

RECORD 2020/2

GSWA 2020 EXTENDED ABSTRACTS

Advancing the prospectivity of Western Australia



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

Geological Survey of
Western Australia





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February 2020

Perth 2020



**Geological Survey of
Western Australia**

MINISTER FOR MINES AND PETROLEUM
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DIRECTOR GENERAL, DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY
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Cover image: Packing up the campsite in a claypan about 5 km south of Minilya in the southern Pilbara (photo by Olga Blay)

GSWA Open Day 2020 program

21 February 2020, Esplanade Hotel Fremantle

8.15 – 8.45	REGISTRATION		
8.45 – 9.00	Welcome and opening remarks	Hon Bill Johnston MLA, Minister for Mines and Petroleum	
SESSION 1	Chair: Jeff Haworth		
9.00 – 9.20	The next generation of outcrop: MinEx CRC and the National Drilling Initiative in Western Australia	Richard Chopping	
9.20 – 9.40	Land use planning	Warren Ormsby	
9.40 – 10.00	Exploring the southwest Canning Basin: GSWA Waukarlycarly 1 and the Kidson Sub-basin seismic survey	Leon Normore	
Morning tea 10.00 – 11.20			
SESSION 2	Chair: Michele Spencer		
11.20 – 11.40	World's oldest regional salt seal in the Amadeus and Officer Basins: implications for subsalt helium and hydrocarbons	Peter Haines	
11.40 – 12.00	Loop 3D geological modelling: speeding up the workflow	Mark Jessell, CET	
12.00 – 12.20	The Eastern Goldfields high-resolution seismic survey: preliminary interpretation and tectonic implications	Ivan Zibra	
Lunch 12.20 – 1.30			
SESSION 3	Chair: Simon Johnson		
1.30 – 2.40	In this session, seven 10-minute talks will be given on the following: Managing an abandoned mine as a future resource: Ellendale diamond mine; AusAEM20-WA; Rare-element pegmatites in the Mineral Systems Atlas; The last gasp of King Leopold: new insights into the evolution of the West Kimberley; Exploring the link between a suture zone, an ophiolite and a seahorse; A subduction origin for 2820 to 2735 Ma magmatism in the western Youanmi Terrane, Yilgarn Craton; MRIWA: leading impactful research, meaningful collaboration and effective knowledge transfer	Tara Read, John Brett, Paul Duuring, Imogen Fielding, Catherine Spaggiari, Jack Lowrey, Anil Subramanya	
Afternoon tea 2.40 – 3.30			
SESSION 4	Chair: Klaus Gessner		
3.30 – 3.50	Tectonic setting and exploration potential of the northern Capricorn Orogen	David Martin	
3.50 – 4.10	Smart exploration starts with Western Australia's rich data endowment: MINEDEX, WAMEX and WAPIMS databases	Nicole Wyche	
4.10 – 4.30	Interactive feedback session	Robin Bower	
Sundowner 4.30 – 6.00			

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The next generation of outcrop: MinEx CRC and the National Drilling Initiative in Western Australia

by

R Chopping, CV Spaggiari, DE Kelsey, S Jakica, N de Souza Kovacs, EG Finch and IM Tyler

Introduction

The Mineral Exploration Cooperative Research Centre (MinEx CRC) is the world's largest geoscience research consortium, with cash and in-kind funding of more than \$230 million over a 10-year lifespan. Research partners in the MinEx CRC comprise several universities, mineral exploration and service companies, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), State and Territory geological surveys and Geoscience Australia (GA). Research within the MinEx CRC is to be conducted over three 3-year phases plus start up and shut down phases of six months over the 10-year lifespan. The first year of phase 1 is now complete, and the initial research direction established is discussed below.

MinEx CRC consists of three programs: Drilling Technologies, Data from Drilling and the National Drilling Initiative (NDI). The Geological Survey of Western Australia (GSWA) participates in both the NDI and a project within the Data from Drilling program (Project 6: Automated 3D Modelling). Within the NDI, projects are focused on the proposed drilling campaigns, including Maximizing the Value of Data and Drilling Through Cover (Project 7), Geological Architecture and Evolution (Project 8) and Targeting Mineral Systems in Covered Terranes (Project 9). Research in Western Australia within the NDI will concentrate on mapping 'The Gap' as discussed in Gessner et al. (2019; Fig. 1).

Research highlights

Automated 3D modelling

The Automated 3D Modelling project, led by Professor Mark Jessell and Dr Mark Lindsay at The University of Western Australia, has a goal of reducing the time taken to generate mine-scale 3D probabilistic models to one week. Presently, generation of a single 3D model can take months and does not capture the uncertainties inherent in 3D modelling, which requires adopting probabilistic approaches and necessitates the production of ensembles of models rather than a singular 3D model.

Project research to date has focused on automated extraction of data and knowledge from publicly available data sources (e.g. GSWA's online databases and maps), enabling 3D modelling to include more complex structural data, and on exploring the data requirements around value of information. This includes an analysis of the

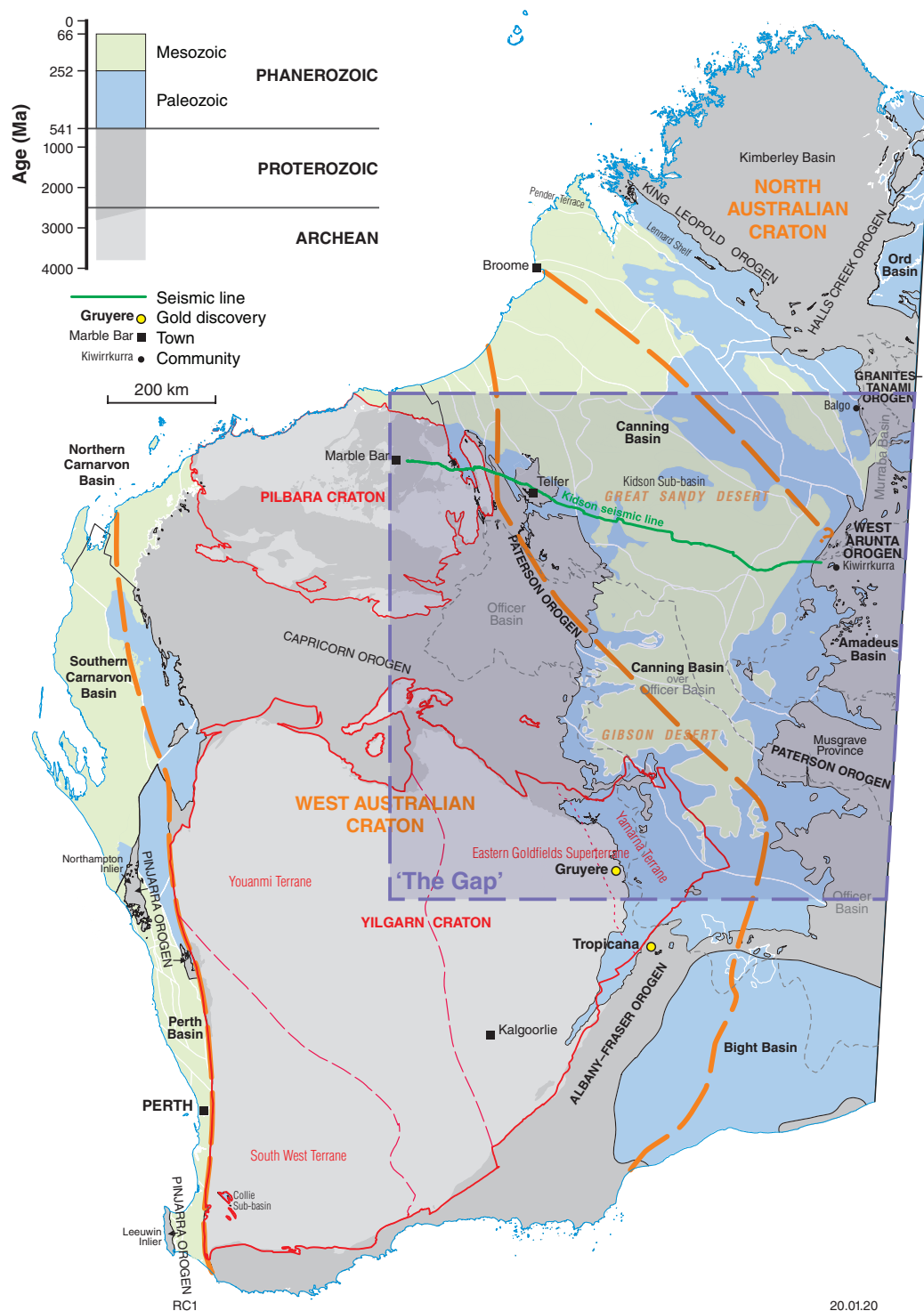
optimal geographical areas or methods for further data collection to better constrain 3D models, key elements to successfully reducing the time taken to produce models.

The work of the Automated 3D Modelling project is directly aligned with the Loop 3D OneGeology Australian Research Council Linkage project. The MinEx CRC project is leveraging investment in that initiative to make strides in mine-scale to regional-scale modelling.

The National Drilling Initiative: demonstrating discovery across scales

Within the MinEx CRC, the State and Territory Geological Surveys and GA are collaborating on the NDI along with Program 3 research partners: The University of Adelaide, University of South Australia, Curtin University, University of Newcastle, Australian National University and CSIRO. The goal of the NDI is to investigate and demonstrate how novel techniques developed within the MinEx CRC can better delineate mineral prospectivity under cover. Research within the NDI is geographically and scientifically diverse. Projects within the NDI focus on:

- enhancing knowledge from data, especially using modern artificial intelligence/machine learning approaches and data delivery and visualization (Project 7)
- geological research into understanding terranes including petrophysical to geophysical research, regolith geoscience, and basement terrane fingerprinting through isotopic and geochronology approaches (Project 8)
- mineral systems research, concentrating on how best to apply mineral systems approaches to cross scales and produce regional-scale discovery methodologies applicable to the NDI focus regions for each participating State and Territory (Project 9).



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Figure 1. 'The Gap' is the informal name referring to basement underlying and proximal to the margins of the Canning Basin in northern and central Western Australia, as this region is characterized by a gap of scientific data

The chosen NDI focus areas vary across the States from enhancing prospectivity near known mining centres to investigating greenfields prospectivity. Within the Gap region, areas of interest for mineral prospectivity are the:

- West Arunta Orogen west of the Northern Territory Border, including the region around the Kiwirrkurra Community
- Paterson Orogen, especially the poorly understood terranes of the Rudall Province, and the Yeneena Basin
- Canning Basin, a potential host for mineralization
- Yamarna Terrane, in the eastern Yilgarn Craton, with its well-known potential for Au and Ni mineralization.

Phase 1 will focus on the West Arunta and Paterson Orogens. In the West Arunta Orogen, work is underway on Exploration Incentive Scheme (EIS) Co-funded drillcores. A new mapping campaign will commence in 2020 to investigate the structural evolution and lithological links to known prospects in the region, including those in the adjacent Northern Territory. This region is prospective for Cu, Au, Zn, Pb and possibly U; previous GSWA geochemical soil surveys identified several samples with elevated and anomalous concentrations of Au. Additionally, elevated concentrations of Zn and elements such as Ti in regolith and/or spinifex associated with the Stansmore Fault indicate potential buried mineralization

hosted in sedimentary rocks consistent with sedimentary exhalative (SEDEX)-style mineralization. In the Paterson Orogen, the focus over the next 12 months will include drillcore analysis of EIS Co-funded and exploration drillcores, linked with activities of the Minerals Research Institute of Western Australia (MRIWA) M521 project. The Paterson region is prospective for Au, Cu, Pb, Zn, W and U and is the current focus for a number of exploration company drilling programs.

For research within both of these regions, a key goal will be to demonstrate targeting methodologies applicable at the challenging camp scale. With a focus on greenfields undercover exploration likely to continue, guiding principles on how to best utilize geophysical and rock property data will be a key area of research alongside improving drilling and drillsite data acquisition technologies. This will help identify the undercover mappable expressions of the key basement terranes and their margins, which are likely to be the prime controls on mineralization.

References

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Land use planning

by

WR Ormsby

The Land Use Planning branch provides geological advice to government on land use planning while, wherever possible, ensuring a strong emphasis on maintaining access for resource exploration and development. Although many people realize the importance of the resource industry to the Western Australian economy, increasing awareness of the importance of the natural environment and environmental impacts has led to more conservation and vegetation-related carbon sequestration initiatives in recent times. The consideration of native title and Aboriginal welfare has been a key driver for government initiatives that involve joint management of new and existing conservation parks and entry into Indigenous Land Use Agreements incorporating substantial land components.

Sustainability can be defined as ‘meeting the needs of current and future generations through integration of environmental protection, social advancement and economic prosperity’. The Land Use Planning branch contributes to sustainability by, wherever possible, working with government to reduce the impacts arising from land use changes on access for exploration and development of the State’s mineral, basic raw material, petroleum and geothermal energy resources.

The Land Use Planning branch helps to maintain resource access primarily by:

- responding to specific proposals for land tenure changes from other government agencies (referrals)
- interacting with other government agencies to shape land use and policy
- providing resource potential mapping to government and the public.

