2018 | Hosted at The University of Western Australia

GESS
GSA Earth Sciences Student Symposium
WA

ABSTRACT VOLUME

GEOLOGICAL SOCIETY OF AUSTRALIA Incorporated

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Curtin University

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WELCOME TO GESSS-WA 2018

We would like to extend a massive welcome to everyone here including all the Earth science personnel from academic, industry and government organisations. The inaugural Geological Society of Australia Earth Sciences Student Symposium is set to showcase the best of Western Australia's postgraduate geoscience research.

We have had an overwhelming response from Honours, Masters and PhD students wishing to present, from multiple universities and a variety of geoscience disciplines. The quality and breadth of research here today is highly commendable, with presentations including ore geology, sedimentary basins, orogenesis, geochronology, stable isotope and biomarker geochemistry, geobiology, palaeomagnetism, and computational geoscience.

This symposium is one of 5 organised by student groups in individual states following a Geological Society of Australia (GSA) mandate to help postgraduate students self-organise a showcase of their work. We sincerely thank the GSA for their enthusiasm, mentorship and assistance over the last 12 months.

The GESSS-WA student committee followed this mandate but furthermore decided to increase ties with the Universities thus making the event a joint GSA, UWA and Curtin collaboration. This means we are not only a platform to showcase postgraduate research but also a major event for facilitating University collaboration, as well as providing opportunities to strengthen ties between students, industry and government.

In the aim of facilitating postgraduate and research collaboration between the Universities, we extend great thanks particularly to the School of Earth Science at the University of Western Australia, and the School of Earth and Planetary Science at Curtin University. Both schools have offered a huge amount of support and have committed time, students and funds to this event, and have ensured the event annual continuation.

Most gratefully, we sincerely thank our industry partners for their sponsorship and support. Without your generous contributions we could not host this event today. We are sure today will give you an opportunity to engage with some brilliant and awe inspiring geoscience students, many of whom we are sure are set to become future leaders in the resource and energy sector. We hope to continue these mutually beneficial partnerships in future years.

As a committee we are extremely proud to have organised this conference for you, and we hope this provides a solid foundation for the future annual GESSS-WA events.

Finally a massive thank you to everyone on the GESSS-WA student committee, which formed together from multiple University postgraduate committees, and have worked over the last 12 months bringing this event together, it has been a privilege working with you all.

See you again at GESSS-WA 2019!

GESSS-WA 2018
Organising Committee

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GESSS-WA

ORGANISING COMMITTEE

Julian Chard
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Dennis Sugiono
Lilly Kendall-Langley

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2018 Committee

ON THE DAY

GENERAL INFORMATION

The presentations will be held in the Geology building at UWA with the afternoon Sundowner and poster session held at the nearby Watersports Complex, UWA. Presentations will run in two concurrent sessions during the day (with the exception of session 1), in the Woolnough and Webb Lecture Theatres.

REGISTRATION

The registration desk will open at 8 am, and can be found in the foyer of the Geology Building (see map on back page) for you to collect your lanyard and conference bag.

ORAL PRESENTATIONS

Time allocated for oral presentations are 15 minutes (12 min talk, 3 min questions) and 5 minutes (including questions) for short talks. All presenters should upload their presentation via USB stick to the laptop provided during morning registration, prior to the Keynote talk. If you are unable to upload your talk during morning registration please do so at the beginning of the break before your session, or at your earliest convenience.

POSTER PRESENTATIONS

The poster session and sundowner will be held at the UWA Watersports Complex on the Matilda Bay Foreshore (see map). Posters can be left at the registration desk during the day and collected at the end of the last session. Access to the venue will not be available until 4 pm. GESSS-WA committee members will be at the Watersports complex from 4.30 pm, and poster presenters are welcome to put up their posters from this time.

PRIZES

There will be a number of prizes up for grabs for the best presentations at GESSS-WA 2018. Prizes have been generously donated from Quadrant Energy, Westernex, Prospectors, AusIMM and GSA-WA Division. The winners will be decided through a general ballot with the most popular presentations to be awarded their prizes during the sundowner. Voting slips are given out upon registration and should be submitted to the ballot box located in the Geology foyer, next to the registration desk. Voting for the oral presentations closes at the end of the final session (5 pm), if you haven't already, please submit your slips on the way out.

CATERING

Morning and afternoon tea will be served in the Geology foyer. Lunch will be provided for in the Tropical Grove. Light refreshments will be available at the Sundowner at the UWA Watersports Complex.

INVITED GUESTS
KEYNOTE SPEAKERS

PHIL BLAND

Phil's talk titled "Planetary Science Past and Present" will be at 9:00 am in the Woolnough Lecture theatre.

Phil Bland is a Professor of Planetary Science at Curtin University. His research is focused on the origin and evolution of the solar system through analysing meteorites to explore unanswered questions such as how our planet formed and how it acquired the ingredients for life. In 2006, Asteroid '1981 EW21' was renamed '(6580) Philbland' in recognition of his contributions to planetary science. He established the Desert Fireball Network (DFN) as an Australian Laureate Fellow and founded the multi-award winning Fireballs in the Sky outreach and citizen science program. In 2015 Professor Bland established a partnership between NASA and Australia in planetary, space and exploration science. He has recently established the Space Science and Technology Centre at Curtin University.

GRAHAM BEGG

Graham will be speaking after lunch from 1:25 pm in the Woolnough Lecture Theatre. He will presenting a talk titled "From Geosystem to Mineral System: Contextualising Ore Deposits"

Graham Begg has over 30 years in the mining and minerals exploration sector, and a PhD in tectonics and epithermal deposit geology from Monash University. Since 2002 he has also spearheaded collaborative research at Macquarie University, aimed at systematic multi-disciplinary mapping of the architecture and geodynamic evolution of the continental lithospheric mantle and crust, with the aim to facilitate a breakthrough in greenfields exploration discovery. The outputs contribute towards the commercial Global Lithospheric Architecture Mapping (GLAM) product, a framework for area selection in the resource sector marketed by his consultancy Minerals Targeting International (MTI).

OUR VARIOUS
PARTNERS

ILUKA RESOURCES

Who we are

Iluka Resources Limited (Iluka) is a major participant in the mineral sands industry. The company is the largest global producer of zircon and a major producer of the high-grade titanium dioxide products rutile and synthetic rutile. Iluka's products are used in an increasing array of applications including home, workplace, medical, lifestyle and industrial uses.

With approximately 2,500 direct employees, Iluka has been involved in mineral sands exploration, mining, processing, marketing, and rehabilitation for over 60 years. The company has operations in Australia and Sierra Leone; development activities in Australia, Africa, Sri Lanka and Canada; and a globally integrated marketing network. Iluka is listed on the Australian Securities Exchange and has a market capitalisation of approximately $5 billion. The company is head-quartered in Perth, Western Australia.

Rehabilitation

Land management and rehabilitation are a major focus for Iluka and constitute a significant, continuous part of the company's activities. Iluka has an established record of land rehabilitation over several decades. Its rehabilitation efforts are aligned with leading practice and undertaken in a socially and environmentally responsible manner. Iluka manages a diverse range of land uses including native vegetation across a range of climate zones and agricultural sites. Closure planning begins before mining starts and where possible, rehabilitation occurs progressively with ongoing mining activity.

Geology

Iluka Resources employ a team of geoscientists who are involved in all stages of the exploration and mining cycle. The key elements of the exploration and evaluation process are;

- review and field inspect the geological features of potential mineral provinces to identify the most likely areas for the formation of mineral sand deposits;
- remote sensing using aerial geophysical surveys, satellite imagery, Geospatial Information Systems (GIS) and accurate regional topographic images;
- drilling to collect samples;
- laboratory analysis of samples to assess the heavy mineral content and quality, and other economically important characteristics; and
- extensive computer modelling and evaluation of data collected, to establish the physical and commercial viability of each deposit.

UWA SCHOOL OF EARTH SCIENCES

In UWA's School of Earth Sciences, in the Faculty of Science, we are proud of our well-established reputation in geoscience research, both fundamental and applied, and how our expertise underpins undergraduate teaching in geology and marine science, honours and coursework masters, and our research degrees. Our staff are enthusiastic, passionate researchers and educators.

Our location in WA, proximal to ancient cratons, orogens and resource-rich sedimentary basins, and the magnificent coastline, provide much impetus for onshore and offshore research and learning opportunities. The School has several world-class centres and research groups, i.e. Centre for Exploration Targeting (CET), Centre for Energy Geoscience (CEG), Oceans and Coastal Systems, and Hydrogeology, with enduring, strong collaboration with, and support from, federal and state government agencies and industry over many years. These centres and groups are the foci for attracting high quality research students to UWA from all over the world, and we continue to host a diverse and motivated cohort of students working on an array of exciting projects.

Two elements characterise our school's activities. Firstly, our research and teaching emphasise integration of geology, geochemistry, geophysics, geobiology, numerical modelling and data analytics to solve increasingly complex problems in earth sciences. Many projects have both fundamental and applied elements, the latter driven by exploration for resources in WA (minerals, petroleum and groundwater) and in a wide range of countries and regions globally. Secondly, fieldwork is a key component in many of our research projects, and is further emphasised in our undergraduate and postgraduate learning and teaching. As a core competency, it is further enhanced by the prominence of practical skill development and application through all our courses. Industry geoscientists are important contributors to these courses, e.g. our Masters of Geoscience, Hydrogeology, Ore Deposit Geology and Petroleum Geoscience, and we acknowledge this contribution to our curriculum, as well as exciting extra-curricular activities provided by fieldtrips, shipboard cruises, internships and part-time and vacation work experience, that all contribute to employability of our graduates.

We are proud that our efforts in research and teaching are recognised by international and national measures, e.g. UWA Earth and Marine Sciences is ranked 3rd in Australia and 32nd globally (QS rankings 2018), and 3rd in Australia in Earth Science and 63rd globally (ARWU), and 'above world average' in ERA (2015). UWA Science undergraduate and postgraduate student experience rate well within the Group of Eight universities (QILT).

GEOCONFERENCES WA

The **6th International Archean Symposium (6IAS)** is the premier international symposium dedicated to Precambrian geoscience, with a specific focus on the Archean. The symposium will be hosted at the University of Western Australia in **Perth, Australia on July 14-16, 2020**. It is presented by the not-for-profit organisation, Geoconferences, marking the sixth in a series that began in 1970. 6IAS is designed to promote discussion and communicate the latest concepts, methodologies and technologies relevant to unlocking the secrets of the Archean to all geoscientists. The symposium will be followed by Target 2020, a one-day meeting focusing on exploration strategies for the future sustainability of the minerals industry.

