, in the 2680–2650 Ma time span, i.e. in the mature stages of the 2730–2650 Ma Yilgarn orogeny. The pre-2680 Ma tectonic evolution of the area is cryptic, and includes:

1. c. 3000 Ma rifting event followed by basin deepening and development of the 2960–2750 Ma Youanmi greenstones
2. Basin inversion and subduction (along the Ida Fault) of the eastern portion of the Youanmi Terrane (Fig. 2) under the Eastern Goldfields Superterrane, during the 2730 Ma onset of the Yilgarn orogeny
3. Development of the 2720–2690 Ma Kalgoorlie Group, which was unconformably emplaced above the Youanmi Terrane greenstones.

This case study stresses that multidisciplinary studies play an essential role in unravelling the protracted, complex and partially cryptic tectonomagmatic evolution of the Archean lithosphere.

GSWA Report 227 Tectonomagmatic evolution of a major Archean terrane boundary: the Ida Fault, Yilgarn Craton will be released this financial year.

For more information, contact **Ivan Zibra**.

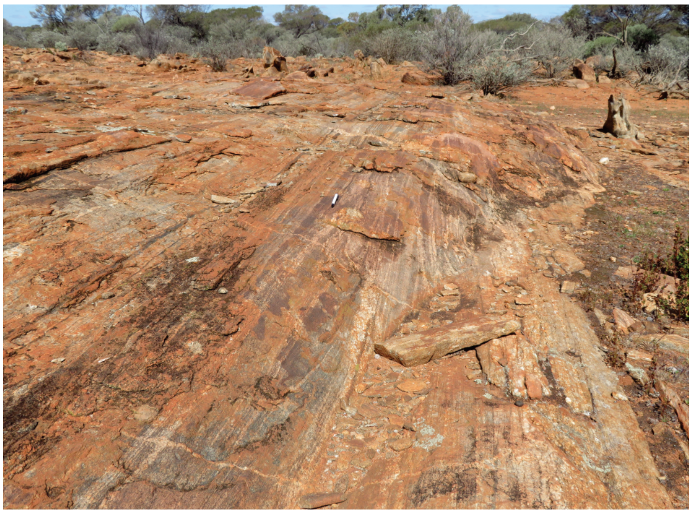


Figure 1. Strongly deformed, layered granite exposed along the Ballard shear zone, near Leonora

Figure 2. Garnet–pyroxene–quartz gneiss, representing an eclogite-facies metabasalt, exposed along the Waroonga shear zone, near Agnew. This rock testifies that c. 2820 Ma volcanic and sedimentary rocks of the Youanmi Terrane, originally deposited on the ocean floor, were subsequently buried to a ~30 km depth, during the Yilgarn orogeny

Monitoring the Arthur River earthquake swarm

On 5 January 2022, the residents in the Southern Wheatbelt were in for a shock – quite literally. They experienced a magnitude 4.0 earthquake. Reports from the area tell of cracks in houses and pictures falling off the walls. However, as yet, no surface rupture has been found. Although the State's southwest is known to be one of the most seismically active regions in Australia, this event came as a surprise to many and there was more in store for this normally quiet community.

To accurately locate an earthquake and its aftershocks, monitoring stations surrounding the event sequence are critical (Fig. 1). A team from the Geological Survey of Western Australia (GSWA) rapidly mobilized and added another eight instruments in the epicentral area as defined by Geoscience Australia. Days after this deployment, a magnitude 4.8 earthquake occurred in the region resulting in ground shaking six times stronger then the initial tremor, and was felt from Albany to Perth. In the first three weeks of the GSWA deployment, Geoscience Australia recorded 94 much smaller events using only the national network of seismometers. When the rapid deployment data were analysed, over 900 earthquakes were identified with magnitudes down to –0.3 in a tight cluster just west of Arthur River (Fig. 2). The earthquake sequence will either continue to produce moderate-magnitude earthquakes, or will simply fade away. The objective now is to see if a fault plane can be defined and ground shaking can be measured accurately to improve the understanding of seismic risk in the area.