Changes to land tenure can have serious consequences for land access for exploration and mining. A core part of the branch’s activities is responding to many hundreds of referral requests for such changes each year. Most changes of land tenure involving Crown land are referred to the Department of Mines, Industry Regulation and Safety (DMIRS) for ‘clearance’ under Section 16(3) of the *Mining Act 1978*. About 87% of the State is Crown or reserved land, so these are the changes most likely to affect mining access. Under this part of the Mining Act, a change in tenure from Crown land to private land cannot occur without the approval of the Minister for Mines. Furthermore, governments have, for many years, required the agreement or support of DMIRS before making other changes to Crown land such as changes to reserve type and the creation of conservation reserves. This is

necessary because the Mining Act is very prescriptive about the requirements for carrying out exploration and mining on different types of land tenure. Examples of land changes that can have serious consequences for mining access include:

- a change from Crown land to freehold. This may mean that the consent of the landowner will in future be required before exploration access is permitted to the upper 30 m of the land
- the creation of class A nature reserves or national parks. This would mean that the approval of both the Minister for Mines and the Minister for Environment are then needed before exploration can take place. The grant of a mining lease within a class A nature reserve or national park would require the approval of both houses of Parliament.

Proposals for land use changes on private land come to the Land Use Planning branch under a Memorandum of Understanding (MoU) with the Western Australian Planning Commission (WAPC). These cover private land subdivisions and rezoning proposals outside of the main urban areas, mainly in the southwest of the State. Some of these proposals encroach upon areas that have traditionally supplied basic raw materials needed by the construction industry, and higher value deposits such as titanium–zircon and bauxite. Comments from DMIRS enable the WAPC to avoid future land use conflict by refusing some proposals or by placing a notice on land titles so that future landowners are aware of current or future mining activities.

Similarly, in more recent years the group has formalized dealings in Crown land with the Department of Planning, Lands and Heritage under another MoU. This has led to improved understanding of the roles of the respective agencies and the administrative arrangements for providing recommendations and approvals.

In all cases, the Land Use Planning branch assesses the impact that a proposal may have on access for an existing mining or petroleum tenement and, if deemed significant, refers the proposal to the tenement holder for comment. Irrespective of existing mining or petroleum tenure, the branch also assesses the resources or prospectivity of the proposal area and the impact that the proposal will have on future access for exploration and mining. Recommendations will then be made and, where necessary, approvals provided accordingly, always with the aim of either avoiding or minimizing the impact on present or future access to mineral, petroleum and geothermal energy resources.

Land Use Planning interacts with other government agencies, including local government, to help shape land use decisions and policy in their formative stages. This is normally within the context of an existing government objective, such as conservation. In these cases, the branch aims to achieve an informed outcome in which resource access and economic considerations are taken into account.

A current example of involvement across government is the Land Use Planning branch's participation in the government's Plan for Our Parks conservation initiative, which aims to secure an additional 5 million hectares of land into conservation reserves by February 2024. The branch is playing a major role in carrying out consultation with affected tenement holders, assessing prospectivity, contributing to the Interagency Working Group and in advising DMIRS and the Minister on these proposals.

The branch is involved with other parts of government such as the Geraldton Alternative Settlement Agreement and the South West Native Title Settlement. Both of these large-scale Indigenous Land Use Agreements incorporate substantial land components.

Land Use Planning recently contributed to DMIRS policy development with respect to carbon farming; especially assessing spatial overlap with exploration and mining, and potential impacts on these activities.

By providing resource potential maps tailored for land use planners and the public, the Land Use Planning branch helps to avoid land use conflicts before they occur. This mapping is targeted for those resources most at risk of sterilization in areas of current or future land development. A good example of this is the significant geological supply mapping that has formed the basis for the new State Planning Policy on basic raw materials. The new policy is anticipated to help protect strategic basic raw material sites from encroachment by urban development.

In summary, the Land Use Planning branch plays an important role in informing government on resource access matters, thus ensuring that, wherever possible, the interests of the resources industry are considered and a proper balance between environmental, social and economic factors is achieved in government decision making.

Exploring the southwest Canning Basin: GSWA Waukarlycarly 1 and the Kidson Sub-basin seismic survey

by

LS Normore and Y Zhan

Introduction

Geoscience Australia's (GA) Exploring for the Future Initiative is a four-year program (2016–20) focused on Northern Australia, to gather new data and information about the potential mineral, energy and groundwater resources concealed beneath the surface. As part of this initiative, two major projects have investigated the southern Canning Basin in northern Western Australia. The initial phase, co-funded by the Geological Survey of Western Australia's (GSWA) Exploration Incentive Scheme (EIS), was the acquisition of a deep crustal seismic survey across the southern Canning Basin between the middle of June and late August 2018 to better understand the subsurface geology of this underexplored region. The second phase of this program, funded by GA, was the deep stratigraphic drillhole, GSWA Waukarlycarly 1, located along the Kidson Sub-basin seismic line within the Waukarlycarly Embayment.

Kidson Sub-basin seismic survey

The Kidson Sub-basin seismic survey is the longest continuously acquired seismic line in Australia, running 872 km from Kiwirrkurra near the Western Australian/Northern Territory border to Marble Bar in the eastern Pilbara (Fig. 1). 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 the basement beneath the basin was also inadequately 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.

Geokinetics Inc. (now SAExploration [Australia] Pty Ltd) was contracted as the project operator to carry out data acquisition and Velseis Pty Ltd undertook the data processing.

The final survey data is good quality, particularly in the Kidson Sub-basin, showing continuous parallel reflectors across the depocentre and faulting near the basin margins (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 (www.dmirs.wa.gov.au/wapims), including the seismic report, navigation, SEG-Y in time and depth domains, and velocity profile.

GSWA Waukarlycarly 1 stratigraphic drillhole

Stratigraphic drillhole GSWA Waukarlycarly 1 began drilling on 1 September 2019 in the Waukarlycarly Embayment, southwest Canning Basin, reaching a total depth of 2680.53 m on 30 November 2019. The drilling was conducted by Perth based DDH1 Drilling with InGauge Project Engineering and Well Management providing the Drilling Management Services. Access to the site was from Port Hedland via Marble Bar or alternatively through the Metals X Nifty Copper Minesite airstrip. Pason Australia provided live online data of drilling parameters and mudgas. The main objectives of the stratigraphic drilling include:

- correlation of seismic reflectors and their corresponding stratigraphic horizons across the southern Canning Basin
- continuously coring through the entire Canning Basin stratigraphy
- obtaining 100 m of core from the pre-Canning Basin basement
- acquisition of downhole geophysical surveys, including a standard suite of wireline logs and a vertical seismic profile.

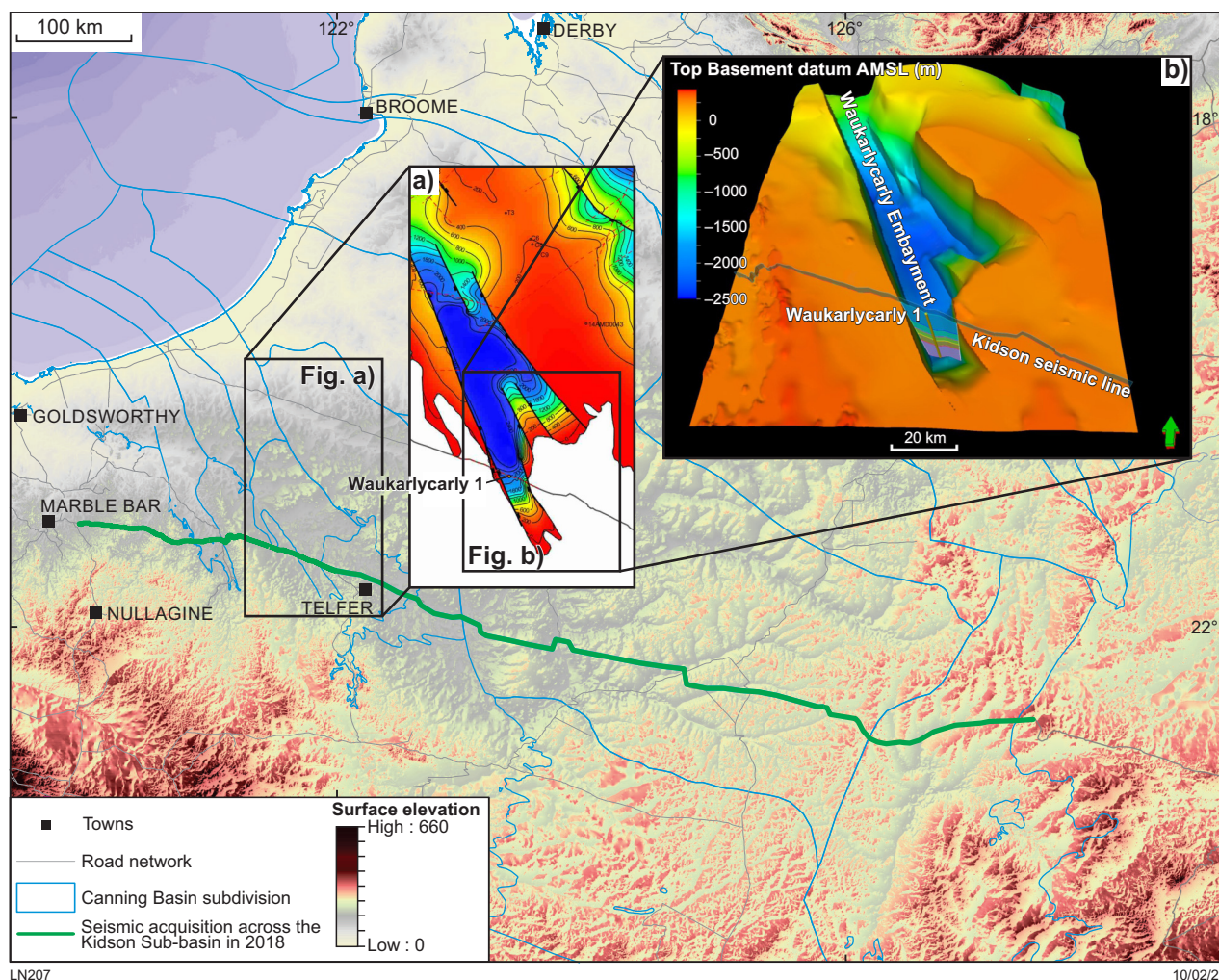


Figure 1. Regional map showing location of the Kidson Sub-basin seismic line with insets: a) depth to basement map (metres) of the southwest Canning Basin showing the location of GSWA Waukarlycarly 1 in the southern Waukarlycarly Embayment along the Kidson seismic line and H96-01. White dashed lines are 2D seismic lines. Modified after Zhan (2018); b) oblique 3D model of the depocentre of the Waukarlycarly Embayment showing the proposed well site. Arrow points north. Abbreviation: AMSL, average mean sea level

The Waukarlycarly Embayment was selected as the general location of the stratigraphic drillhole primarily due to the complete lack of pre-Permian subsurface geological knowledge in this area. A number of additional factors helped define the exact location of the drillhole, including an existing cleared area, available water bores, established stakeholder engagement in the area and budgetary limitations on final total depth.

Well design

The final well design consisted of a top-hole rotary-drilled interval to 580 m followed by a continuously cored section to a total measured depth of 2680.53 m. The rotary-drilled section was broken into three stages, starting with a 311 mm (12¼")-diameter hole down to 23.63 m, followed by a 216 mm (8½")-diameter hole to 218.00 m and finally a 156 mm (6⅞")-diameter hole to 580 m. For well control safety a blow out preventer (BOP) was installed after the 216 mm-hole section; however, the selected site was chosen so the well did not intersect any potential structural hydrocarbon traps as interpreted from the Kidson Sub-basin seismic line. Cuttings were collected at 3 m intervals over the 580 m-long rotary-drilled section.

There were three stages of continuous coring to total depth (Table 1); SQ core from 580 to 727.10 m (147.10 m length), PQ core from 727.10 to 1602.00 m (874.90 m length) and HQ core (e.g. Fig. 3) from 1602.00 to 2680.53 m measured depth (1078.53 m length).

All the primary objectives of the GSWA Waukarlycarly 1 stratigraphic drillhole were successfully achieved. Each core tray was photographed dry, wet and under ultraviolet light as soon as possible after core reached the surface, utilizing the specifically designed facilities of the DDH1 'GeoShack' (Fig. 4). The full core and cuttings were analysed using the GSWA HyLogger-3 at the Perth Core Library. The GSWA Waukarlycarly 1 basic data, Well Completion Report will be released in the second quarter of 2020. A number of post-well analyses are planned, including organic and inorganic geochemistry, geochronology, routine core analysis and various paleontological studies prior to the release of the interpretative Well Completion Report and a Digital Core Atlas.