A number of field trips have been planned in association with the conference to visit classical geological terranes and mineral deposits in Western Australia.

PRE-CONFERENCE TRIPS

July 5 - July 12 2020:

- Palaeoproterozoic reworking of an Archean craton margin: a transect across the southern Gawler Craton;
- Pilbara Craton: evolving Archean tectonic styles.

POST-CONFERENCE TRIPS

July 18 - July 25 2020

- The Archean-Proterozoic boundary — out with the old, in with the new: a traverse through the Mount Bruce Supergroup;
- A traverse across the Yilgarn Craton in Western Australia: From the Jack Hills to the Yamarna Terrane;
- Mineral deposits in the Yilgarn Craton of Western Australia.

The Target 2020 meeting will be held on July 17 at the University of Western Australia. The meeting is co-organised by Geoconferences and the Centre for Exploration Targeting and will showcase innovations developed to aid discovery of new tier-one deposits and broaden the exploration space under cover. Target 2020 will focus on all aspects of mineral exploration and provide a unique opportunity to workshop solutions to the mineral industry challenges that lie ahead, covering multi-commodity exploration at a regional scale for greenfields and brownfields, as well as mine exploration. We expect attendees from both the Australian and international mineral exploration community, including executives, professionals, researchers and university students.

Symposium themes include:

- Early Earth evolution: perspectives from the oldest minerals and rocks;
- Emergence of atmosphere and life on early Earth and other terrestrial planets;
- Development of Archean continental crust and lithosphere: latest insights;
- Role of Archean lithosphere in the evolution of younger terranes; understanding Archean terranes and their margins;
- Archean terranes and craton margins in BRICS region (Brazil-Russia-India-China-South Africa);
- Archean to Proterozoic transition; and
- Mineral systems of Archean terranes and their margins.

IGO: COMMITTED TO GROWTH THROUGH EXPLORATION AND DISCOVERY

IGO's Regional Exploration & Development Projects / Exploration Opportunities

FRASER RANGE

Ni, Cu & Co

Regional geochemical sampling, geophysical surveying and drilling. Aircore drilling and geophysical programs have identified numerous anomalous results requiring additional exploration.

RAPTOR

Ni, Cu & Co

A new belt-scale project targeting the Willowra Gravity Ridge in the Northern Territory. Regional aeromagnetic and radiometric surveys planned.

LAKE MACKAY

Cu, Au, Ni & Co

Unlocking a new under-explored mineral province in the Northern Territory. Regional geochemical sampling, airborne electromagnetic surveys, prospect mapping and rock sampling has further confirmed project potential.

FRONTIER, GREENLAND

Cu & Co

A belt scale joint venture targeting Zambian-style copper. Regional reconnaissance mapping and rock geochemical sampling underway.

IGO is a leading ASX-listed mining and exploration company with a strategic focus on high quality assets of scale and longevity, and an evolving strategy to align the business to the structural shift to energy storage and electric transport. Our focus is on the 100%-owned, world class Nova nickel-copper-cobalt operation, the 30% interest in the Tropicana Gold Operation (a Joint Venture with AngloGold Ashanti Australia), and our portfolio of belt-scale exploration projects in Australia and abroad.

Exploration and discovery are core to the IGO DNA and are a key driver for our future growth strategy. Over the last few years, we have transformed our exploration project portfolio with the consolidation of an extensive brownfields ground position in the highly prospective Fraser Range of Western Australia, to take advantage of our major infrastructure investment and advancing geological understanding at Nova, and securing the Lake Mackay and Raptor Projects in the Northern Territory, and the Frontier Project in Greenland.

Graduate & Vacation Programs

IGO's Graduate Program offers university graduates two or three year programs commencing in January/February each year, with the aim of supporting them in their transition from study to career. Our flexible program is designed to support, challenge, and reward graduates in a work environment that will foster and develop them into future leaders and technical experts.

IGO's Vacation Program offers both undergraduate and post-graduate students the opportunity to participate in a 12-week paid program held over the Australian summer break-commencing in November each year and concluding in February the following year. The program is specifically designed to optimise student's exposure and practical experience in their chosen discipline.

IGO is very proud of the "best in class" in-house geoscience team working for us who are passionate about their work in making a step-change discovery for the business.

Last year, IGO spent $55 million on exploration, including acquisitions in mineral interests and investments in growth opportunities, as well as in cutting-edge innovative technologies such as the largest hard-rock 3D seismic survey ever undertaken in Australia, and commissioning SpectremAir to perform airborne electromagnetic surveys.

In the 2019 financial year, IGO has committed another $51 million for its exploration program with two thirds of this earmarked for Nova and the Fraser Range to continue our systematic regional exploration and drill test targets identified to date.

For more information about IGO go to www.igo.com.au and follow us on LinkedIn & Facebook.

ANGLOGOLD ASHANTI

AngloGold Ashanti graduate programme fosters career developments

As the world's third largest gold producer with a global reach AngloGold Ashanti has been a long-time supporter of geosciences and this year it is looking to grow its talent pool with the launch of a structured graduate programme in Australia.

SUSTAINING

VALUE CREATION IN THE LONG TERM

The two-year programme is based on best practice and provides opportunities for graduates to work at the Tropicana open cut mine and Sunrise Dam underground operation. The disciplines include Mining Engineering; Geology, Metallurgy; Geotechnical Engineering; Mechanical and Electrical Engineering; and Open Pit and Underground Surveying.

In addition, the company is offering vacation work to second, third or fourth year students with the opportunity for scholarships and graduate positions. AngloGold Ashanti has learning and development at its heart and people are our business and our business is people.

Tropicana, a joint venture between AngloGold Ashanti (70% and manager) and Independence Group NL (30%), is located 330 kilometres east-northeast of Kalgoorlie and poured its first gold in September 2013. The open pit operation features a large-scale, modern processing plant which uses conventional CIL technology and includes high pressure grinding ls for energy-efficient comminution.

Sunrise Dam is located 220 km north-east of Kalgoorlie and 55 km south of Laverton. In March 2017 the mine celebrated 20 years of uninterrupted gold production. The mine transitioned from combined open pit and underground mining in 2013 to become a purely underground site in early 2014.

ASEG

The Australian Society of Exploration Geophysics (ASEG) & the ASEG Young Professionals Network (ASEG YPN)

The ASEG is a non-profit company founded in 1970. Its aims are to promote the science of geophysics, and specifically exploration geophysics, throughout Australia. In addition, the ASEG aims to foster fellowship and co-operation between geophysicists, to encourage closer understanding and co-operation with other earth scientists and to assist in design and teaching of courses in geophysics and to sponsor student sections where appropriate.

In addition to looking after student interests the ASEG identified a need to increase focus on early career development to maintain the future of the society. The ASEG YPN is a group of young professionals who champion the interests of young employees in the profession of geophysics. There is no age limit applied to the network, but it is intended for people aged under 35, or those new to the profession i.e. less than 10 years experience.

The goal of the network is to provide opportunities for professional development and technical education, to facilitate networking with industry, academia and government and to improve access to local mentoring in every state across Australia.

To become a member of the ASEG YPN contact ypadmin@aseg.org.au – Your career is in your hands so it's up to you to get in touch and get involved!

RIO TINTO

New challenges demand new ideas

As experts in mining and metals, we're looking for the next generation of challengers, visionaries and pioneers. The people who will think beyond possibility to deliver ideas and answers that are essential to human progress.

We are committed to investing in our people and attracting diverse and high-calibre talent into the business. With this investment, we aim to build a dynamic and high-performing workplace with the capability to meet current and future business needs.

Our dynamic graduate programme provides you with the opportunity to work for a business that's making a meaningful difference in the way we resource the world. With a focus on environmental sustainability, all while developing the skills of future experts and leaders, we are creating a legacy that will improve the lives of millions of people globally.

We challenge you to be the progress.

riotinto.com/graduates

CSA GLOBAL

CSA Global offers a unique set of integrated services in the areas of corporate, mining, resources, exploration, technology and data.

Our teams produce optimal outcomes for clients by taking clients projects from concept to prospect and, onto a defined deposit and through feasibility to a profitable mine.

With a renowned team of consultants across multiple disciplines, CSA Global provides an innovative approach to all our projects, and our pool of experts enable us to provide an integrated and cost effective solution for any project or commodity.

We possess more than 30 years international experience across many mineral commodities, and service our clients worldwide from our offices in Australia, Canada, Indonesia, Singapore, South Africa, Russia, and the United Kingdom.

The diversity of our services provides successful solutions for our clients' needs and ensures an innovative approach to all our projects.

Find out more about what we do at: www.csaglobal.com

TIGeR

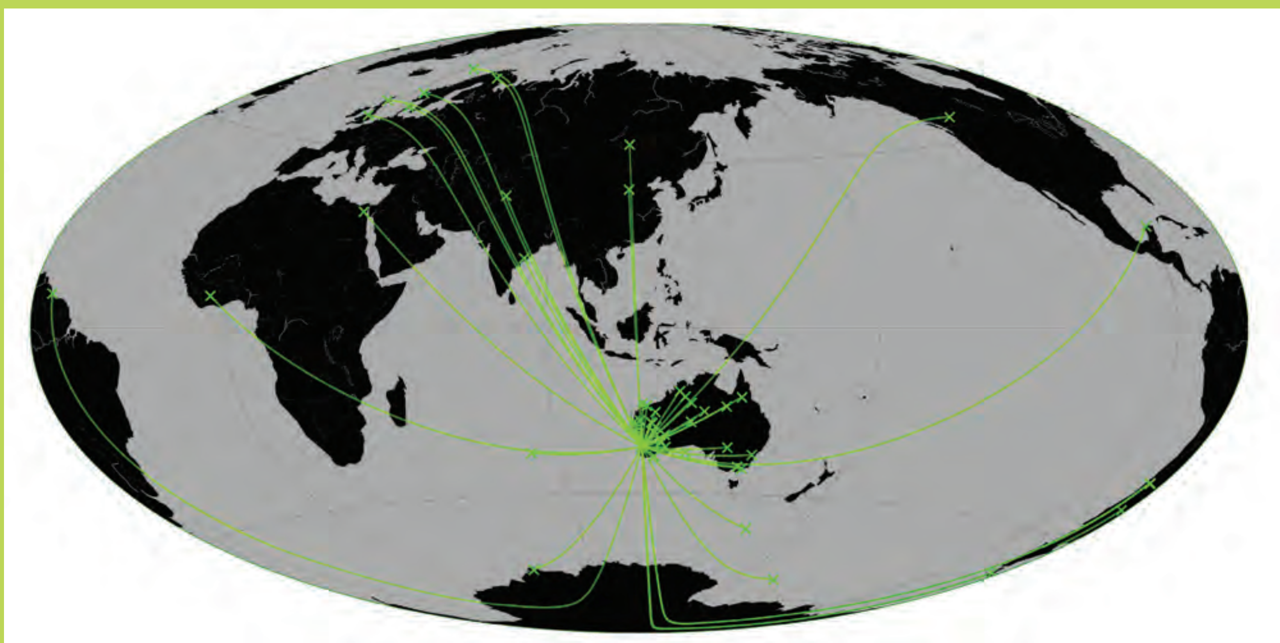
The Institute for Geoscience Research brings together active researchers across the spectrum of geosciences within Curtin University, with the common goal of understanding the mechanisms and the timescales of the processes that control Earth's dynamic evolution.