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

Figure 1. A typical installation for evaluation of seismic risk includes a seismometer (front) and an accelerometer (back) to accurately record seismic waves and ground shaking caused by earthquakes

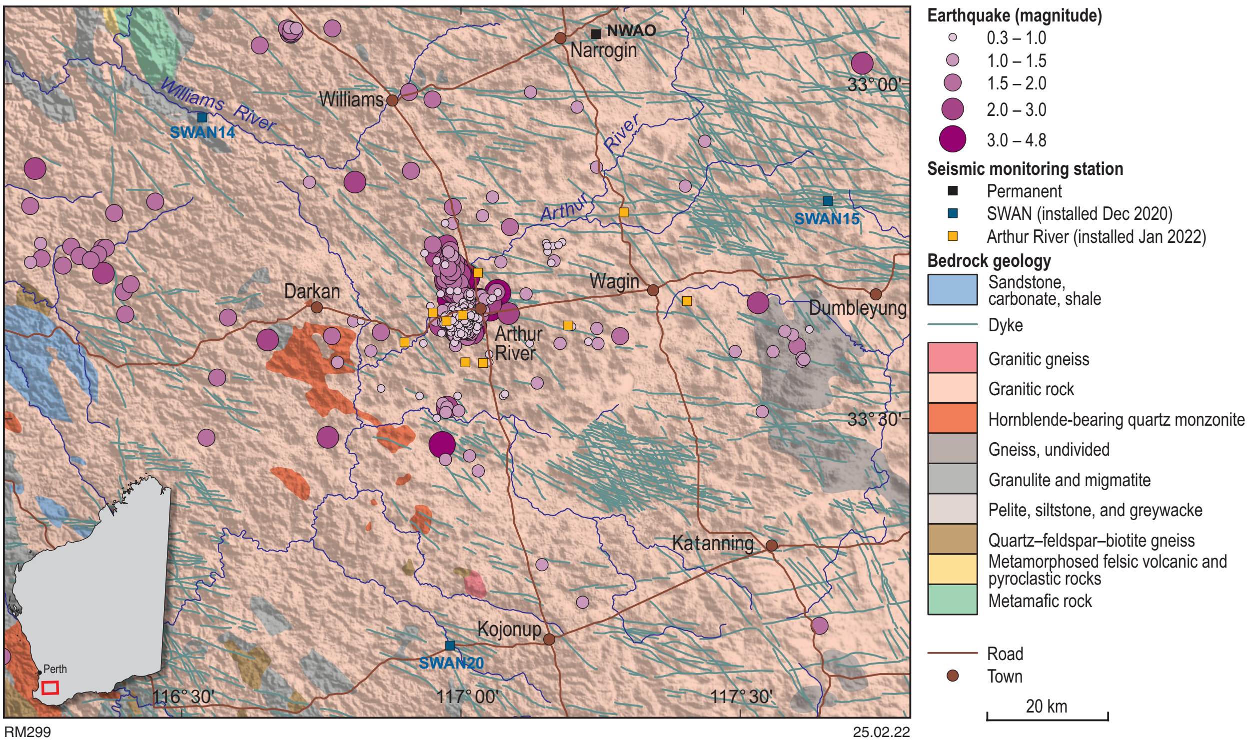


Figure 2. Locations of the earthquakes in the Arthur River area from 5 January to 1 February 2022

Product releases

• BOOKS •

Paleontology reports

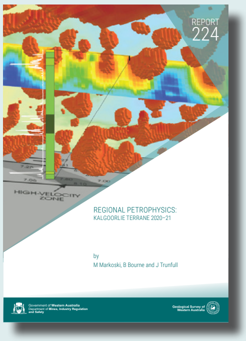
Report 221 Hydrogen storage potential of depleted oil and gas fields in Western Australia – literature review and scoping study
RISC

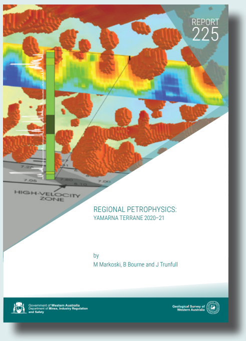
Report 222 The Cobb Embayment: Ordovician syntectonic siliciclastic deposition on the eastern margin of the Canning Basin, Western Australia
Haines, PW, Allen HJ, Wingate, MTD, Zhan, Y and Dent, LM

Report 223 Alteration and Cu–Au mineralization at the Obelisk prospect, Paterson Orogen, Western Australia
Duuring, P, Guilliamse, JN, Kelsey, DE, Fielding, IOH and Fonteneau, L

Report 224 Regional petrophysics: Kalgoorlie Terrane 2020–21

Report 225 Regional petrophysics: Yamarna Terrane 2020–21
Markoski, M, Bourne, B and Trunfull, J





• MAP •

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

• FLYERS •

Airborne Electromagnetic Coverage (AusAEM) — Western Australia (RIU Explorers 2022)

Geochemical characterization of the magmatic stratigraphy of the Kalgoorlie and Black Flag Groups — Ora Banda to Kambalda region (RIU Explorers 2022)
Smithies, RH

Regional petrophysics (RIU Explorers 2022)
Brisbout, L

Southwest Yilgarn interpreted bedrock geology and seismic monitoring (RIU Explorers 2022)
Murdie, RE

Western Australia selected exploration and mining highlights, January 2022

• ONLINE PRODUCTS •

Geological Survey Annual Review 2020–21