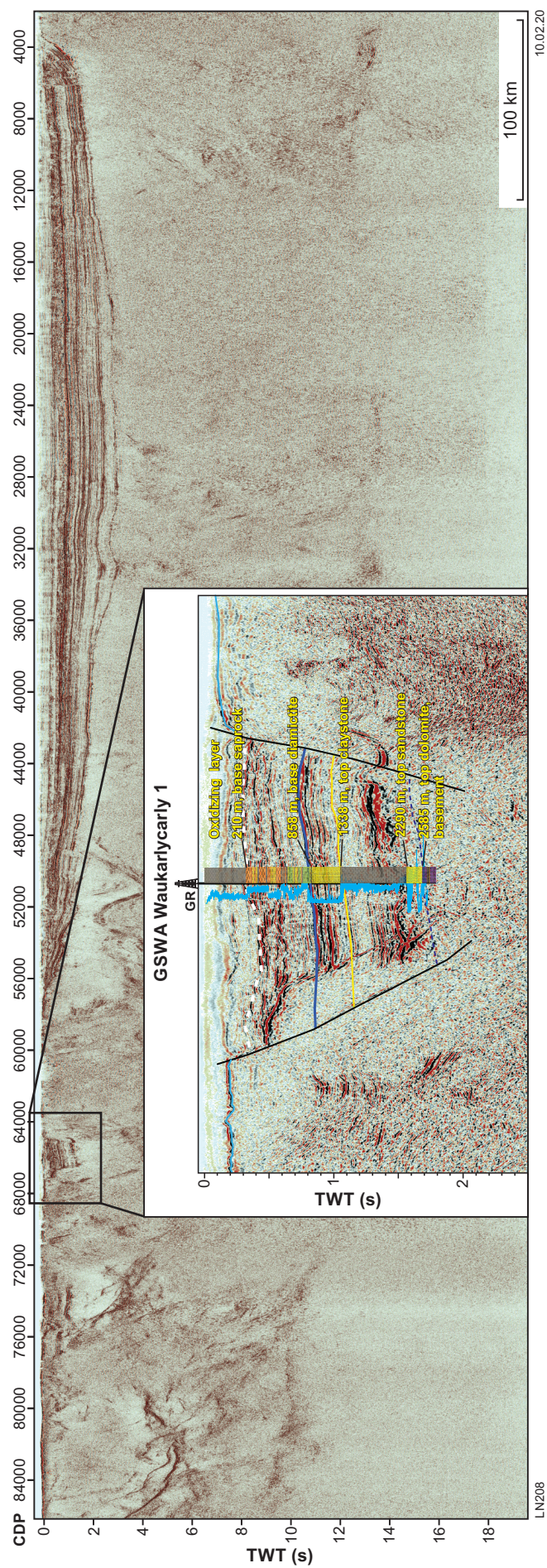


Figure 2. Kidson Sub-basin seismic line with inset of Waukarlycarly Embayment seismic section. Abbreviation: SP, shot point

Table 1. Cuttings and core recovery

<i>Drill type</i>	<i>Sample</i>	<i>Hole diameter</i>	<i>Depth from (m)</i>	<i>Depth to (m)</i>	<i>Recovery</i>
Rotary	Cuttings	12¼"	0	23.63	21.00
Rotary	Cuttings	8½"	23.63	218.00	194.37
Rotary	Cuttings	6⅞"	218.00	580.00	362.00
Core	SQ core	5¾"	580.00	727.10	147.10
Core	PQ core	4½"	727.10	1602.00	874.90
Core	HQ core	3½"	1602.00	2680.53	1078.53



Figure 3. Fresh HQ size diamond drill bit with DDH1 Drilling's ER01 rig in the background



Figure 4. Core ready to be photographed and processed in DDH1 Drilling's GeoShack

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World's oldest regional salt seal in the Amadeus and Officer Basins: implications for subsalt helium and hydrocarbons

by

PW Haines and HJ Allen

Introduction

Thick salt (halite or anhydrite) accumulations within sedimentary basins can exert controls over the structural development of fluid traps and provide the highest quality seals. Sealing capacity becomes particularly important when prospecting for relatively early generated hydrocarbons trapped in old, long-stable sedimentary basins. Old salt seals also have particular significance for the trapping of He, a light, inert and highly mobile element that largely escapes through less efficient seals over geological time. Helium is constantly generated in the crust as a daughter product of the radioactive decay of U and Th and can also be sourced from the mantle; most commercial He is extracted as a minor byproduct during commercial hydrocarbon production. Although low concentrations of He may be commercially extracted from shale-sealed traps, high concentrations (>1%) typically require very effective seals and long accumulation times, favouring traps in old, stable salt-bearing basins. Components of the Centralian Superbasin, particularly the Amadeus and Officer Basins of central and west Australia (Fig. 1), contain widespread deposits of Tonian (early Neoproterozoic) salt believed to be the oldest regionally extensive salt deposits in the world. At the time of deposition, these basins were at least partly linked, as attested by similar stratigraphy, biostratigraphy and depositional history, but were separated during late Neoproterozoic and younger tectonism (Walter et al., 1995; Munson et al., 2013). Exploration for subsalt hydrocarbons and He in this extensive province is in its infancy, but early results from the eastern Amadeus Basin are encouraging.

Salt in the Centralian Superbasin

Amadeus Basin

The Tonian stratigraphy of the Amadeus Basin (Fig. 2) starts with a basal sandstone-dominated unit, the Heavitree Formation in the north and laterally equivalent Kulail Sandstone and Dean Quartzite in the southwest, although this package is locally absent in the southeast. These units are overlain by the Bitter Springs Group

comprising the Gillen Formation (mudstone, carbonate and halite-dominated evaporites), Loves Creek Formation (stromatolitic carbonate) and Johnnys Creek Formation (evaporitic dolomitic redbeds, carbonate and minor mafic volcanics), in ascending order. The youngest Tonian unit, the Wallara Formation, comprises mixed sandstone, carbonate and shale facies.

Officer Basin

In the central Western Australian Officer Basin, the entire Tonian succession is within the Buldya Group (Fig. 2), with basal sandstone-dominated Townsend Quartzite present locally. The overlying and more extensive Browne Formation contains two halite-dominated evaporite units (Fig. 3), separated by stromatolitic carbonates of the Woolnough Member. The siltstone-dominated Lefroy Formation lies between the Townsend and Browne Formations locally in outcrop, but has not yet been recognized in drillholes. The upper Buldya Group (Hussar, Kanpa and Steptoe Formations) is a mixed sandstone, mudstone and carbonate succession, with local evidence of evaporites and mafic volcanics.

Age and correlations

The Tonian successions of the Amadeus and Officer Basins have a similar depositional history and can be correlated using biostratigraphy and chemostratigraphy (Fig. 2). The carbonate-dominated Loves Creek Formation and Woolnough Member are correlated based on the stratigraphically restricted *Acaciella australica* Stromatolite Assemblage (Grey et al., 2012) and the presence of the globally recognized $\delta^{13}\text{C}$ Bitter Springs Anomaly. However, the boundaries of this isotope anomaly are strongly facies controlled in the Amadeus Basin, so may not correlate in entirety to this c. 800 Ma isotope anomaly elsewhere (Klaebe et al., 2017). These constraints imply that Gillen Formation salt correlates with the lower Browne Formation salt, while the less extensive upper Browne Formation salt may correlate with the evaporitic redbeds (with halite pseudomorphs) of the Johnnys Creek Formation, although no preserved salt is known at this level in the Amadeus Basin. The post-salt succession can likewise be correlated between the

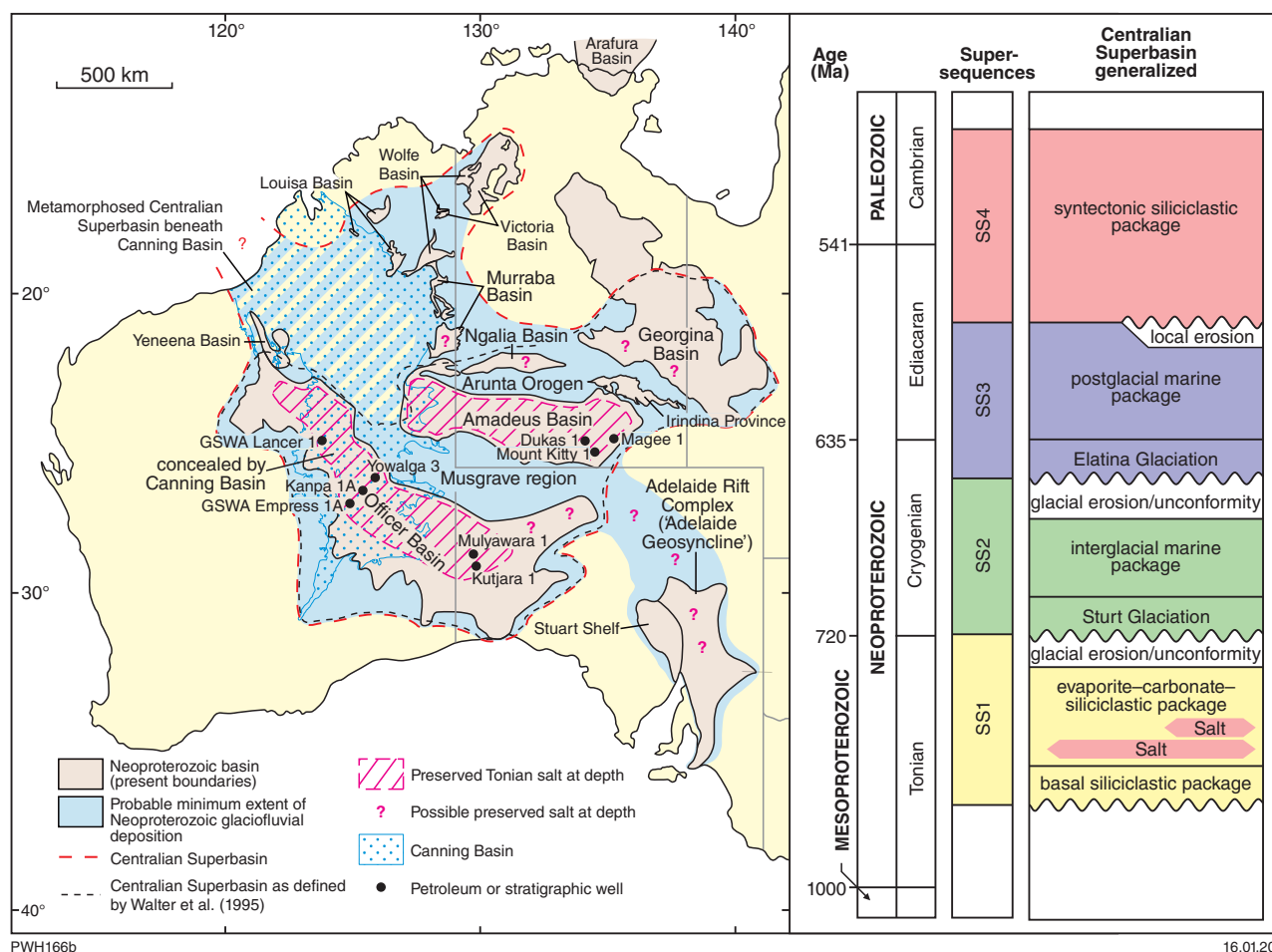


Figure 1. Map of the Centralian Superbasin and component basins (modified after Munson et al., 2013), with generalized Neoproterozoic stratigraphy on the right indicating the position of the main Tonian salt units. Known and inferred distribution of preserved subsurface salt in the Amadeus and Officer Basins is based on seismic data and drilling, where available, or extrapolated beyond, while possible occurrences in other basins are also indicated. The selected petroleum and stratigraphic wells are referred to in the text

basins based on stromatolites (*Baicalia burra* Stromatolite Assemblage) and microfossils (Grey et al., 2012). The current constraints suggest the oldest salt horizon is somewhat older than 800 Ma.

Subsalt exploration

Two wells drilled to basement beneath Gillen Formation salt in the eastern Amadeus Basin, Magee 1 and Mount Kitty 1, both flowed hydrocarbon gas to the surface, demonstrating the existence of a subsalt hydrocarbon system in this area, presumably sourced from organic-rich shales in the lower Gillen Formation. Lower Gillen Formation shales have a total organic carbon content of up to 1.8% (Jarrett et al., 2016). Both wells had exceptional He contents; 6.2% in Magee 1 (Wakelin-King, 1994) and 9% in Mount Kitty 1 (Boreham et al., 2018; McInnes et al., 2017), the latter being one of the highest recorded He concentrations for any well. Such extraordinary He values demonstrate the integrity of the salt seal and suggest gas accumulation since the Neoproterozoic. The Mount Kitty 1 gas composition (9% He, 61% N₂, 13% CH₄, 4% C₂H₆ and 11% H₂) is particularly unusual; the high H content possibly resulting from either hydrocarbon oxidation, or an abiogenic breakdown product of hydrocarbons in the granite reservoir

(McInnes et al., 2017). Despite being technically successful, both wells suffered from poor reservoir quality. Magee 1 produced gas from a very thin (4.5 m) fine-grained sandstone (inferred as Heavitree Formation by Wakelin-King, 1994) overlying crystalline basement, while Mount Kitty 1 lacked any subsalt sandstone, producing gas from fractured and weathered crystalline basement. Drilling of a third subsalt exploration well, Dukas 1, was suspended at the time of writing. No deep drilling has been undertaken in the Western Australian Amadeus Basin; however, salt is inferred to extend into this area based on structural interpretations and significant thicknesses of subsalt shale and sandstone are expected based on extrapolation from outcrop (Haines and Allen, 2019). Despite poor outcrop of the basin in Western Australia, the Tonian succession can be confidently correlated with the better known eastern part of the basin with the aid of stromatolite biostratigraphy (Allen et al., 2012; Allen and Haines, 2019).