TIGeR researchers study processes over a wide range of scale: from the nanoscale to the macroscale, from reactions operating at grain boundaries in rocks to global tectonics and the origin of the solar system.

Since the establishment of TIGeR, our researchers have been at the forefront of high-quality, world-leading research in the earth sciences. We produce geochronological, geotectonic, geodetic and geochemical records, using the latest technology and field an laboratory data, to enhance our knowledge of the Earth's origin within the solar system, its evolution and its current configuration.

Our research forms the basis of understanding the element cycles operating within the Earth and their application to the formation of natural resources, such as mineral, oil and gas.

GESSS-WA RESEARCH LOCATIONS



Curtin University

THE INSTITUTE FOR GEOSCIENCE RESEARCH (TIGeR)

Top right - red and white banded sandstone at Kalbarri National Park. Bottom right - Stromatolites at Lake Thetis, Cervantes

PROGRAM

8:00 AM - REGISTRATION DESK OPEN

8:50 AM - WELCOME WOOLNOUGH LECTURE THEATRE

9:00 AM - KEYNOTE - PHIL BLAND "PLANETARY SCIENCE PAST AND PRESENT" WOOLNOUGH LECTURE THEATRE

9:30 - 10:45 AM - SESSION 1

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11:05 - 12:35 PM - SESSION 2

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TROPICAL GROVE

1:25 - 1:55 PM - KEYNOTE - GRAHAM BEGG "FROM GEOSYSTEM TO MINERAL SYSTEM: CONTEXTUALISING ORE DEPOSITS"

WOOLNOUGH LECTURE THEATRE

2:00 - 3:00 PM - SESSION 3

3A - CENOZOIC

WOOLNOUGH LECTURE THEATRE

3B - ARCHEAN

WEBB LECTURE THEATRE

3:00 - 3:20 PM - BREAK FOR TEA/COFFEE

GEOLOGY FOYER

3:20 - 5:00 PM - SESSION 4

4A - PROTEROZOIC

WOOLNOUGH LECTURE THEATRE

4B - LOOKING FORWARD

WEBB LECTURE THEATRE

5:00 - 8:00 PM - POSTERS AND SUNDOWNER

WATERSPORTS COMPLEX

MAJOR SHORELINE RETREAT IN THE WAKE OF SNOWBALL EARTH

***Adam R. Nordsvan*[1]*, Ross N. Mitchell*[1]*, Uwe Kirsher*[1]*, Milo Barham*[1]**

[1] *Earth Dynamics Research Group, ARC Centre of Excellence for Core to Crust Fluid Systems (CCFS) and The Institute of Geoscience Research, School of Earth and Planetary, Curtin University, Bentley, WA, Australia*

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Neoproterozoic glacial diamictites have stimulated geological debate for over a century. Originally providing an argument for continental drift, they now provide a debate around a frozen planet Earth. There is a possibility that these globally pervasive deposits represent a Snowball Earth, where a runaway ice albedo allowed the oceans to freeze from pole to pole. The hypothesis demands that, in order to bring the planet back from its icy state, volcanic degassing would increase greenhouse gasses to a critical point to overcome the albedo effect. Once this occurs, the planet should shift rapidly from a snowball to a hot house, possibly, as has been proposed, within less than 2000 yrs. However, cap-carbonate rocks overlying the glacial sediments that are typically interpreted as transgressive deposits show evidence indicating that they accumulated instead over 100's of thousands of years, such as multiple magnetic reversals. If so, sea-level rise following the glaciation would have been significantly prolonged compared to the reigning paradigm of rapid deglaciation. We discuss modern transgressive deposits and sequence stratigraphy in order to hypothesize that cap-carbonates represent a period that followed rapid shoreline migration landward during the demise of Snowball Earth. Progressive erosion of the continents during the lowstand sea-level transferred large masses of sediment into the oceans creating broad continental shelves. The barren, low-gradient topography that was left in the Snowball aftermath allowed shorelines to migrate uninterrupted landward for potentially 100's of kilometres during a period of rapid deglaciation. Shorelines took 100's of thousands of years to prograde back to the continental shelves, providing a sediment hiatus that allowed for the precipitation of cap carbonate.

Key words: Snowball earth, sedimentology, glacial deposits

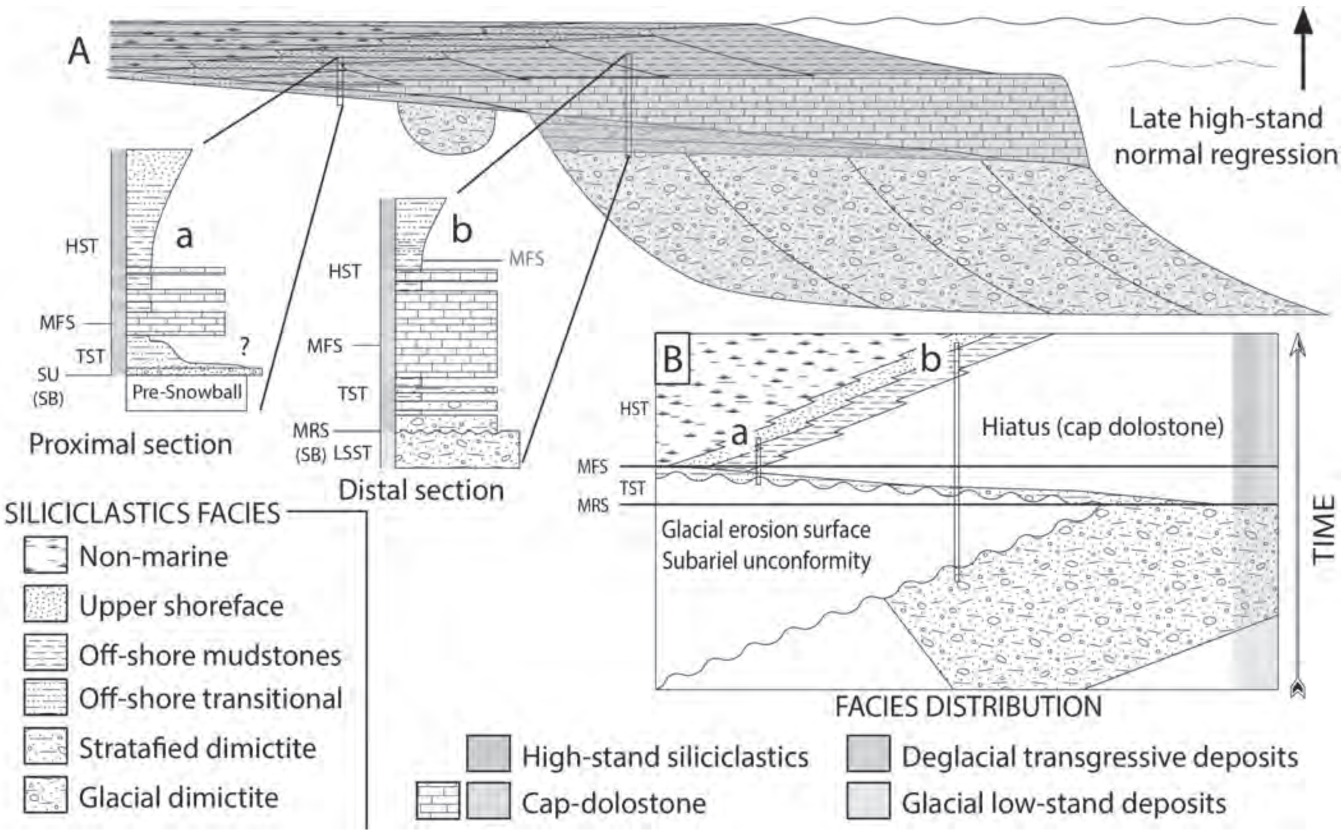

Figure. A) Along dip cross section of sedimentary facies predicted following a major glaciation. B) Wheeler diagram shows the significant hiatus predicted after the major shoreline migration caused by significant post-snowball glacioeustatic rise.

NEOPROTEROZOIC ^{40}AR/^{39}AR MICA AGES MARK THE TERMINATION OF A BILLION YEARS OF INTRAPLATE REWORKING IN THE CAPRICORN OROGEN, WESTERN AUSTRALIA

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The tectonic history of the Proterozoic Capricorn Orogen, Western Australia, records complex intraplate reworking lasting nearly one billion years. Although the Palaeo–Mesoproterozoic reworking history is well defined in the crystalline basement of the Gascoyne Province, at the western end of the orogen, the younger reactivation history remains unclear. Four reworking events affected the orogen at 1820–1770 Ma, 1680–1620 Ma 1320–1170 Ma, and 1030–900 Ma. These events were succeeded by a breakout in predominantly dextral strike-slip reactivation of major shear zones across the Gascoyne Province. Currently, the age of this reactivation is constrained by only one date of c. 570 Ma from a single shear zone, but field relationships imply that some of the shear zones must be older than a suite of c. 755 Ma dolerite dykes. In order to constrain the age of fault and shear zone reactivation we obtained new ^{40}Ar/^{39}Ar dates for mica and in-situ SHRIMP U–Pb dates for xenotime within shear zones. Our results when combined with previously published data, show that reactivation occurred between 920 and 830 Ma. Furthermore, Neoproterozoic U–Pb phosphate ages are known from the bounding cratons and faulting within the adjacent Mesoproterozoic sedimentary basins suggest this event is of regional significance. In contrast to previous suggestions that this Neoproterozoic reactivation was the result of a collision from the west, we propose that it reflects north-south compression that caused dextral strike-slip fault reactivation in the north and exhumation of the southern part of the orogen.