Within the Western Australian Officer Basin, there has been no serious exploration for subsalt traps. Fully cored Geological Survey of Western Australia (GSWA) stratigraphic wells GSWA Lancer 1 and GSWA Empress 1A reached basement beneath lower Browne Formation salt, but lacked significant subsalt reservoir and were not drilled on recognized traps. Two deep exploration wells, Yowalga 3

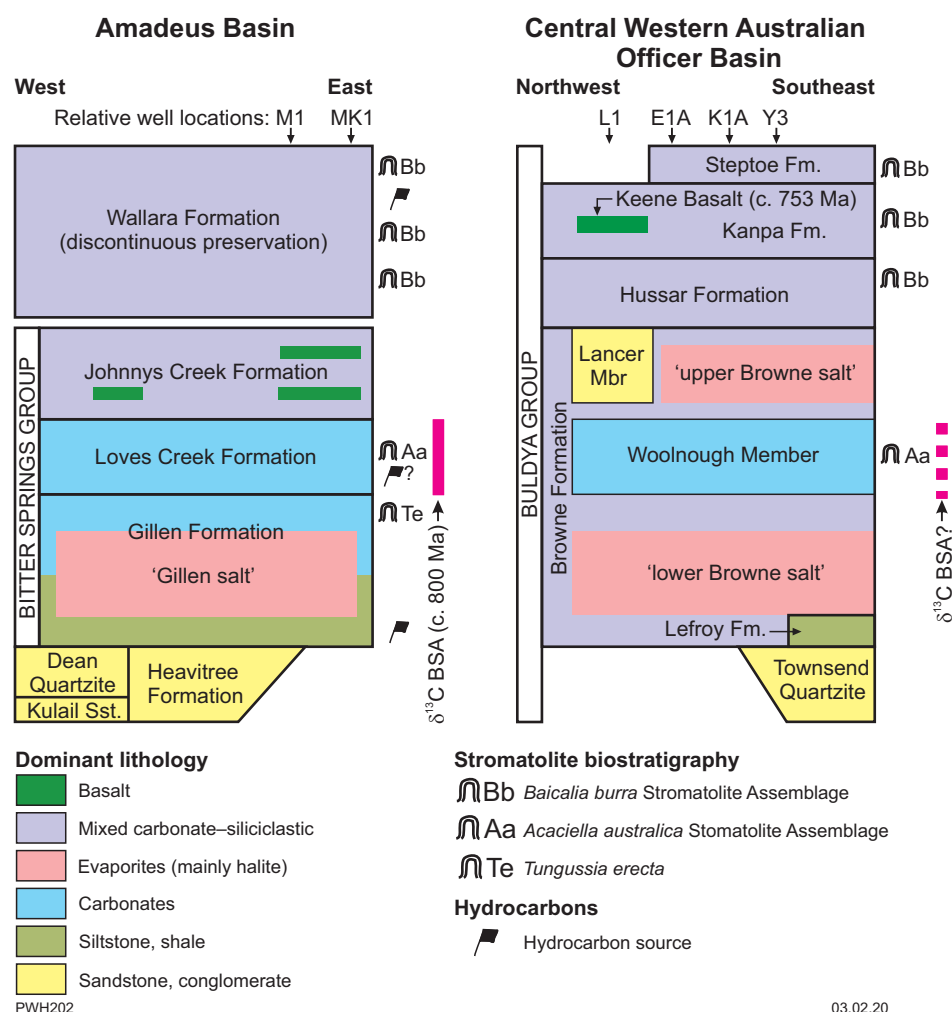


Figure 2. Stratigraphic correlation between the Tonian successions of the Amadeus and central Western Australian Officer Basins with the main stromatolite biostratigraphic ties and the extent of the $\delta^{13}\text{C}$ Bitter Springs Anomaly (BSA) indicated. Well positions: M1, Magee 1; MK1, Mount Kitty 1; L1, GSWA Lancer 1; E1A, GSWA Empress 1A; K1A, Kanpa 1A; Y3, Yowalga 3

and Kanpa 1A, drilled beneath Browne Formation salt but also failed to intersect subsalt reservoirs. Yowalga 3 drilled a salt-tectonic structure and did not reach the level of the Townsend Quartzite (potential reservoir), whereas Kanpa 1A was probably outside of the deposition or preservation limit of this unit, drilling through an unconformity into likely Mesoproterozoic rocks beneath the Browne Formation (Simeonova and Iasky, 2005).

Two exploration wells drilled in South Australia near the Western Australian border, Mulyawara 1 and Kutjara 1, intersected equivalents of Browne Formation salt overlying subsalt shale and sandstone units. The presence of numerous minor gas shows below and above the salt suggests the presence of a hydrocarbon system at this level in the area, but it is possible the salt is locally too disseminated to form an effective seal. There is considerable scope for future exploration for subsalt traps in the Officer Basin, particularly in the extensive area between deep wells in the central Western Australian part of the basin and the South Australian border, an area where subsalt reservoirs and shales are considered more likely based on adjacent outcrop, but where there is currently very little subsurface information.

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Figure 3. Interbedded halite (orange-brown) and dolomite (pale grey to grey-brown) in the lower Browne Formation in GSWA Lancer 1 (1454.14 – 1458.75 m). Significant halite dissolution during drilling is indicated near the bottom of the core tray

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Loop 3D geological modelling: speeding up the workflow

by

M Jessell¹, M Lindsay¹ and V Ogarko²

Introduction

The Loop 3D consortium aims to improve all aspects of the geological modelling workflow to reduce the construction speed and cost, and improve the quality and value of 3D geological models. In this study, we present the first attempts at improving that part of the workflow related to the transformation from raw data to first model, which is one of the most time-consuming parts (hours to days) of the model-building process. Starting from standard Geological Survey of Western Australia (GSWA) map products, and by extracting primary and secondary geometric information as well as fault and stratigraphic topological relationships, we are able to export a complete input file for three geomodelling packages (gempy, LoopStructural and GeoModeller) in under five minutes.

Prototype Loop Information Manager

The goal of the Loop Information Manager is to take digital geological data, either from files or online data servers, and extract the maximum geological information available for use as constraints on the 3D modelling process, as well as other geological studies.

Input data

In this proof of concept, we use the 2016 1:500 000 State interpreted bedrock geology map of Western Australia (GSWA, 2016) and the Western Australian Field Observation database (WAROX) as sources of the data needed to build

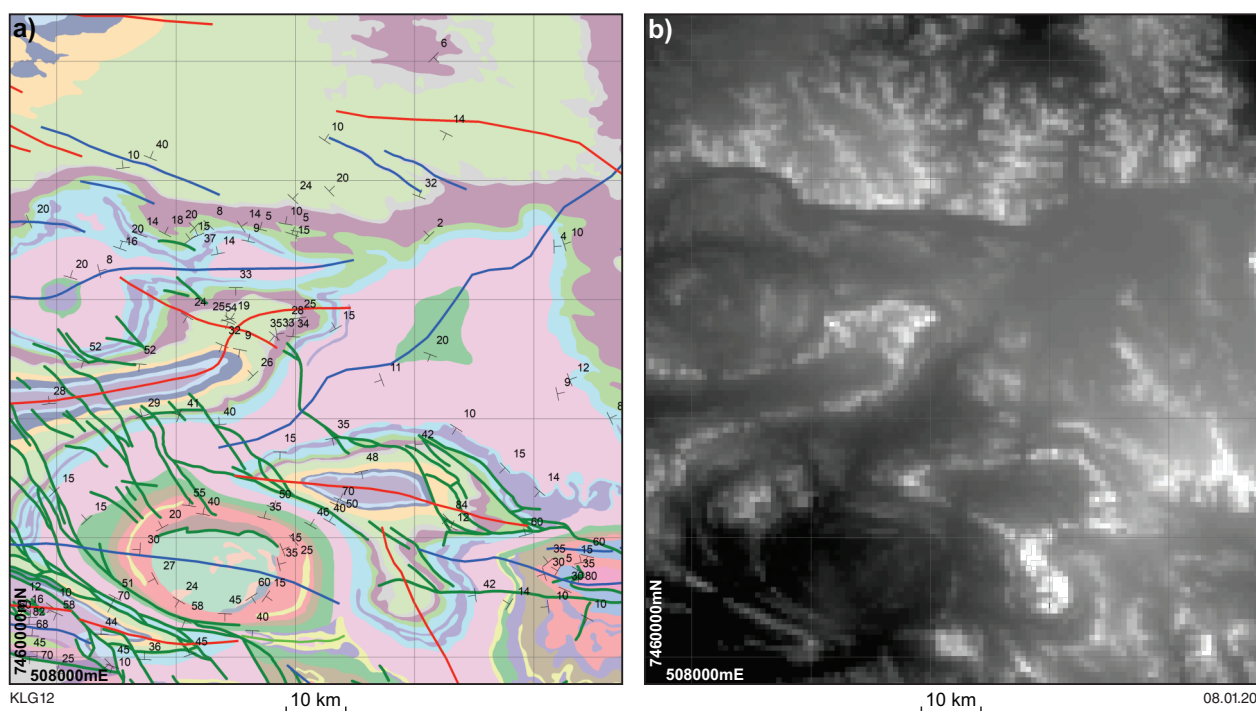


Figure 1. Input data for model: a) 1:500 000 interpreted bedrock geology of the Rocklea Dome/Turner Syncline region of Western Australia, showing the different datasets used to create the 3D model. Red lines are synclines, blue lines are anticlines, green lines are faults and structural symbols show bedding orientations. The region shown is approximately defined by latitudes -22°S and 23°S, and longitudes 117°E and 118°E. Grid references are MGA coordinates, Zone 50; b) SRTM digital terrain model sourced directly from Geoscience Australia (2016) at <<http://gaservices.ga.gov.au>>

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a first-pass model of the region around the Rocklea Dome and Turner Syncline in the Hamersley region of Western Australia (Fig. 1). The area consists of upright refolded folds of Archean and Proterozoic stratigraphy overlying an Archean basement cut by over 50 northwest–southeast trending faults that form a part of the Nanjilgardy Fault System.

Derived modelling inputs

Using a series of scripts contained within the C++/python *map2loop* package (<https://github.com/Loop3D/map2loop>) we are able to convert the input layers into primary data: structural dips of beds; fault and fold traces; and the stratigraphic base of each unit, which represent decimated equivalents of the source data. In addition, we can derive secondary information: apparent fault throw, interpolated bedding orientations and local formation thickness that are needed by some modelling systems (Fig. 2).

The third class of modelling constraints derived by the *map2loop* algorithms extract spatial and temporal topology from the map layers. Specifically, it creates network diagrams showing the stratigraphic relationships between units in the region of interest (c.f. Thiele et al., 2016), network diagrams of the relationships between faults, and relationship tables showing whether a particular fault cuts a formation or group (Fig. 3).

Resulting 3D model

The outputs of *map2loop* described above provide all of the information required to build a 3D geological model in GemPy (de la Varga et al, 2019), LoopStructural (<https://github.com/Loop3D/LoopStructural>) and GeoModeller (www.intrepid-geophysics.com). In Figure 4, we show the 3D model and top surface of the volume as calculated using GeoModeller, together with an uncertainty voxel based on the variation in lithology at the voxel model for a randomly generated suite of models based on the input data (Pakyuz-Charrier et al., 2018).

While this is very much a work in progress, the ability to generate all necessary input data for a geological model from a set of geological layers in a matter of minutes demonstrates the potential for this approach to reduce

the entry barrier for geologists who wish to make 3D models as part of their exploration or research programs. The whole system relies on the quality of the input data, and when under cover, different and more geophysics-centric approaches need to be taken. A description of the integration of geophysics into the workflow is being developed by the Loop consortium, but is beyond the scope of this abstract.

Acknowledgements

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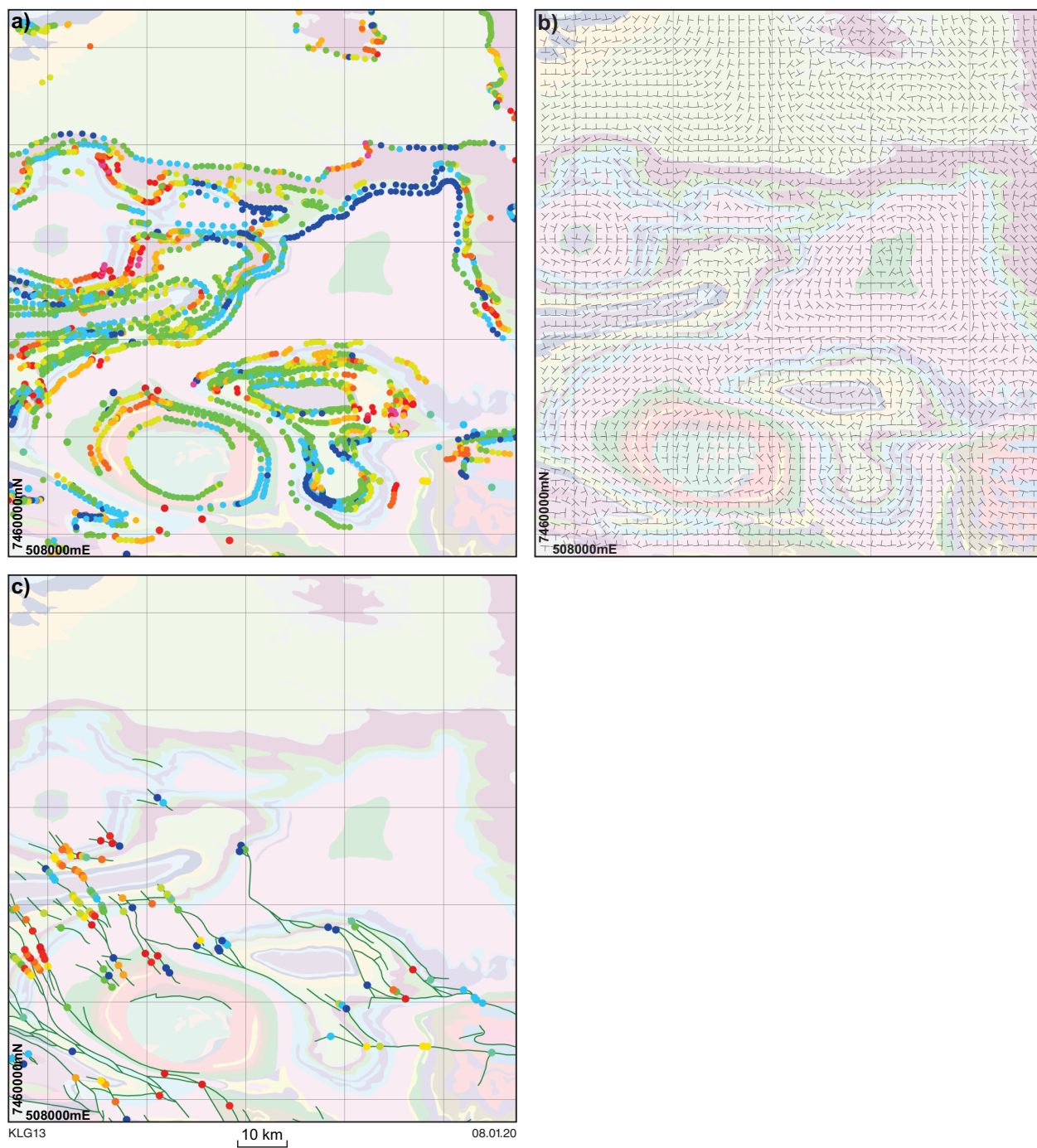