Keywords: intraplate orogeny, ^{40}Ar/^{39}Ar geochronology, U–Pb xenotime geochronology, Neoproterozoic, Capricorn Orogen, West Australian Craton

INTEGRATING HF-ISOTOPES AND NUMERICAL MODELS TO CONSTRAIN GEODYNAMIC EVOLUTION OF THE HALLS CREEK OROGEN

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Hf-isotopes have proven invaluable in understanding the evolution of Earth's crust-mantle system. In this study, we introduce a new approach to predict the Hf-isotopic evolutionary pattern based on the integration of numerical models and ^{176}Hf/^{177}Hf isotopes. The geodynamic numerical models allow us to estimate the proportion of juvenile material added to the crust through time. On the basis of this proportion we calculate changing ^{176}Hf/^{177}Hf ratios using mixing models. We use this modelling approach in the case study region of the Halls Creek Orogen (HCO) to elucidate its tectonic setting through time. In this work two plausible tectonic scenarios for the Halls Creek Orogen are examined using a 2D thermo-mechanical-petrological numerical experiment based on I2VIS code. The results of numerical models indicate that the geology of the Halls Creek Orogen is best represented by two possible tectonic models of west-dipping subduction at the margin of the Kimberley Craton. In considering two possible tectonic scenarios with different magmatic evolution, U/Pb and Hf isotopic values of magmatic and detrital zircon crystals from the HCO are used to constrain the geodynamic models in combination with Hf evolution patterns derived from the numerical models. The links between predicted Hf isotopic evolution, geodynamic numerical models and measured Hf isotopic evolution trend resolve three discrete stages in the tectonomagmatic development of the Halls Creek Orogen: (1) subduction; (2) back-arc basin formation with addition of juvenile mantle melt; and (3) collision of the North Australian and Kimberley cratons with an apparent mixing of juvenile and reworked source.

Keywords: tectonics, numerical modelling, Hf-isotopes, Palaeoproterozoic, Halls Creek Orogen

METAMORPHISM AND HYDROTHERMAL ALTERATION IN RELATION TO MINERALISATION OF THE HARRIS LAKE SHEAR ZONE, ALBANY-FRASER OROGEN, WESTERN AUSTRALIA

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U-Pb and trace element analysis of zircon and rutile was used to investigate metamorphic and hydrothermal alteration across a gold mineralised section of drillcore from the Harris Lake Shear Zone, which separates the Biranup Zone from the Fraser Zone of the Albany-Fraser Orogen. Samples were collected across unaltered rock to fault-fill vein. Diamond drillcore provides an opportunity to evaluate otherwise inaccessible bedrock and to explore rocks related to the Proterozoic reworking of the Yilgarn Craton, and specifically in relation to hydrothermal alteration that may control gold (re)mobilisation. Here we focus on three metasedimentary samples of variable hydrothermal alteration, from barren to mineralised (81.39 ppm Au) content [1].

Zircon and rutile from the three samples indicates the following: (1) detrital zircon U-Pb ages between 2600 to 1548 Ma, (2) across all three samples, zircon yields a metamorphic age of c. 1230 Ma and a flat HREE profile characteristic of partitioning during garnet growth, (3) one group of zircon grains in the barren yet hydrothermally altered sample has a geologically meaningless date of 1225 ± 7 Ma (MSWD of 9), and elevated LREE profiles. The high MSWD value is consistent with variable Pb mobility and the elevated LREEs correspond to hydrothermal alteration, (4) the other zircon group in this sample has an age of 1221 ± 3 Ma (MSWD = 0.56) and no elevation of LREE. These grains are interpreted to be metamorphic grains shielded from alteration and therefore indicate that hydrothermal alteration occurred post-metamorphism at this time, (5) rutile present across all three samples yields a consistent U-Pb cooling age of c. 1171 Ma, (6) there is significant enrichment of Fe, W, Nb and Ta in rutile associated with the mineralised horizon, corresponding to depletion of Zr, Cr and Mo within the grain during fluid-rock interaction and rutile alteration. From these observations we conclude that a relatively low temperature fluid-rock interaction event related to mineralisation and brittle deformation occurred after the metamorphism recorded by zircon and rutile. These findings define a maximum age for gold mineralisation at c. 1171 Ma and provide evidence for the youngest known gold mobilisation event in the Albany-Fraser Orogen.

Key words: zircon, rutile, U-Pb geochronology, trace elements, metamorphism, hydrothermal alteration, Albany-Fraser Orogen, gold mineralisation

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RECONSTRUCTING NORTH CHINA IN SUPERCONTINENTS NUNA AND RODINIA

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The North China Craton (NCC) covers crust as old as 3.8 Ga, but the positions of this craton in the Precambrian supercontinents Nuna/ Columbia and Rodinia are still unclear. The studies of large igneous provinces (LIPs) and palaeomagnetism are key methods for reconstructing palaeogeographic history. During the past two decades, multiple geological and palaeomagnetic studies have been carried out. By far, episodes of mafic magmatism have been documented in the NCC at 2.5 Ga, 2.15-2.09 Ga, 1.97-1.93 Ga, 1.89 Ga, 1.78 Ga, 1.73 Ga, 1.68 Ga, 1.62 Ga, 1.32 Ga, 1.23 Ga, 0.92-0.89 Ga and 0.81 Ga, but only the 1.78 Ga and 1.32 Ga events/LIPs are well studied. Meanwhile, reliable palaeomagnetic poles have been acquired at 1.78 Ga, 1.68 Ga, 1.62 Ga, ~1.5 Ga, 1.32 Ga, 1.23 Ga and 0.89 Ga.

Based on the current palaeopoles and geological comparison, the northeastern NCC could be linked with McArthur basin of the North Australia through the Yanliao rift from ~1.70 Ga to 1.32 Ga. The northwestern NCC (Zhaertai-Bayan Obo-Huade rift) and the Siberia could be across a small basin during Nuna period. In the southern NCC, the thing becomes more complex because of the controversial tectonic setting (Xiong'er Group: rift or arc?) in the late Palaeoproterozoic. The NCC developed 1.0-0.8 Ga sedimentary and mafic sills in the southeast, providing more possibility to discuss the palaeogeography in Rodinia. Currently, NCC-Congo/ Sãn Francisco connection at ~0.9 Ga has been proposed. In summary, significant progresses have been made for the NCC in supercontinents Nuna and Rodinia and more geological evidences are needed to verify these models, as well as palaeomagnetic studies.

Keywords: North China Craton, Precambrian, Supercontinents, large igneous province, Palaeomagnetism

PROTEROZOIC MICROORGANISMS MAY HAVE METABOLISED RARE EARTH ELEMENTS

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Microorganisms dominated the early history of life on Earth and have developed diverse metabolisms that we can quantify in modern environments. However only a few types of metabolisms are detectable in the fossil record. Here we present data that show possible methylotrophy at ~1 000 Ma, in lake deposits from Northern Scotland. The samples are from the Torridon Group, a molasse of the Grenville Orogen recording a succession of fluviatile sandstones, and lacustrine shales with calcium phosphate concretions. These phosphatic nodules contain abundant and exquisitely preserved microorganisms in three dimensions. They occur as isolated cells or as clusters of four to tens of cells, most of them having intracellular inclusions (ICI). We targeted these fossils with ICI for 2D and 3D electron microscopy imaging plus elemental mapping using X-ray Energy Dispersive Spectrometry, in order to characterise the structure and chemistry of these inclusions. Our findings show that some cell clusters have rare earth (RE) phosphate minerals closely associated with the carbon-rich ICI. As RE elements typically have a low solubility and a high affinity with phosphate, their precipitation likely happened during very early diagenesis, facilitating the preservation of the organic content of the cell as ICI. Furthermore, recent research on REE in biological systems shows that Lanthanides are necessary ligands for enzymes involved in methylotrophy metabolisms [1]. The REE could have been present as trace metals within the cell when it died, possibly revealing methylotrophy by microorganisms in early Neoproterozoic lakes.

Keywords: Proterozoic, organic-walled microfossils, micropalaeontology, exceptional preservation, REE, metabolism, electron microscopy.

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CONTROLS ON HIGH-GRADE GOLD MINERALISATION AT THE CALLIE WORLD-CLASS DEPOSIT, NORTHERN TERRITORY, AUSTRALIA

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High-grade gold intercepts (>100 g/t) are a common feature in world-class orogenic gold deposits where visible gold is usually concentrated in quartz and carbonate veins. However, the processes associated with the deposition of large concentrations of gold is enigmatic, primarily because hydrothermal fluids can only carry a limited amount of gold in solution (e.g. < 20 ppb, [1]). Large amounts of visible gold imply that the gold veins are enriched 50 to 500 times with regards to the mineralising fluid. With an endowment of 14.2 Moz Au and gold intercepts commonly >100 g/t, Callie is an excellent natural laboratory to study high-grade deposition processes. The Callie mine is situated in the Granites-Tanami Orogen in the Northern Territory (Australia) and is hosted in Palaeoproterozoic metasedimentary rocks. The ore at Callie is expressed as two contrasting styles of mineralisation including vein-hosted and stratabound. The vein-hosted mineralisation consists of high-grade visible gold in quartz veins hosted in decarbonised siltstones; whereas, the stratabound mineralisation is associated with arsenopyrite concentrated in bedding-parallel sulphide-rich layers hosted in iron-rich siltstones. Structural and petrographic analysis combined with U-Pb geochronology on hydrothermal xenotimes show that both ore styles formed contemporaneously along the same structural pathways. Petrographic observation and mass balance calculations based on whole-rock geochemistry suggest that the Callie system is rock-buffered whereby host-rock composition controls the geochemical signature of the gold deposition processes. Assuming a single fluid composition, the host-rock directly impacts the gold endowment implying that deposition processes driven by carbonaceous siltstones preferentially deposit high-grade ore.

Keywords: High-grade Gold, orogenic gold, absolute dating of mineralisation, carbonaceous sedimentary rocks

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ATTAINING AND PRESERVING MULTI SCALE DISEQUILIBRIUM IN ULTRA-HIGH TEMPERATURE GRANULITES

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Phase equilibrium models are frequently employed to infer the geodynamic regime of granulite facies terranes. Realistically, defining a suitable equilibrium volume is non-trivial with open system behaviour – partial melting, melt loss or gain, and deformation – in addition to small scale variations in protolith composition. Consequently, peak assemblages which vary on the centimetre scale, and small scale textures indicative of transient disequilibrium are often preserved in granulites. The processes which attain and preserve disequilibrium on both scales must be assessed in order to make safe assumptions when interpreting phase diagrams. A combined phase equilibrium forward modelling and calculated chemical potential (μ-μ) approach was applied to simulate the supersolidus evolution of a chemically heterogeneous pelite. Assuming equilibrium within domains of average pelite and Al-Mg pelite starting composition, main phase assemblages vary significantly over a representative high dT/dP clockwise granulite P—T path. Meanwhile, most small-scale post peak textures in pelites can be achieved by chemical potential gradients in μMgO and μFeO; assuming the presence of melt on grain boundaries, relative immobility of Al_2O_3, far greater mobility of K_2O and SiO_2 saturation. However, μSiO_2 gradients are significant in SiO_2 undersaturated systems. Spatial μ variations can be established by changing phase topology when crossing a univariant reaction in P—T space. Preserving these μ variations can depend on the rate of solid state or fluid diffusion, depending on the length scale of solid phase and liquid, grain size, surface area, and mobility of relevant components in both solid and fluid phases.

Keywords: phase equilibria, chemical potential, granulite metamorphism, ultra-high temperature

HYPERSPECTRAL DETECTION FOR ZONED MINERAL FOOTPRINT AROUND UNDERCOVER SEDIMENT-HOSTED POLYMETALLIC ABRA

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Undercover polymetallic Abra deposit is situated at 250 metres depth and hosted within an interface of deep-shelf carbonaceous and shallower siliciclastic fan-deltaic sediments in the 1620-1465 Ma Edmund Basin of the Western Australia. It was believed that 1590 Ma exhalative [1] mineralisation and related alteration were cut by marine flooding erosion [2], which would have erased any detectable footprint above. A vertically zoned mineral footprint, which relates to compositional shift in white micas, chlorites and carbonates, was delineated from processed short-wave infrared (SWIR) and thermal infrared (TIR) hyperspectral data from exploration drill cores. Processing involved application of scalars (filters) that target mineral specific absorption features in the hyperspectral data. Identified hyperspectral mineral compositions and mixtures were verified using whole rock geochemistry, optical microscopy, micro-XRF and SEM-EDS analysis. Proximal to the deposit SWIR data delineates an abundant mixture of relatively Fe-rich chlorite and Al-poor white mica (phengite). Chlorite content decreases with distance from the deposit, and distal alteration which is cut by present day surface consists of phengite. Phengitic composition is partially preserved through weathering, and is detectable at the surface from field spectrometer and remotely sensed ASTER and potassium gamma-ray spectrometry data. Vertically zoned carbonate footprint identified from TIR data is from proximal to distal: Mn-siderite → ankerite → ferroan dolomite. The SEM-EDS analysis revealed that Fe/Mn-carbonates replace dolomite matrix, which, with the presence of mineral footprint above the deposit suggests that the Abra deposit formed, not through seafloor exhalation, but via replacement in permeable sequences.

Keywords: sediment-hosted, base-metal, hyperspectral, hydrothermal alteration, replacement deposit

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GEOLOGICAL SURVEY OF
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MARGINAL PALAEOZOIC FAULT SYSTEMS OF THE NORTHERN CARNARVON BASIN, NORTH-WEST SHELF, AUSTRALIA: INSIGHTS FROM SEISMIC INTERPRETATION AND NUMERICAL MODELS

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Detailed mapping of the geometry and tectono-stratigraphy of Permian and Carboniferous structures of the inboard Barrow, Dampier and Beagle sub-basins of the Northern Carnarvon Basin is possible using regional scale interpretation of publicly available 2-D and 3-D seismic data. We show two distinct orientations of structures that provide evidence for a poly-phase rift history of the North-West margin during the Palaeozoic. NNE trending faults of the Barrow sub-basin were initiated in the Carboniferous or Devonian but were underfilled, resulting in erosion of the fault block crest and filling of the remnant rift-related topography by conformable sequences of later Permian and Triassic sediments. By contrast, NE-SW oriented faults of the Dampier sub-basin experienced a distinct phase of Permian activity and are unconformably overlain by Triassic sediments. In the Beagle sub-basin, both orientations of structures are present.

Palaeozoic extension was the precursor to multiple episodes of Mesozoic rifting. Mesozoic faults have complex geometries across the basin and are affected by structural inheritance of Palaeozoic fabrics. We use a particle-in-cell finite element code, Underworld, to run a generic set of lithospheric scale models at a very high resolution. We investigate the sedimentation and fault patterns that result from varying the strength of the lower crust and the velocity of extension at a continental margin. In contrast to previous models, the high resolution models allow for detailed analysis of sedimentation and strain patterns under lithospheric extension. Together this work has implications for understanding the geodynamic evolution of poly-phase extensional continental margins.

Keywords: Northern Carnarvon Basin, North West Shelf, Passive margins, poly-phase extension, numerical modelling

REDUCTION SPHEROIDS FROM THE TUMBLAGOODA SANDSTONE AS POTENTIAL BIOMARKERS FOR THE TERRESTRIALISATION OF ARTHROPODS

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Reduction spheroids are small-scale (< 30 cm) spheroidal features that are observed in red beds globally. They typically contain a dark metallic central core, with a surrounding pale haematite dissolution halo. Reduction spheroids are of note as their dark central cores are commonly strongly enriched in exotic redox-sensitive metals, such as V, U, Au, and Cu. The prevailing model for reduction spheroid genesis proposes that they are formed through the metabolic processes of dissimilatory metal-reducing bacteria. It is believed that these bacteria consume detrital organic matter in the sediment, using it as a reductant and energy source. These bacterial reductive processes are therefore proposed to be the mechanism for the enrichment of metals in reduction spheroid cores. Due to this formation mechanism, the authors propose that reduction spheroids could be of use as a terrestrial biomarker; providing a proxy for organic matter supply into terrestrial sediments. This is of particular significance within the Tumblagooda Sandstone; an Ordovician–Silurian red bed that records evidence of early terrestrial arthropods through its very rich trace fossil assemblage. Despite this, very few body fossils have ever been recovered from the Tumblagooda Sandstone. As such, it is proposed that the unusually abundant reduction spheroids within the unit may be a product of a thriving terrestrial animal biota providing an abundant supply of detrital organic matter into the sediment during its deposition. These abundant reduction spheroids may therefore represent the fossil record for some of the earliest terrestrial arthropods on Earth.

Keywords: Biomineralisation, redox, Carnarvon Basin, dissimilatory metal reduction, diagenesis

THE ORIGIN OF CUYANIA REVEALED BY HF ISOTOPES OF ZIRCON

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The proto-Andean margin of South America is scattered with suspect terranes. The origin of one such terrane, Cuyania in western Argentina, is the cause of considerable debate. There are two prevailing models for the origin of Cuyania: the Laurentian microcontinent model [1], in which Cuyania rifted from the Ouachita Embayment in the Cambrian and collided with Gondwana in the mid-Ordovician; and, the parautochthonous Gondwanan model [2], where Cuyania rifted from southwest Gondwana in the early-mid Ordovician and was transported laterally before re-accreting to the Gondwanan margin in the Silurian-Devonian. We present new zircon U-Pb-Hf data from Palaeozoic Cuyanian strata and Mesoproterozoic basement inliers of central Argentina and compare these with published data from the Grenville margin of Laurentia and the Namaqua-Natal belt of Kalahari (southwest Gondwana). Mesoproterozoic zircons from the Grenville margin of Laurentia have characteristically depleted εHf, and so are easily distinguishable from Namaqua-Natal belt zircons, which record crustal reworking of the Kalahari craton with Mesoproterozoic zircons yielding enriched εHf values.

Detrital zircon results from Cuyania show a variation in provenance up-sequence. Cambrian strata yield Mesoproterozoic zircons with depleted εHf correlating with Grenville samples, as well as a Cambrian zircon population that correlates directly with rift related rocks from the Ouachita Embayment. In contrast to the lower sequences, zircon deposited in mid-upper Ordovician strata record a larger range of Mesoproterozoic εHf values, correlated with zircons from inboard proto-Andean Mesoproterozoic inliers, and reflecting provenance from the Gondwana margin. Zircons from the Namaqua-Natal belt do not correlate with Cuyanian strata, suggesting that the Kalahari craton was not the source of these sediments. Variation in provenance between Cambrian and Ordovician strata reflects the tectonic evolution of Cuyania proposed by the Laurentian microcontinent model: Cambrian rift-drift sediments were sourced from the margin of Laurentia and Ordovician syn-orogenic sediments were sourced from the Gondwanan margin. These data not only obviate the parautochthonous Gondwana model, but verify the Laurentian microcontinent model for the origin of Cuyania.