Figure 2. Secondary geological information automatically derived from maps: a) normalized local formation thickness (hotter colours show thicker formations); b) interpolated estimated bedding orientations for the Hamersley and Fortescue Groups; c) apparent fault throw (hotter colours show larger throw)

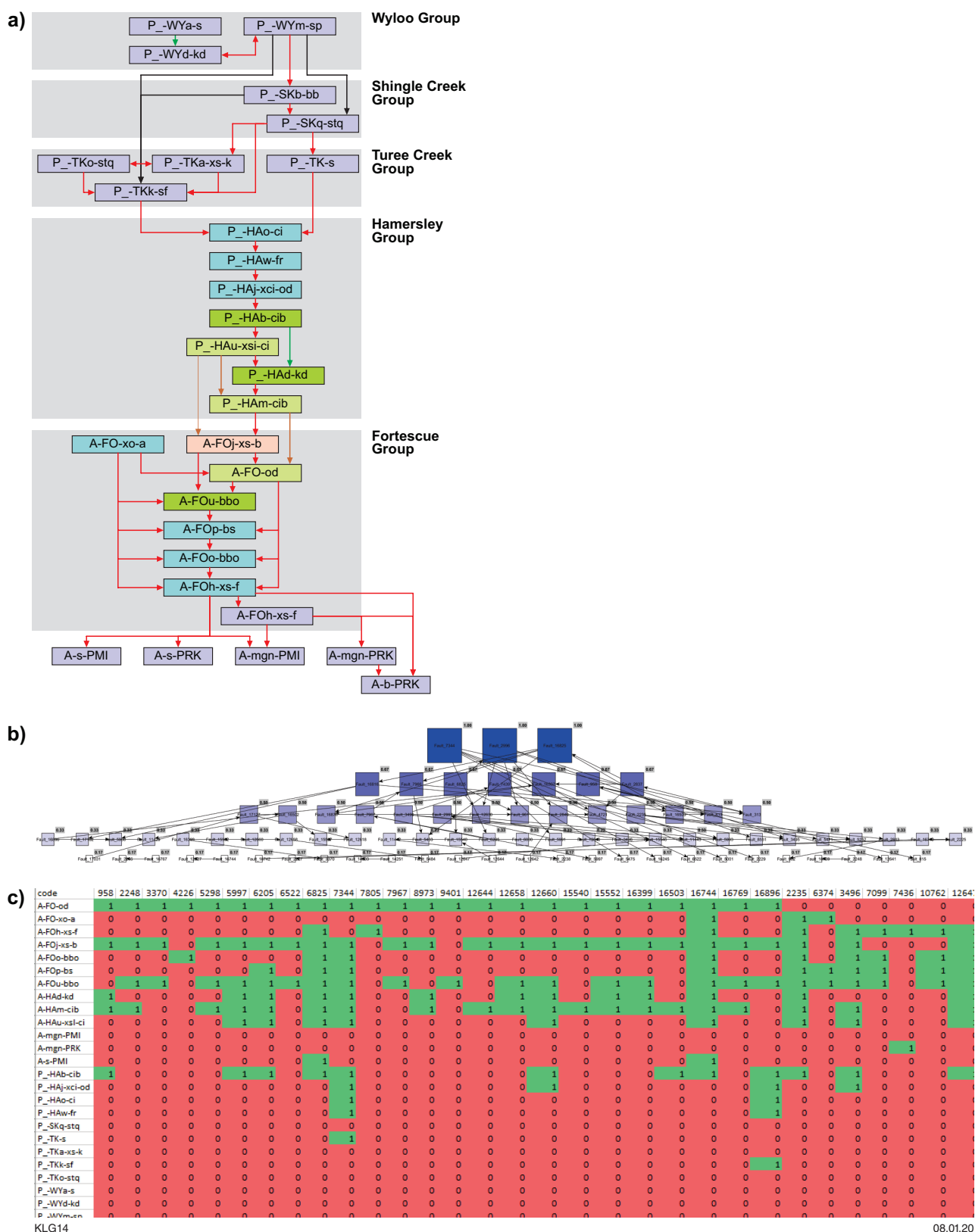
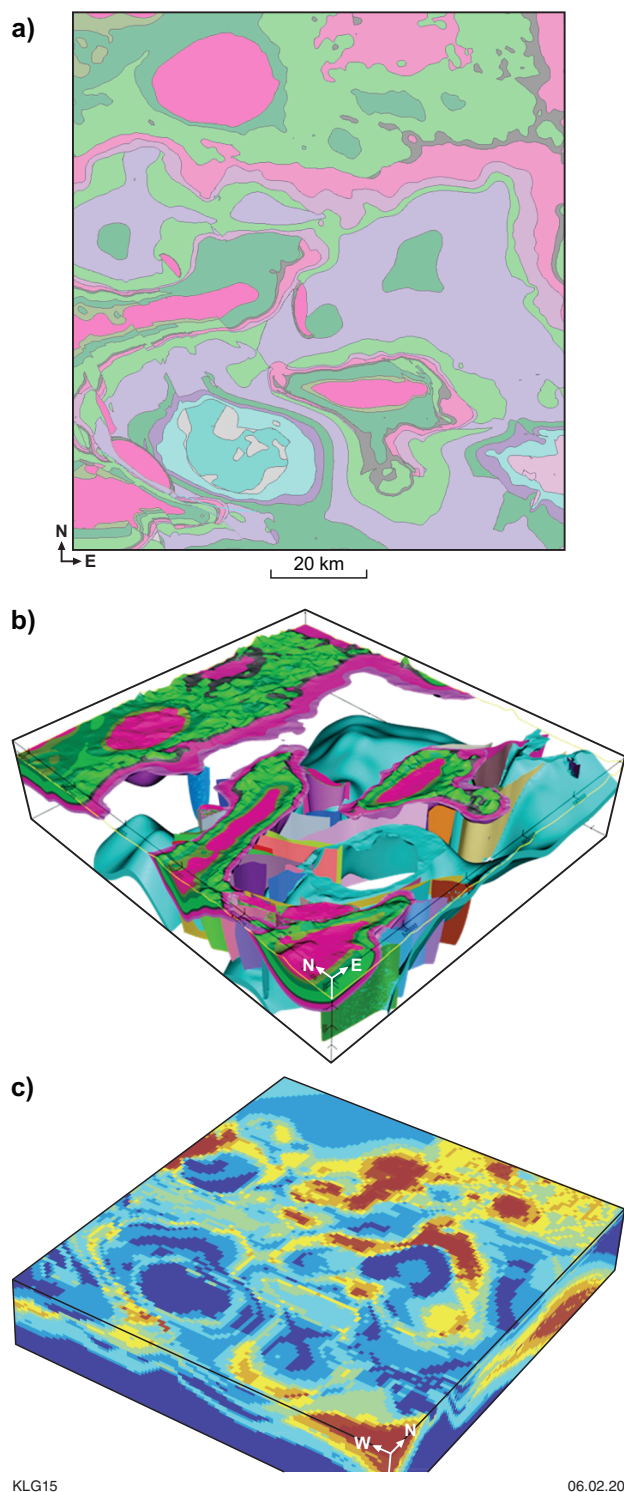


Figure 3. Topological information automatically derived from maps: a) stratigraphic relationships between the different formations found in the region of interest. Each rectangle represents one formation, and the arrows point to younger formations; b) fault relationships, each fault is one rectangle, and the larger and darker the rectangle, the more important the fault is based on the number of faults that connect to it; c) the fault-formation relationship matrix. Green cells indicate that a specific fault (columns) intersects a given formation (rows), otherwise the cell is red



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Figure 4. 3D geological model produced using the input data created by *map2loop* by creating an intermediate 'taskfile' that can be converted by the GeoModeller system into the full model: a) top surface of the geology; b) 3D model with some layers rendered transparent to highlight subsurface fault relationships; c) uncertainty voxel produced by building a suite of 300 models and comparing them on a voxel by voxel basis (hotter colours represent parts of the model that are less well constrained by the data)

The Eastern Goldfields high-resolution seismic survey: preliminary interpretation and tectonic implications

by

I Zibra

Introduction

The Geological Survey of Western Australia (GSWA) commissioned Velseis Pty Ltd to carry out a high-resolution seismic survey in the Kalgoorlie area, in Western Australia's Eastern Goldfields. The project involved the acquisition, processing and interpretation of seven 2D Vibroseis reflection lines with a total length of approximately 305 km. A preliminary interpretation of the seismic data was completed in August 2019 by Velseis, with input from GSWA geoscientists. The objective for the preliminary interpretation was to correlate major seismic features with interpreted structures from previous Geoscience Australia (GA) seismic surveys, and with GSWA gravity, magnetic and geological maps. Acquisition and processing information and a preliminary geological interpretation were summarized in an interpretation report that, together with the full package of geophysical data, was publicly released in September 2019 (available for download from <www.dmir.wa.gov.au/geophysics>). This talk will concentrate on chief aspects of the recently acquired seismic data, from the perspective of the tectonomagmatic evolution of the Yilgarn Craton, with particular focus on the Kalgoorlie Terrane.

Tectonic evolution of the Yilgarn Craton

The Yilgarn Craton mainly exposes upper-crustal, Mesoproterozoic to Neoproterozoic granite–greenstone terranes. The Youanmi Terrane and the Eastern Goldfields Superterrane represent the two main crustal blocks of the craton (Fig. 1). Seismic and field data indicate that the whole craton includes a series of dominantly east-dipping, listric, crustal-scale shear zones (Zibra et al., 2014). At least some of these structures represent long-lived, transpressional shear zones that were active during the emplacement of syntectonic plutons in the 2730–2660 Ma time span (Zibra et al., 2014). The tectonic evolution of the Yilgarn Craton is controversial, with tectonic models ranging from arc accretion (Myers, 1995) to long-lived intracratonic settings (Van Kranendonk et al., 2013).

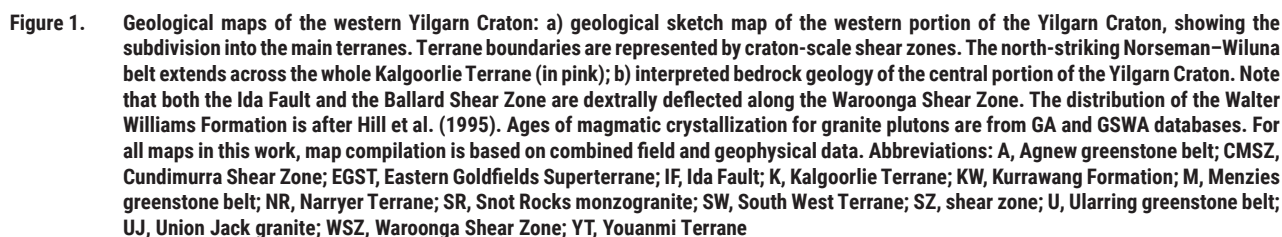
At the scale of the Kalgoorlie Terrane, recent structural studies have highlighted that this portion of the Yilgarn Craton was shaped during two major transpressional events (the terrane-scale D₁ and D₂). These events reflect bulk east–west shortening and took place at 2680–2660 Ma (Fig. 2), during the mature stages of the Neoproterozoic Yilgarn Orogeny.

D₁ was associated with the development of the Ballard Shear Zone, a ≥200 km-long, north-striking transpressional structure that is exposed in the central portion of the terrane, north of the Kalgoorlie area. The Zuleika Shear Zone is interpreted as the southern continuation of the Ballard Shear Zone and represents the most prominent structure in the Kalgoorlie area (Fig. 3). The target area for the recent seismic survey is dominated by greenstone sequences that preserve a higher structural level than the northern portion of the Kalgoorlie Terrane, where more granitic gneisses are exposed. In the Kalgoorlie area, the northwest-striking Zuleika Shear Zone is associated with a dense network of subparallel, smaller-scale structures, which mainly nucleated along the steep limbs of kilometre-scale upright folds.