Keywords: Zircon, U-Pb-Hf, isotope geochemistry, tectonics, South America, Gondwana

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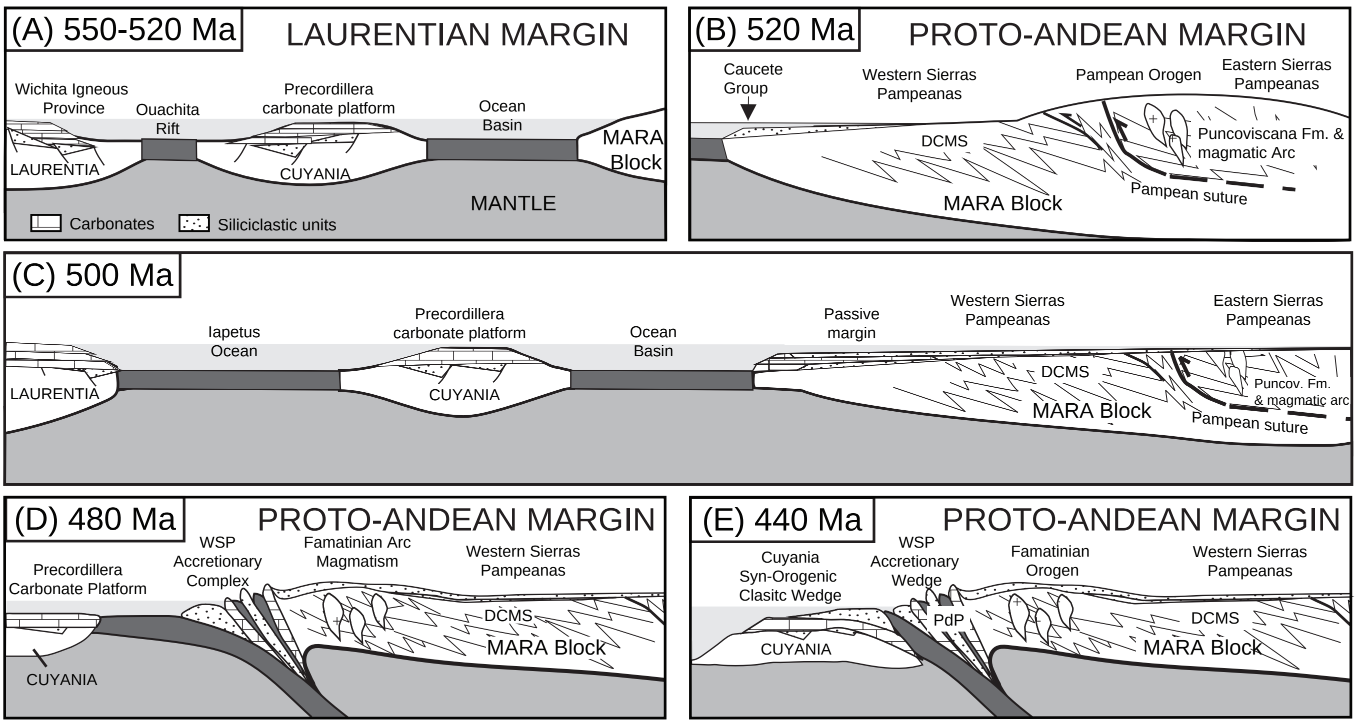

Figure. Tectonic evolution of the Cuyania Terrane: Cuyania rifts from the margin of Laurentia in the early Cambrian (A, B), drifts across the Iapetus ocean (C), and accretes to the proto-Andean margin of South America in the Middle Ordovician (D, E).

NEW INSIGHTS ON PORPHYRY-COPPER DEPOSIT FERTILITY INDICATORS: UNFOLDING THE ADAKITIC SIGNATURE IN PATAGONIA

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Although all Porphyry Copper Deposit (PCD) magmas are adakitic, many adakites are apparently barren. To address this question, we selected the seemingly unmineralised mid-Miocene Patagonian adakites to test whether they record differences on magmatic hydration, oxidation state and igneous complex lifespan compared with those from giant PCD districts. Zircon LA-ICPMS analyses (U-Pb and trace elements), whole-rock geochemistry and Al-in-hornblende geobarometry were performed on 5 igneous centres. Well-endowed PCD are associated with adakites with high fO_2 (~NNO+2), high H_2O melt (~ 10 wt%), and emplaced during long lifespans (~ 7 − 20 Myr) under tectonic compression. Preliminary results indicate that the Patagonian adakites occurred during shorter lifespans and were characterised by low-medium dissolved water contents and fO_2 near the FMQ buffer, hence displaying a barren PCD fertility signature. We argue that the adakitic geochemical signatures (e.g. high Sr/Y ratios; steep REE patterns) can be attained rapidly once the confining horizontal compression is enough to trap certain volume of magma at mid-lower crust depths, prompting high-pressure magmatic differentiation. However, they cannot be used as a self-sufficient Cu-fertility proxy as they do not correlate neither the duration nor the magnitude of the compressive tectonic stress, which are critical to enhance H_2O and fO_2 in the melt through time, as well the size of the magmatic system. For the Patagonian adakites, even though high-pressure magmatic differentiation stages were revealed by Al-rich hornblendes (up to ~ 7 kbar, base of lower crust), the migrating compressive wave generated by the subduction of the Chile Rise was too brief and weak to achieve the ideal conditions for PCD formation.

Keywords: Patagonia, adakites, Porphyry Copper Deposit, zircon LA-ICPMS, geobarometry, tectonic compression

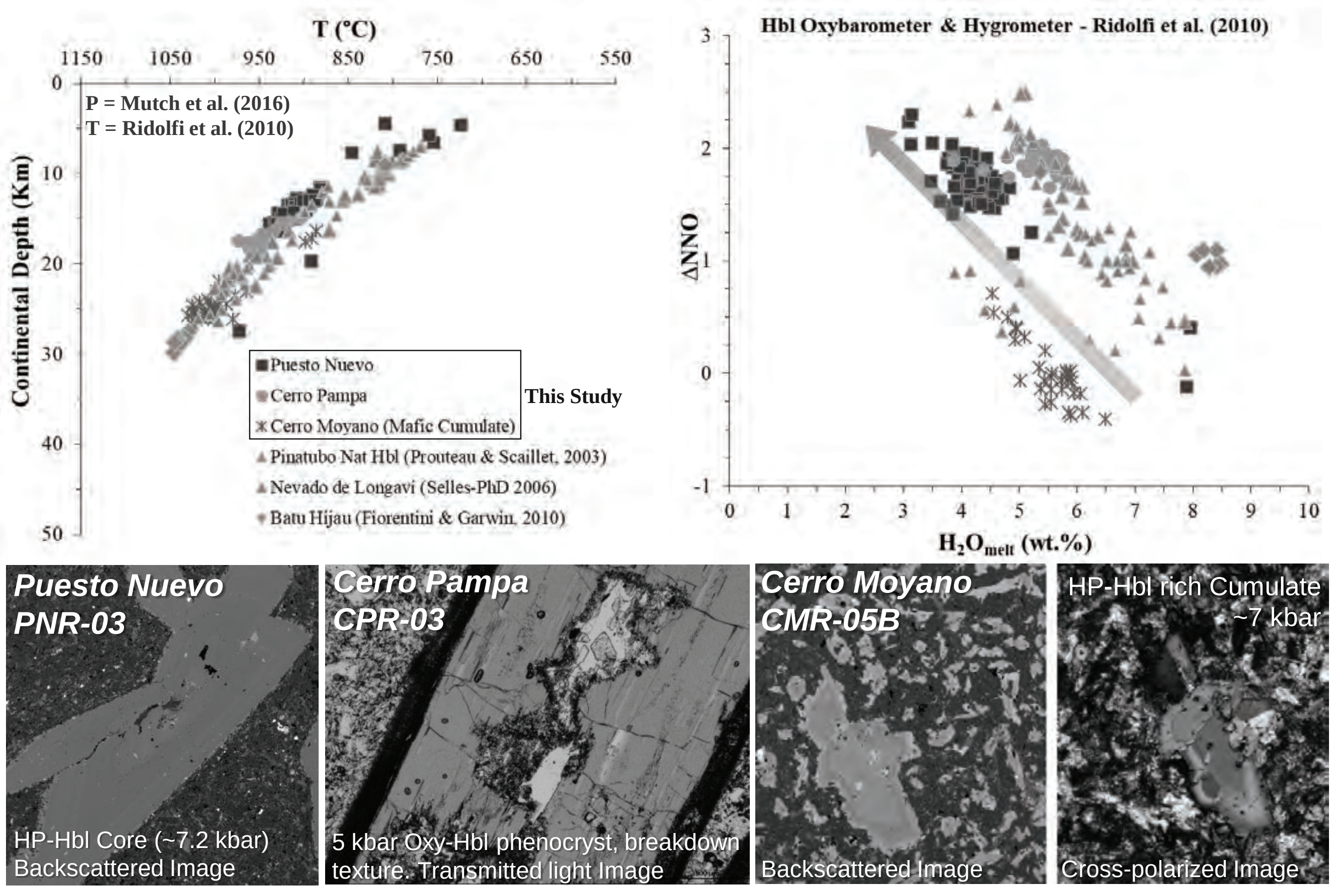

***Figure.** Pressure, fO_2 and H_2O_{melt} comparison between Patagonian adakites (this study) with other infertile adakitic igneous suites and Batu Hijau PCD, based on hornblende phenocryst chemistry*

A THERMOCHRONOLOGICAL HISTORY OF LINDÅS NAPPE AMPHIBOLITES BASED ON COMBINED MICROSTRUCTURAL AND GEOCHEMICAL ANALYSIS OF RUTILE

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Metamorphic rutile provides temporal constraints on Caledonian amphibolite-facies hydration and deformation in the Lindås Nappe of southwestern Norway. In outcrop, the juxtaposition of a statically hydrated rutile-poor amphibole-feldspar gneiss and dynamically hydrated porphyroblastic rutile-bearing leucocratic gneiss provides key contextual information on both the ambient conditions of hydration and deformation and the properties of the infiltrating fluid. Using combined microstructural and geochemical analyses of rutile in both of the lithologies a multi-stage history of Lindås Nappe amphibolite is constrained. An age of 437 ± 3 Ma obtained through rutile U-Pb geochronology is interpreted to best reflect the initial crystallisation of rutile during syntectonic fluid infiltration. Temperatures of up to 861 ± 45°C are reported for rutile in the dynamically hydrated rock, recording the crystallisation of rutile as a result of simultaneous fluid and heat fluxing along localised pathways. The background metamorphic conditions are recorded during static hydration of the amphibole-feldspar gneiss, Zr-in-rutile thermometry indicating peak ambient temperatures of ~ 700°C. A second age of 409 ± 2 Ma recorded by U-Pb in rutile is interpreted to reflect exhumation of the amphibolite-facies gneiss to the mid crust. Exhumation to the mid-crust is additionally constrained by small (< 150μm) rutile in high strain zones, recording temperatures of ~ 600°C. Here, both Zr-in-rutile thermometry and U-Pb geochronology are consistent with resetting controlled by deformation-enhanced diffusion in rutile. Our data allows for a comprehensive reconstruction of the thermochronological history of the amphibolite-facies rocks of the Lindås Nappe and highlights the importance of microstructural data integration during application of thermometers and geochronometers.