Preliminary interpretation of the new seismic survey

The mainly east–west oriented seismic traverses intersect the general northerly trend of regional structures at high angles (Fig. 3), offering favourable conditions for imaging the crustal architecture with its true across-strike geometry. For the purpose of this preliminary interpretation, we can identify a group of four main lithotectonic elements that are readily recognizable in both the geological map and seismic images. These include:

- a lower, dominantly mafic–ultramafic greenstone succession (Kalgoorlie Group) that generally produces prominent reflectors in the seismic images
- an upper, dominantly felsic greenstone succession that includes the Black Flag Group and remnants of younger, unconformable sedimentary sequences; these elements are generally transparent in the seismic images
- granites and granitic gneisses with intrusive contacts into the greenstones; granites are generally transparent in the seismic images, while pervasively foliated felsic gneisses might produce well-defined reflectors, particularly when they contain greenstone slivers
- Proterozoic mafic dykes, which are discordant with respect to Archean lithotectonic elements and may or may not produce prominent reflectors in the seismic images.



In the seismic images, the prominent reflectors generated by mafic-ultramafic portions of the Kalgoorlie Group define open folds that can be readily matched with corresponding structures identified on the geological map. Likewise, offsets and truncations of these prominent reflectors constrain the geometry of the major shear zones at depth. Other well-defined reflectors, morphologically similar to those attributed to the Kalgoorlie Group, are imaged in the deeper portions of most lines. These strong reflectors may correspond to tectonically buried portions of the Kalgoorlie Group, implying that the orogenic events produced important duplications of supracrustal units. Alternatively, they might correspond to remnants of the older greenstone successions, which are preserved in portions of the Kalgoorlie Terrane, or to other units that have not been recognized at the surface. Most of the

shear zones that, at the currently exposed crustal level, are subvertical, show an overall listric geometry and commonly become shallow dipping below 2–3 s TWT. One of the most prominent structures in the area, the Zuleika Shear Zone (Fig. 3), is readily identifiable along the western portion of Lines 1, 2, 4 and 6, where it is imaged as an east-dipping listric structure representing the western boundary of the Kurrawang Formation (e.g. Fig. 3). This structure can be generally traced down to the deeper portions of most seismic images. The Zuleika Shear Zone is locally associated with, or displaced by, west-dipping, smaller scale structures that are generally confined to the upper 2–3 s of the seismic images. Results from the new seismic traverses are in substantial agreement with the larger scale image produced earlier by GA (Drummond et al., 2000), indicating that the Zuleika Shear Zone is oriented subparallel to the Ida Fault and can be traced down to lower crustal levels.

Field data indicate that most of the shear zones in the area exploit lithological boundaries, highlighting the role of competency contrast in localizing deformation in upper-crustal environments. This phenomenon introduces a degree of uncertainty in the seismic interpretation; in most cases it remains unclear to what degree the shape, thickness and other features visible in the images reflect the primary stratigraphic architecture, a tectonic overprint, or a combination of both.

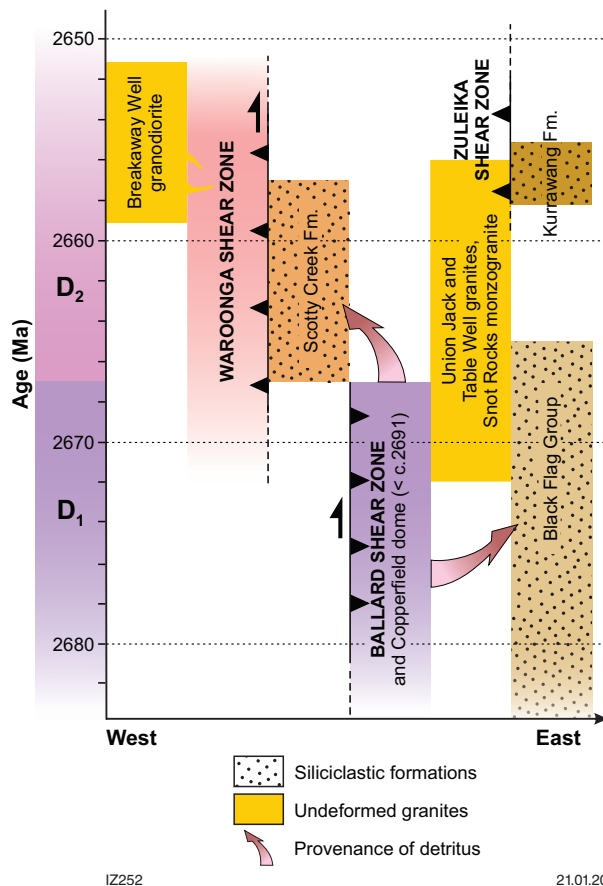
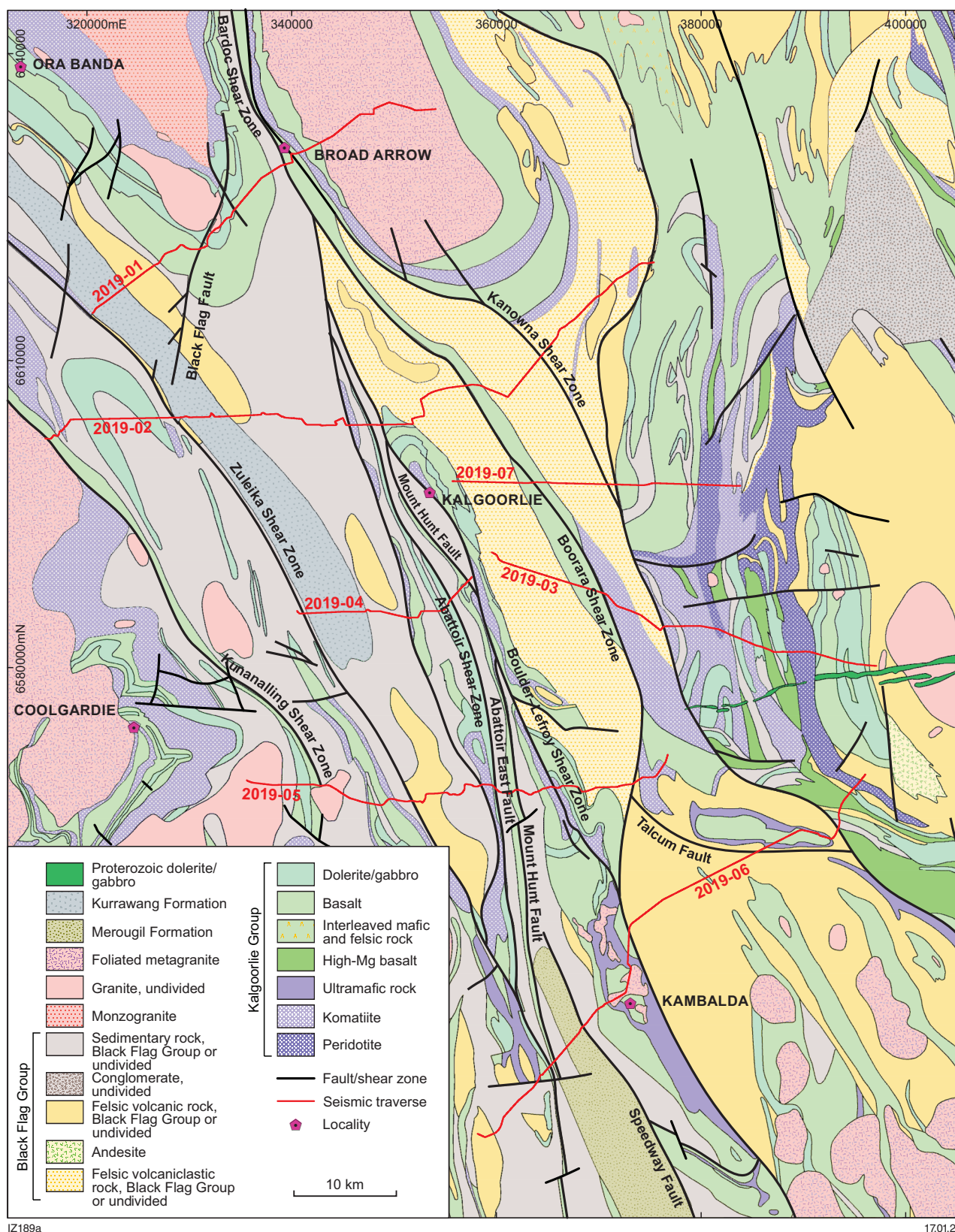


Figure 2. Sketch illustrating available time constraints for development of the main structures in the study area. The different units are shown in an ideal east–west section, also detailing the type of contacts (intrusive vs tectonic)

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Figure 3. 1:500 000-scale geological map of the survey area. Grid references are MGA coordinates, Zone 51

This abstract is part of the session of 10-minute talks

Managing an abandoned mine as a future resource: Ellendale diamond mine

by

T Read

Mining for internationally acclaimed high-quality (fancy) yellow diamonds occurred at Ellendale diamond mine from 2002 to 2015, ceasing in July 2015 when Kimberley Diamond Company NL entered into administration, and subsequently into liquidation. Following the site being disclaimed under the *Corporations Act 2001 (Cth)*, Ellendale was formally declared an abandoned mine site on 4 December 2015. As the remaining diamond resource at Ellendale is of significant value to the State, it is the objective of the Department of Mines, Industry Regulation and Safety to ensure the site remains viable for future responsible resource development.

Ellendale is located on the Lennard Shelf in the northeastern portion of the Canning Basin. The geology is dominated by the Devonian marine sediments (siltstones, shales, limestones) of the Fairfield Group, which are unconformably overlain by Permian-age fluvial sandstones (Grant Group). During the Tertiary Period, the Canning Basin was intruded by lamproitic plugs and subsequent eruptions have filled the volcanic vent with lamproitic pyroclastic tuffs.

Waste rock generated following the removal of the target diamond-bearing material within the plug has been used to construct both waste-rock landforms and tailings storage

facilities (Fig. 1). These constructed landforms show varying degrees of erosion across the landform surfaces; on some structures the significant level of erosion has the potential to lead to wall instability and, under extreme conditions, wall failure if no remediation action is taken.

Studies undertaken on the main waste materials confirmed the cohesiveness of the material types as being too low to resist the erosive force of surface water flows across current batter designs. The weathering rate of the waste materials is a major contributing factor affecting erosional stability, with both siltstone and magmatic wastes breaking down from blocky waste rock to very fine-grained particles after being blasted, excavated, transported and exposed to the elements.

Landform remediation options include the use of rock armouring utilizing the blocky sandstone material and adoption of modifications to the current batter design to reduce run-off potential. This will result in a more stable landform into the long term, reducing the potential for environmental impacts, and will preserve the Ellendale site for future use.



Figure 1. Ellendale 9 TSF-1D Cell 3 western wall, indicating significant gullying and sediment deposition. Gullies are greater than 2 m deep and extend from crest to toe. Remediation options will include rock armouring and modifications to the outer batter slope angle

AusAEM20-WA project

by

J Brett

AusAEM20 is a collaborative national goal of the Commonwealth, State and Territory geological survey agencies to acquire airborne electromagnetic (AEM) data at 20 km or closer line spacing across the Australian continent. It is a successor to the 2017–20 Geoscience Australia Exploring for the Future (EFTF) AusAEM project, which, on completion, will have covered a substantial part of northern Australia.

The AusAEM20-WA project, as the Western Australian agreement is referred to, will complete the 20 km line spacing AEM coverage of those parts of Western Australia that were not surveyed during Year 2 of EFTF AusAEM (Fig. 1).

It is anticipated that acquisition of the 65 000 km of data that will be needed for this coverage will take place over the next two to three years.

Geoscience Australia's EFTF AusAEM surveys have demonstrated that, even at 20 km line spacing, AEM data are coherent at very broad reconnaissance scales and may be used:

- to determine trends in regolith thickness
- to map regional variations in bedrock conductivity, within the depth of penetration of the system
- to set context for and guide mineral exploration project generation by industry
- to improve targeting for water resources definition
- as input for other land use applications in other industry sectors and land use agencies.

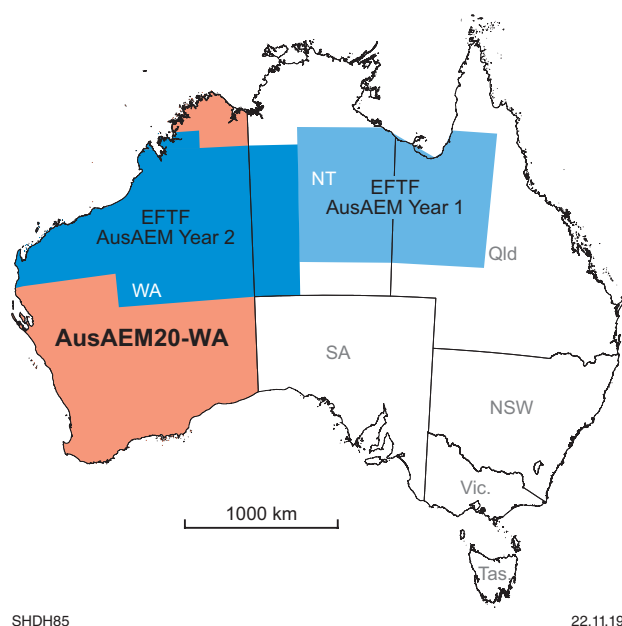


Figure 1. Location of AusAEM20-WA survey areas

This abstract is part of the session of 10-minute talks

Rare-element pegmatites in the Mineral Systems Atlas

by

P Duuring



Rare-element pegmatites are important hosts for Li, Cs and Ta mineralization in Western Australia, with examples including the world-class Greenbushes, Pilgangoora and Wodgina deposits. The Minerals Geoscience branch has undertaken an analysis of the rare-element pegmatite mineral system by reviewing existing literature to define critical geological processes controlling genesis, hence to define mappable proxies that can be translated into a series of geographic information system layers in the Geological Survey of Western Australia Mineral Systems Atlas.