Keywords: Zr-in-rutile, U-Pb geochronology, deformation microstructures, Lindås Nappe

POLYCYCLIC AROMATIC HYDROCARBONS DURING THE RECOVERY FROM THE END-PERMIAN MASS EXTINCTION IN THE NORWEGIAN SEA

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Five mass extinction events are recorded in the geological past. Arguably, the most catastrophic is the end-Permian Mass Extinction (EPE) that occurred approximately 252 million years ago. During this period approximately 95% of marine life and 70% of terrestrial vertebrates became extinct. Biomarkers are molecular fossils of lipids that derive from the 3 domains of life. During mass extinction events they provide insights into the changes of redox, environmental and ecological conditions. One such group of these biomarkers are the Polycyclic Aromatic Hydrocarbons (PAHs). PAHs are associated with hydrothermal activity, the incomplete combustion of fossil fuels and wood, and may be formed during sedimentary diagenesis and catagenesis. During the EPE, the appearance of PAHs associated with incomplete combustion are found in sections from Western Australia, Greenland, China, and Canada. Here, data is shown from the Panthalassa Ocean in the Northern Hemisphere during the recovery of the EPE showing an abundance of PAHs after the EPE. These include benzo(*a*)pyrene, benzo(*e*)pyrene, coronene, fluoranthene and pyrene. The pattern of a uniform increase in each biomarker indicates an emergence of wildfires during the EPE recovery phase. Perylene a potential fungal wood marker, is present in extremely low concentrations. Retene is one such PAH that can be produced by wood combustion, but has also been suggested as a source of phytoplankton in sediments from the geological past. As retene shows a similar pattern to other combustion elated PAHs it is likely tracking the combustion of wood and is thus an additional indicator of wildfire.

Keywords: mass extinction, biomarkers, end-Permian, PAHs

PERMIAN MAGMATISM RELATED TO PORPHYRY AND EPITHERMAL MINERALISATION IN A PERMIAN METALLOGENIC BELT, CORDILLERA FRONTAL, ARGENTINA

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The Andean margin in South America has experienced continuous subduction related processes for over 320 million years and is the case study location for modern "Cordillera-type" arc subduction systems. Across this protracted period of evolution, epochs of porphyry Cu-Au-Mo and epithermal Au-Ag mineral systems have occurred in well constrained metallogenic belts. In comparison to younger Miocene and Eocene belts, Palaeozoic arc-related magmatic belts are lesser known and locally interpreted as unfavourable or infertile with respect to base and precious metal mineralisation. Palaeozoic Andean mineralisation is poorly understood with regards to its timing, magma composition and stress regime. We aim to better understand the overarching tectonic controls on Palaeozoic Andean mineralisation by unravelling the isotope geochemistry of magmatic zircons from Permian intrusions that are spatially related to gold and copper mineralisation.

The Permian Carrizal (30°S) – San Jorge (32°S) magmatic belt in the Cordillera Frontal, Argentina, contains several porphyry (e.g. 278 Ma San Jorge deposit) and epithermal (e.g. 264 Ma Casposo deposit) mineral systems. Here we present 15 new magmatic zircon U-Pb, O and Hf isotope analyses related to Permian mineral occurrences within the Cordillera Frontal, Argentina. This new set of results significantly refine the temporal evolution of the Permian porphyry and epithermal belt, and unravel the source material and tectonic setting of the magmatic arc. This investigation has the potential to open up new targets for exploration with regards to porphyry, skarn and epithermal mineral systems within a previously considered well explored terrain.

Keywords: Continental arc magmatism, U-Pb geochronology, O-Hf isotopes, Cordillera-type subduction

QUANTIFYING THE MAGMATIC VOLATILE BUDGET OF ARC MAGMAS WITH APATITE INCLUSIONS IN ZIRCON

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While some arc-related igneous belts host large and extremely metal rich porphyry deposits, other systems with similar geology are only weakly mineralised or barren. Recent work suggests that the magmatic volatile budgets of arc-related magmas are key to their fertility for ore deposition, however the abundance and behaviour of magmatic volatile species such as H_2O, H_2S, SO_2 CO_2, and HCl remain difficult to quantify. An emerging tool for constraining magmatic volatile activity is the common accessory mineral apatite, which incorporates numerous volatile species into its crystal lattice. This study trials a novel approach to the collection of magmatic volatile data- the analysis of apatite inclusions trapped within zircon. In this state, apatite is protected from late fluid/heating events and is accompanied by a wealth of geochemical information provided by the host zircon. This approach is tested here to quantify and compare the volatile budget of mineralised and unmineralised arc-related magmas in Eastern Australia, employing zircon samples known to be rich in apatite inclusions. Samples were sourced from the Cadia, Copper Hill and North Parkes Cu-Au porphyry systems of the Macquarie Arc and the unmineralised Jindabyne, Why Worry and Cobargo I-type granitic suites in the Lachlan Fold Belt.

Keywords: magmatic volatiles, apatite, zircon, mineralisation, arc magmas

DEFORMATION AND RETROGRESSION INITIATED BY HYDRATION ALONG PRE-EXISTING FABRICS: USING MONAZITE AND APATITE TO TRACK AND TIME GEOLOGICAL EVENTS

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The occurrence of large-scale, granulite hosted shear zones that show evidence for fluid-driven metasomatic overprint and retrogression provides insight into links between deformation and mid- to deep-crustal fluid flow. The granulite-facies, nominally impermeable orthogneisses at Mt Boothby, central Australia contain up to hundred-meter wide muscovite-bearing mylonitic shear zones, with sharp contacts to the surrounding country rock. This site provides case study area to investigate the effects of deformation, associated fluid flow and mass transport. The muscovite poor orthogneiss has developed a foliation defined by megacrystic perthite and biotite. Biotite, aligned with the foliation is also aligned with a weakly developed S-plane that cuts the foliation at a low angle. Monazites parallel to the orthogneiss foliation, and included in foliation defining minerals, have U-Pb ages of ~ 1560 Ma. An age that shows the orthogneiss fabric has developed during the Chewings Orogeny. The orthogneiss foliation is crosscut by a mylonite with asymmetric perthite porphyroclasts that indicate top to the south kinematics. Structural mapping suggests that this shear zone represents a Riedel branch of larger structures active during the Alice Springs Orogeny at ~420 Ma. In the shear zone, perthite is replaced by fine-grained recrystallised K-feldspar and muscovite. With strain increase plagioclase is observed to become progressively albitised and monazite breaks down as a result of synkinematic fluid flow. The timing of deformation and hence also of fluid flow is constrained by U-Pb dating of apatite, which is present as the stable U-bearing phase in both orthogneiss and mylonite. Modelling of apatite radiogenic-Pb retention ages implies growth/recrystallisation at ~ 400 Ma and ~ 1500 Ma, confirming apatite precipitation during Alice Springs shearing and reactivation of Chewing age structures. In addition, we find Alice Springs age apatite along pre-existing fabrics in the orthogneiss in the vicinity of the shear zone indicating fluid flow across the shear zone boundary into country rock that has been unaffected by Alice Springs age deformation.

Keywords: Alice Springs Orogen, deformation, geochronology

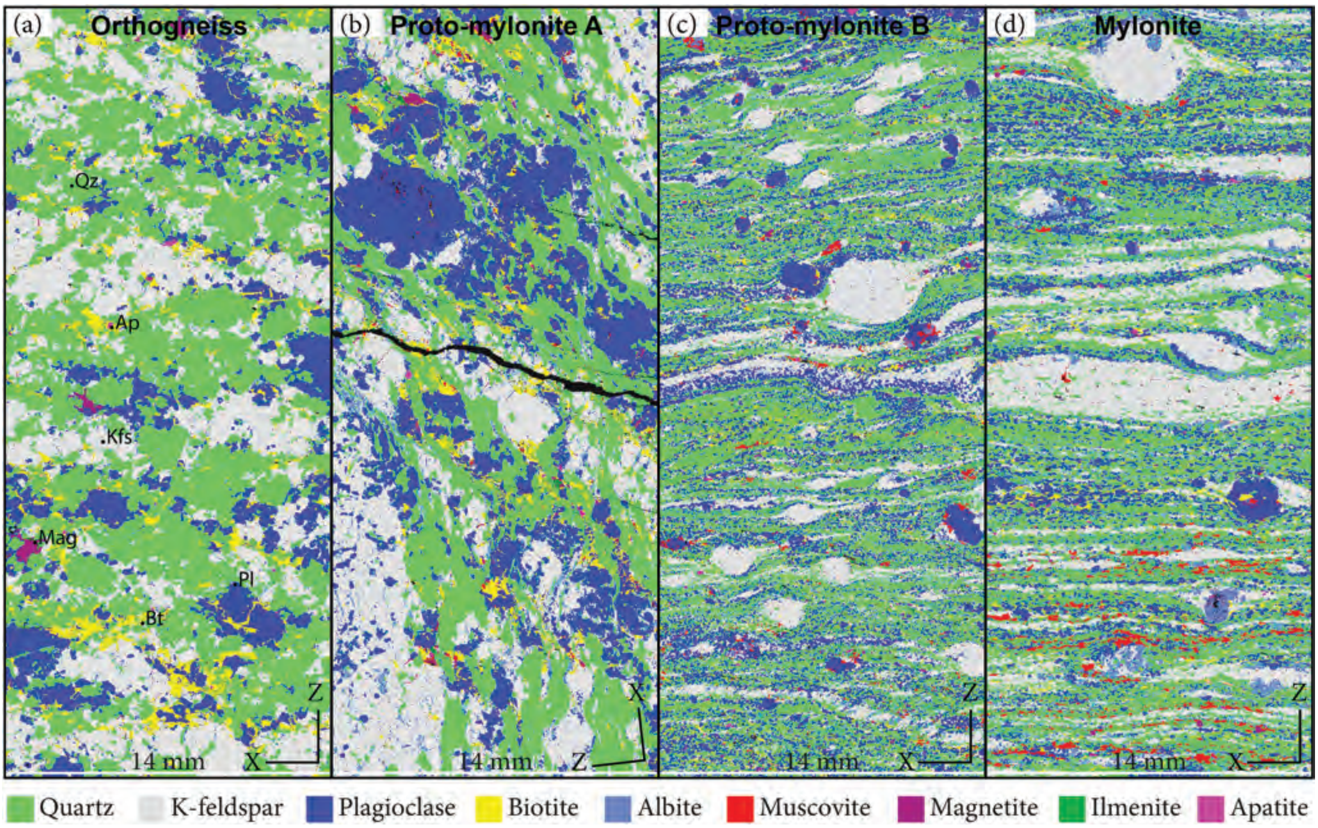

Figure. TIMA image showing mineral phase distribution accross the shear zone interface.