Critical processes for rare-element pegmatites include: i) generation of magmas that are fertile as sources for fluids and metals; ii) presence of coeval crustal-scale structures that could provide pathways for magmatic–hydrothermal fluids; iii) cooling and chemical diffusion in fractionating granitic magmas to concentrate rare

elements into residual melts that feed compositionally and texturally zoned pegmatites; iv) uplift and erosion of crustal profiles sufficient to expose, but not destroy, rare-element pegmatites.

Mappable proxies for fertile magmas include: i) S-type granites that are enriched in Li, Cs, Ta, Rb, Sn, F, Be, Nb, Ga, Fe, Ti and rare earth elements; ii) granites containing indicator minerals, such as fluorite, cordierite, tourmaline, garnet, white potassium feldspar and green muscovite; iii) granites manifesting high ratios of Li/Mg, Cs/K, Rb/K and Ta/Nb. Mappable proxies for pegmatitic fluid pathways would include distribution maps for faults, fractures, foliation or bedding. Cooling and chemical fractionation in granitic melts may be identified by mapping diagnostic regional mineral and chemical zonation patterns in granites and pegmatite mineralogy.

The last gasp of King Leopold: new insights into the evolution of the West Kimberley

by

IOH Fielding, FJ Korhonen, SS Romano, NJ Evans¹ and MP Roberts²

Constraints on the timing and conditions of metamorphism and deformation in the King Leopold Orogen are limited due to a lack of geochronology and thermobarometry. Existing models associate strike-slip fault movement and coeval metamorphism with the poorly constrained 1400–1000 Ma Yampi Orogeny. The Billyarra Shear Zone is a high-strain zone that crosscuts sedimentary rocks of the Marboo Formation. Pelitic rocks in this zone have a peak metamorphic assemblage comprising garnet, staurolite, muscovite and biotite. Garnet and staurolite occur as porphyroblasts with inclusion trails aligned in a strong foliation defined by biotite–muscovite–quartz, supporting interpretations that peak metamorphism and deformation were coeval.

Interpreted pressure (*P*)–temperature (*T*) estimates predict peak metamorphic conditions of 580–630°C and 5–6 kbar along a clockwise *P*–*T* path, consistent with crustal thickening to a depth of about 13 km (Fig. 1a). In situ laser ablation split stream analyses of monazites aligned in the foliation yield a ²³⁸U/²⁰⁶Pb date of 502 ± 3 Ma (Fig. 1b), interpreted as the age of deformation and associated metamorphism. These results indicate a significantly different and more complex geological history of the shear zones than previously recognized. The fault movement occurred at c. 500 Ma and was accompanied by high-grade metamorphism and crustal thickening, possibly related to the final stages of the 670–510 Ma King Leopold Orogeny.

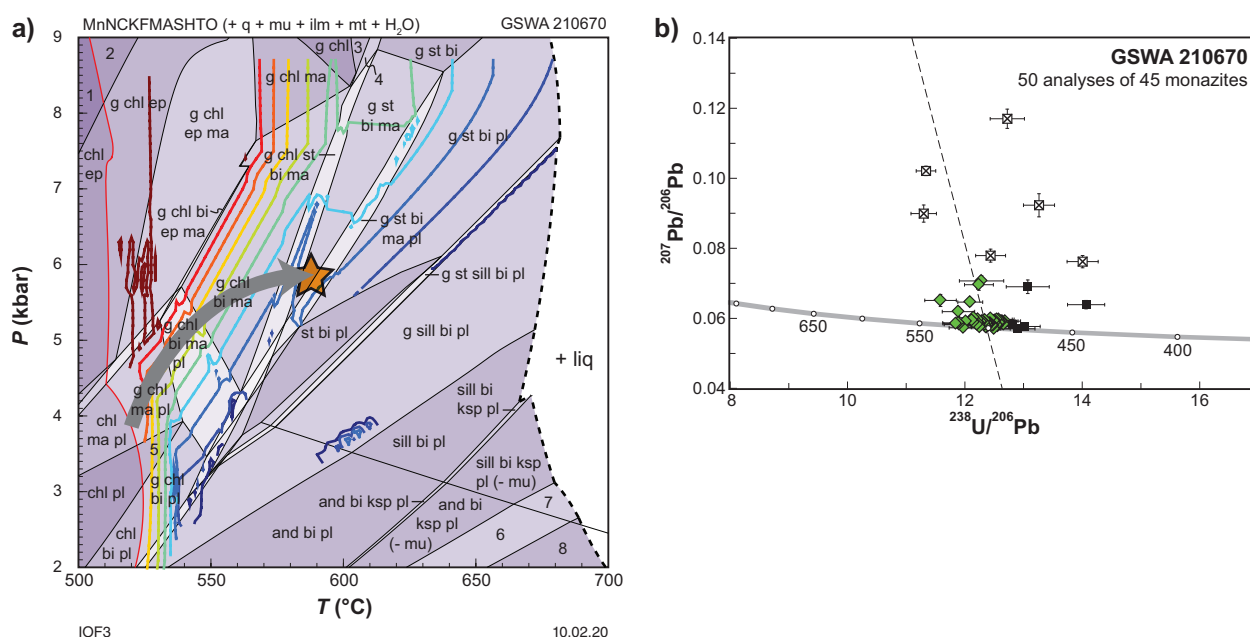


Figure 1. Analytical data for metamorphic monazite in GSWA sample 210670: a) *P*–*T* pseudosection; b) U–Pb analytical data, not corrected for common Pb. The dashed line indicates a regression from initial Pb through data in Group M (metamorphic monazites). Green diamonds indicate Group M; black squares indicate Group P (radiogenic-Pb loss); crossed squares indicate Group D (high common Pb). All analyses were conducted in situ, to preserve the textural relationship of the monazite to surrounding minerals, allowing for direct dating of deformation and peak metamorphism. Abbreviations: and, andalusite; bi, biotite; chl, chlorite; ep, epidote; g, garnet; ilm, ilmenite; ksp, K-feldspar; liq, liquid (silicate melt); ma, margarite; mt, magnetite; mu, muscovite; pl, plagioclase; sill, sillimanite; st, staurolite

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This abstract is part of the session of 10-minute talks

Exploring the link between a suture zone, an ophiolite and a seahorse

by

CV Spaggiari

Between 2009 and 2014, the Geological Survey of Western Australia (GSWA) completed a program of Exploration Incentive Scheme (EIS)-funded geophysical data acquisition and stratigraphic drilling to investigate the greenfields Madura and Coompana basement provinces. In Western Australia, these provinces are completely overlain by up to 500 m of cover rocks belonging to the Bight and Eucla Basins. Data acquisition was followed by a comprehensive program of analysis by GSWA, on the back of which BHP acquired a large tenement package in the shape of a seahorse (Fig. 1). The Seahorse project was initiated to explore for mafic intrusion-hosted Ni–Cu deposits and includes the Rodona Shear Zone and rocks of oceanic affinity in its hanging wall. It also encompasses the Sunset Shear Zone, which separates two structurally and geophysically different domains of the eastern

Nornalup Zone. Combined with extensive tenement uptake by Red Metal Limited and more recently by Rio Tinto Limited, the Seahorse project represents the largest uptake of tenements in the Nullarbor region to date.

The Rodona Shear Zone is defined as a suture zone between the Madura Province and variably modified Archean craton margin crust of the Albany–Fraser Orogen, and trends parallel to the prospective Fraser Zone. The Madura Province is interpreted to contain oceanic basement with remnants of hyperextended continental crust interleaved with 1479–1389 Ma oceanic-arc rocks that were structurally emplaced over the continental margin between 1389 and 1330 Ma, forming the Arubiddy Ophiolite.

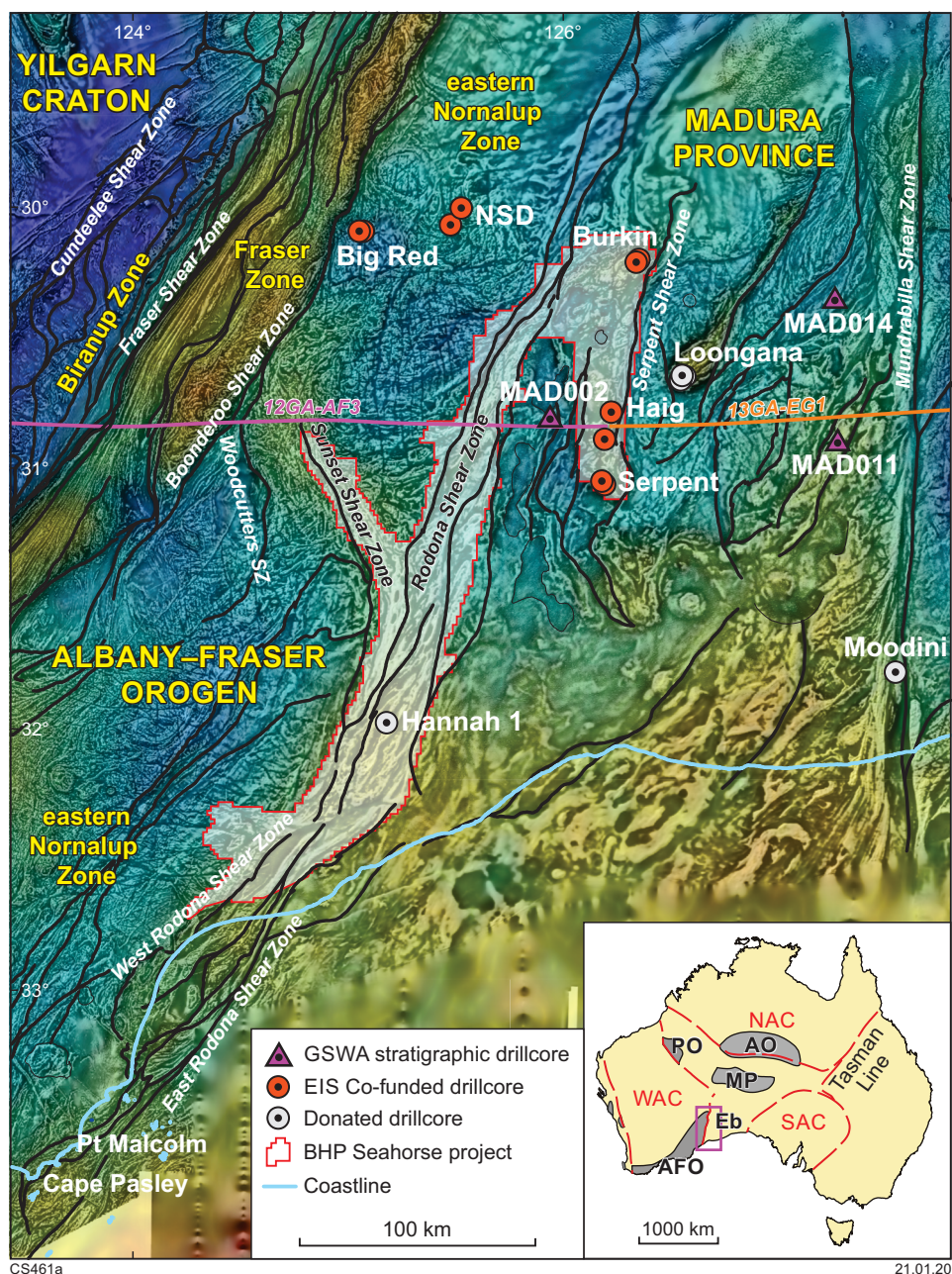


Figure 1. Drape image of gravity (colour) and reduced to pole, first vertical derivative aeromagnetic data (greyscale) showing the location of the BHP Seahorse project tenement package, simplified structures, deep crustal seismic lines and site locations for drillcores archived in the Perth Core Library. Abbreviations on inset: AFO, Albany–Fraser Orogen; AO, Arunta Orogen; Eb, Eucla basement; MP, Musgrave Province; PO, Paterson Orogen

This abstract is part of the session of 10-minute talks

A subduction origin for 2820–2735 Ma magmatism in the western Youanmi Terrane, Yilgarn Craton

by

J Lowrey

During the last several years, evidence has emerged that questions the basis for a mantle plume origin for 2820–2735 Ma high-Mg mafic magmatism in the western Youanmi Terrane (previously the ‘Murchison Domain’) of the Yilgarn Craton. Many, or possibly all, of the ‘platy spinifex’ textured units in the region, have liquid compositions that are notably less magnesian than the International Union of Geological Sciences definition for komatiite, and they are defined by a previously unrecognized platy morphology of pyroxene, rather than the platy olivine spinifex that is commonly observed in komatiites. Samples that contain $\geq 18\%$ MgO invariably contain abundant polyhedral olivine phenocrysts, that is they are picrites or olivine orthocumulates, and do not represent liquid compositions. Hence, the distribution of komatiites appears to be grossly overstated, and the necessity for anomalously high mantle temperatures becomes questionable.

In contrast, multiple lines of evidence point towards a subduction or subduction-like origin:

- Mafic volcanic and subvolcanic rocks with boninite-like chemistry and mineralogy occur in two units at c. 2820 and c. 2800 Ma. In modern volcanic settings, boninitic magmas commonly erupt during the embryonic stages of subduction.
- 2800–2735 Ma mafic–ultramafic sills that intrude the greenstone sequence locally contain abundant hornblende, while 2785–2735 Ma granitic rocks are also commonly hornblende rich and locally have sanukitoid compositions, indicating a widespread hydrous metasomatized mantle throughout the western Youanmi Terrane by 2800 Ma, at the latest.
- The 2820–2735 Ma stratigraphic package also contains tholeiitic basalts and calc-alkaline basalt–andesite–dacite–rhyolite series, locally with adakite compositions, that are all consistent with a subduction origin.

MRIWA: leading impactful research, meaningful collaboration and effective knowledge transfer

by

A Subramanya*

The vision of the Minerals Research Institute of Western Australia (MRIWA) is to support research that will advance Western Australia. This is achieved by focusing on research that is impactful, encourages collaboration and enables effective knowledge transfer to the broader industry and community.

The total value of research supported by MRIWA at the end of the 2018–19 financial year was \$46.6 million of which \$37.7 million was spread over 46 research projects, \$7.1 million invested in three Cooperative Research Centres and \$1.7 million invested in 17 PhD scholarships. A further 45 PhD scholars are supported through our project funding.

An economic impact assessment carried out by ACIL Allen Consulting in 2018 forecast MRIWA's research investment to deliver significant economic and community benefits to the State over the next decade. Through our Research Priority Plan we enable research across the minerals value chain with the aim of increasing the sustainability of the sector, and enable applied research to create capability and deliver economic and social benefits within Western Australia.

Research funding supports innovation in the academic as well as private sector, with MRIWA partnering with major universities, research agencies and the Mining Equipment, Technology and Services sector in Australia and overseas.

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Tectonic setting and exploration potential of the northern Capricorn Orogen

by

DMcB Martin

The Capricorn Orogen is a long-lived zone of accretionary, collisional and intracratonic tectonic activity that formed between c. 2215 and 570 Ma during assembly of the West Australian Craton. Assembly involved accretion of the Glenburgh Terrane to the southern margin of the Pilbara Craton during the Ophthalmia Orogeny, followed by collision of this combined cratonic block with the Yilgarn Craton during the Glenburgh Orogeny. All subsequent deformation was intracratonic. The central and southern Capricorn Orogen have been extensively studied in recent years, and have also been the subject of significant exploration activity leading most notably to the discovery of the Degruessa deposit. Although the northern margin of the orogen is host to vast Fe ore reserves in the Hamersley province, as well as two >1 Moz Au deposits (Paulsen's and Mount Olympus), it has received considerably less exploration interest for commodities other than Fe ore. This presentation re-examines the stratigraphy, structure and tectonic setting of the northern Capricorn Orogen and their implications for mineral prospectivity.

at the base of either the Kungarra Formation or the Boolgeeda Iron Formation. Formerly un-named units have been named, and the lower Wyloo Group has been formalized as the Shingle Creek Group (excluding the Wooly Formation). The Wooly Formation is a revised unconformity-bound unit consisting of both siliciclastic and carbonate rocks (formerly the Wooly Dolomite).

The relationship of angular unconformities to the recently named c. 2208 Ma Balgara Dolerite (Fig. 1) provides important constraints on the timing of Ophthalmian folding. Most importantly, intrusive relationships between the Balgara Dolerite and the Beasley River Quartzite show that all unconformities in the Shingle Creek and Turee Creek Groups are older than c. 2208 Ma. However, relationships between sills and individual unconformities, specifically at the base of the Anthiby Formation (Fig. 1), suggest that there may be an older component within the Balgara Dolerite. Nonetheless, mapped relationships imply that sill intrusion, folding and unconformity development all took place within a narrow timeframe at c. 2208 Ma.

Revised stratigraphy

Recent mapping in the southern Hamersley province, combined with new geochronological data, has identified a number of stratigraphic revisions and important field relationships that have necessitated a re-examination of the geological evolution of this region. First, the contact between the Hamersley and Turee Creek Groups is demonstrably disconformable, with local erosion of up to 200 m of strata. The contact between the Woongarra Rhyolite and the Boolgeeda Iron Formation in the uppermost Hamersley Group is also likely disconformable, but confirmation requires more geochronological data. Existing data suggests that all dates currently reported for the Boolgeeda Iron Formation are maximum depositional ages that primarily reflect erosion of the underlying c. 2444 Ma Woongarra Rhyolite.

Four glacial diamictites have been named in the Turee Creek Group, and recent whole-rock and pyrite Re–Os dating of the Meteorite Bore Member (Fig. 1) allows for a much better constrained global correlation with equivalent units that record the Huronian Glaciation between c. 2.45 and 2.22 Ga. However, constraints on the maximum age of the Turee Creek Group suggest that three of the glacial units are younger than 2425 ± 9 Ma (Fig. 1), and that there could be a significant hiatus

Tectonic setting

The southern margin of the Pilbara Craton has long been interpreted to record a progression from continental rifting (Fortescue Group), to passive margin subsidence (lower Hamersley Group), followed by conversion to a convergent margin (upper Hamersley Group) involving northwards subduction beneath the Pilbara Craton during deposition of the Mount Bruce Megasequence Set (MBMS; Blake and Barley, 1992). In this interpretation, convergence was considered to have culminated in the formation of a retro-arc foreland basin during deposition of the Turee Creek Group, with the Beasley River Quartzite unconformity representing continent–continent collision and post-collisional uplift, although it was recognized that the Shingle Creek Group could also be part of the underlying MBMS. The latter interpretation has now been confirmed, with the Turee Creek Basin consisting of the Boolgeeda Iron Formation, and Turee Creek and Shingle Creek Groups, although incontrovertible evidence for northwards subduction to drive convergence is still lacking. The Wooly Formation is now interpreted to be as much as 172 Ma younger than the Shingle Creek Group and records extension of the southern Pilbara Craton margin accompanied by normal faulting and local mafic volcanism between c. 2031 and 2008 Ma.

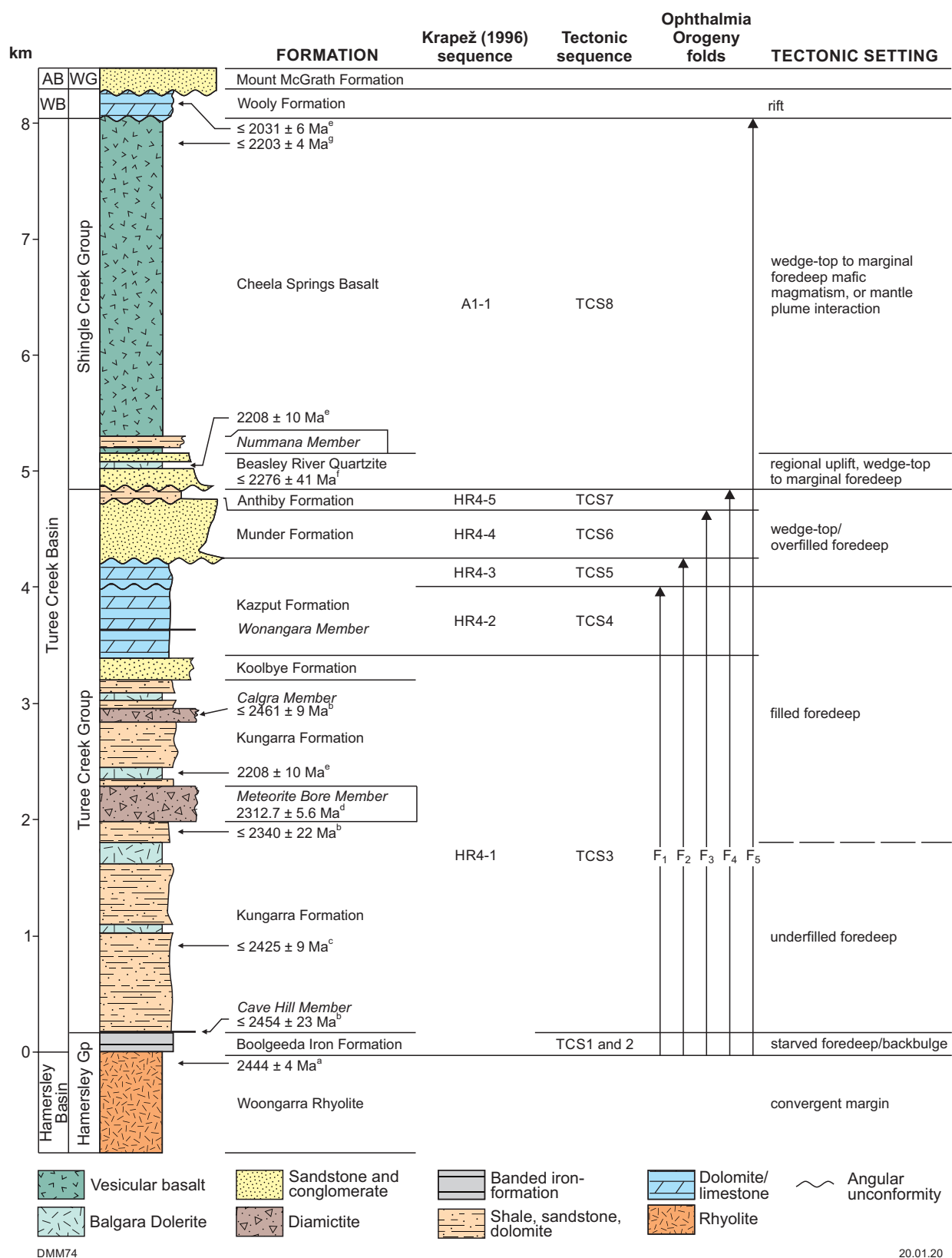


Figure 1. Depositional and tectonic sequence nomenclature, tectonic setting of basin stages, and relationships to Ophthalmian fold events (labelled F₁₋₅) in the Turee Creek Basin. Modified after Martin and Morris (2010), and including new geochronology (with 95% uncertainties) from: a – Wingate et al. (2018a); b – Caqueneau et al. (2018); c – Wingate et al. (2018b); d – Philippot et al. (2018); e – Müller et al. (2005); f – Krapež et al. (2017); g – Wingate et al. (2019). Only robust and geologically meaningful dates are shown. Abbreviations: AB, Ashburton Basin; WB, Woolly Basin; WG, Wylloo Group

Exploration potential

In addition to the well-documented hypogene and supergene Fe ore deposits, the revised tectonic settings have important implications for mineral prospectivity of the southern Hamersley province. In particular, mapping of the wide regional distribution of the revised Woolly Formation shows that it hosts the Mount Olympus Au deposit, as well as some smaller Au and base metal prospects. The close spatial association of these mineral occurrences with regional-scale normal faults that may be related to deposition of the Woolly Formation and also display evidence of significant hydrothermal fluid flux (silica flooding), suggests enhanced prospectivity for a range of deposit styles including orogenic and Carlin-style Au, as well as sediment-hosted base metal deposits. Potential may also exist for flood basalt-hosted Ni – Cu – platinum group element deposits associated with the Balgara Dolerite and Cheela Springs Basalt.

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Smart exploration starts with Western Australia's rich data endowment: MINEDEX, WAMEX and WAPIMS databases

by

NL Wyche, J Thom and F Irimies

***'Where there is Data Smoke,
there is Business Fire.'***

– **Thomas C. Redman**, Data Driven: Profiting from
Your Most Important Business Asset

An essential role of the Geological Survey of Western Australia is to be custodians of data acquired throughout the history of mineral and petroleum mining and exploration in Western Australia. Equally as important is providing this data to our customers to kickstart new exploration. Our key databases allow explorers and researchers alike to easily access this information. The Mines and Mineral Deposits (MINEDEX), Mineral Exploration Reports (WAMEX) and Western Australian Petroleum Information Management System (WAPIMS) databases provide access anywhere, anytime to Western Australia's past and present mining and exploration data.

MINEDEX provides detailed spatial and textual information on over 42 500 Western Australian mines, mineral occurrences and mining infrastructure. Available data include site locations, project structure, owners and operators, commodities, resource estimates and production data, basic geological information and mineralization styles. Users can also access environmental registration documents (for example, mining proposals) related to projects and the Inventory of Abandoned Mine Sites. MINEDEX also offers comprehensive searching and data export options, compatibility with mobile devices, and accessibility for users with disabilities.

WAMEX stores over 93 000 detailed reports on prior exploration in Western Australia. Mineral explorers are required to report annually on their exploration projects under Western Australian legislation. After a period of confidentiality, these exploration reports and data are made available to the public. The reports and related raw data, such as drilling data, geochemistry results, geophysical data, 3D models and ore resource calculations, are stored as searchable PDF files and are searchable and downloadable via our free GIS mapping tool GeoVIEW.WA.

WAPIMS stores information on petroleum exploration completed in Western Australia submitted to the department in accordance with the *Petroleum and Geothermal Energy Resources Act 1967 (WA)* and the *Petroleum (Submerged Lands) Act 1982 (WA)*. Datasets include well reports, logs and samples, seismic surveys, field and processed data, survey reports, observer's logs, annual assessment title reports and sample analyses. WAPIMS also contains pre-competitive data extracted from reports, including biostratigraphy, formation tops and porosity. WAPIMS allows data downloads and provides order forms for large datasets. Data is discovered using inbuilt spatial and textual searching.

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