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EXTENT AND SIGNIFICANCE OF GONDWANAN STROMATOLITES FOLLOWING THE PERMIAN-TRIASSIC MASS EXTINCTION

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The northern Perth Basin, Western Australia, records one of the few well-preserved stromatolite occurrences at high palaeolatitudes following the Permian-Triassic (P-Tr) mass extinction. Microbial communities are known to proliferate in the aftermath of mass extinctions when there is less predatory ecological competition. The peak of microbial activity in the Phanerozoic is recorded as stromatolite and other microbialite beds in the Early Triassic as a direct consequence of the mass extinction at the P-Tr boundary. Stromatolites were abundant in the low-latitude Tethyan Ocean but rare at high palaeolatitudes and in continental interiors. Only three intracontinental occurrences are known: Greenland, Madagascar and Western Australia. In Western Australia, the main stromatolite locality (Blue Hills) is furthest from the Siberian Traps (the presumed cause of the extinction) and occurs at the highest palaeolatitude (~ 60°S), yet it remains poorly characterised in terms of spatial and vertical extent. Here, we use field mapping and satellite imagery to show that the Blue Hills stromatolites cover a wide lateral extent and display considerable vertical complexity. Detailed sedimentary logs and thin section observations reveal numerous discrete stromatolite growth intervals separated by minor breaks in deposition. The punctuated spatial and temporal variations in deposition show that the biotic system after the P-Tr event was sensitive to localised changes in sea level, sediment supply, along with other physicochemical pressures and processes. The depositional model developed here provides a detailed interpretation of these local changes and a basis to understand the biological rebound at high southern latitudes following this major ecological crisis.

Keywords: microbialites, palaeo-deposition, Gondwana, Triassic, extinctions

THE BIOSTRATIGRAPHIC IMPLICATIONS OF NEW DINOFLAGELLATE CYSTS FROM THE BATHONIAN–KIMMERIDGIAN OF THE NORTH WEST SHELF, AUSTRALIA

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The Late Jurassic strata of the North West Shelf of Australia contain numerous world-class oil and gas fields, which remain the focus of significant investment from major international exploration companies. This study presents the geographic and stratigraphic range of new Bathonian–Kimmeridgian dinoflagellate cyst marker specie of North Western Australia. Palynofloral assemblages from new and legacy palynological preparations from the Alaria-1 and Laminaria-2 wells (Laminaria High, Bonaparte Basin), and Elm-1 and Taltarni-1 wells (Vulcan Sub-basin) were documented. The exceptionally well-preserved Oxfordian palynomorph assemblages from the Janzs-Io Field (Northern Carnarvon Basin) were also reviewed and legacy stratigraphic data was incorporated. A total of nine species of dinoflagellate cysts, and one species of uncertain affinity are formally described. An additional 16 known dinoflagellate cyst marker species were imaged for the first time using Scanning Electron Microscopy (SEM), further demonstrating the high degree of intraspecific variability, and resulting in three generic and four formal taxonomic emendations. Third generation Focused Ion Beam-SEM imaging was used to produce high resolution cross-sections of multi-layered dinoflagellate cysts species to further investigate wall structure. Palynological analyses from wells in the Bonaparte Basin were used to identify correlatable biostratigraphic events; this data was then compared to existing palynostratigraphic studies from the NWS to determine the geographic range of these events. From these analyses several new regional marker events for the Bathonian–Kimmeridgian have been identified and corroborated in both the Bonaparte and Northern Carnarvon basins.

Keywords: dinoflagellate cysts, biostratigraphy, taxonomy, North West Shelf, Jurassic

REALISTIC AND THEORETICAL 3D MODELLING OF THE SEDIMENTATION, BURIAL, THERMAL AND TECTONIC HISTORY OF THE GIPPSLAND RIFT BASIN

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Significant advances have been made in the theoretical understanding of basin development in the past few decades but it has proved difficult to reconcile these models with actual well, seismic and field data. The aim of the project is to calibrate the sedimentary, burial, thermal and tectonic history of a rift basin, using actual realistic 3D models of the basin made in Petrel (Schlumberger) software, to constrain the theoretical deterministic models made in Badlands (Earthbyte) software. The experimental design aims to estimate and evaluate the most important controlling variables, produce the associated statistical equations, and test many of the accepted theoretical equations for basin development.

The Gippsland Basin is being used as the basis, given it is a relatively simple, rapidly buried, young divergent margin tectonic basin which has a wealth of well, seismic and other geophysical data. In future, the research may compare and contrast the results with 2D/3D lines in a deeply buried foreland tectonic basin to determine the wider applicability of some relationships (e.g. Temperature, Pressure, time, vitrinite reflectance) to rates of burial/extension/compression in a different tectonic setting (e.g. the Palaeozoic section in SE Bolivian Andes, Papua New Guinea or New Zealand).

The interpretation and realistic modelling is being done in Petrel using open file well log, core and seismic data assisted by gravity and magnetic data. The sedimentation, burial, thermal and tectonic modelling will use 3D forward modelling in Petromod (Schlumberger) and Badlands.

Keywords: Basin modelling, burial thermal history, experimental design, Gippsland Basin

BIOMARKER AND STABLE ISOTOPES AT THE CHICXULUB IMPACT CRATER

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The meteorite impact event 66 Ma ago has been widely accepted as the main cause of the End-Cretaceous mass extinction event. The event led to an extinction of 75% of all species on Earth. For this study samples (impact melt, breccia, suevite and sediments) from Integrated Ocean Drilling Program (IODP) 364 drilling expedition “Chicxulub: Drilling the K-T Impact Crater” were extracted for biomarkers and analysed to investigate the molecular and isotopic organic record of biotic and environmental change before and after the K/Pg boundary event.

Biomarkers of dinoflagellates, diatoms and land plant markers were detected in the Cenozoic and their variations indicate alternating inputs of organic matter from marine and terrestrial sources. Diagnostic biomarkers of green, brown and purple sulphur bacteria were identified and their distributions support the rapid occurrence of photic zone euxinia (PZE) before and after the K/Pg boundary. The significance of PZE (episodic vs. persistent) throughout the section reflects a variation in marine productivity cycles up to the top of the Eocene. Further, high amounts of organosulphur compounds in the Eocene support early diagenetic sulphurisation (inter and intra-molecular) of biomolecules in the ancient column water. Further analysis of the samples and the coupling with the stable isotope data have revealed important information on the palaeo environmental depositional setting at ground zero.

Keywords: Chicxulub impact crater, end-Cretaceous mass extinction, biomarker, photic zone euxinia

GROWTH OF CONTINENTAL CRUST AT ISLAND ARCS REVEALED BY HIGH-PRECISION GEOCHRONOLOGY

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A long-standing consensus regarding subduction-related island arcs is that these are the locations responsible for the cumulative production of Earth's continental crust since the Archean. Eruptive lavas and intrusive plutons produced by arc magmatism typically possess geochemical compositions comparable with the accepted composition of bulk continental crust [1]. Whilst the magmatic output from an arc is andesitic, the magmatic input stems from fluid-fluxed melting of the mantle wedge [2]. Accordingly, the basaltic input and andesitic output produces compositional stratification throughout the arc crust, with a silicic upper crust but more mafic lower crust. Therefore, if continental crust is generated within subduction-related arcs modification of the lower arc crust must occur. Though the modification process is debated, there is an agreement that successive cycles of dense magmas underplating the arc base, followed by fractionation and delamination of mafic-ultramafic cumulates is necessary to drive arc crust towards compositions approximating continental crust. In recent years these de-lamination models have received widespread support from geochemical evidence [3], but geochronological evidence for such processes are lacking due to the scarcity of exposed samples from the deeper arc crust. Here we utilise high-precision U-Pb, Sm- Nd, and Lu-Hf geochronology to demonstrate a progressively younging-downward age gradient from ~ 110-92 Ma across the lower arc cumulates of the Cretaceous Kohistan Arc Complex of north-eastern Pakistan. These new radio-isotopic ages represent the first conclusive geochronological evidence in support of delamination models, revealing a fundamental process involved in the genesis of continental crust.

Keywords: Kohistan, island-arc, geochronology, crustal growth

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APPLICATION OF THE UNMANNED AERIAL VEHICLES (UAVS), ADVANCE 3D MODELLING AND INTERACTIVE GIS WEB-BASED SYSTEMS FOR PALAEONTOLOGICAL AND GEOLOGICAL STUDIES

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This presentation focuses on the application of the Unmanned Aerial Vehicles (UAVs), advance 3D modelling and interactive GIS web-based systems for geological and palaeontological studies in National dinosaur park of Alberta/Canada. Application of UAVs and web-based Geospatial database enable the researcher and academics to improve the process of the fossil discovery from planning to implementation phases. This research focuses on the process of UAV based data capturing, pre and post processing of the captured data and development of a 3D interactive database/ model (Geo modelling) of the dinosaur park and its geological features. This presentation is the outcome of a collaborative research with Center for Innovation and Research in Unmanned Systems (CIRUS) in Southern Alberta Institute of Technology (SAIT) in Canada.

Keywords: Unmanned Aerial Vehicles. Palaeontology, geology, 3D modelling

HETEROGENEOUS MANTLE SOURCE OF MID-OCEAN RIDGE BASALTS FROM THE MACQUARIE RIDGE COMPLEX

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Chemical heterogeneity of the depleted upper mantle is a significant problem for understanding the genesis of mid-ocean ridge basalts (MORB). An isotopically unusual series of ridges and seamounts are found along the Australia–Pacific plate boundary south of New Zealand, known as the Macquarie Ridge Complex (MRC). Major and trace elements of the MRC basalts range from N-MORB to E-MORB but are otherwise relatively homogeneous along the ridge, indicative of source extraction from the uppermost mantle. However, limited Sr-Nd-Pb isotopic data, predominantly from the only emerged portion of the MRC (Macquarie Island), reveal a highly correlated Pb isotopic trend between Pacific MORB and a HIMU-like source. Currently, no isotopic data are available from other parts of the MRC so it is uncertain whether this HIMU-like component is restricted to Macquarie Island or is systemic to the whole MRC. Moreover, a lack of robust geochronological constraints means that it is uncertain whether the contribution of the HIMU component varies with time. With the current paucity of data, three possible models exist: (i) the HIMU component is well-mixed with the depleted asthenosphere, (ii) fine-scale HIMU blobs are evenly distributed throughout the upper mantle, or (iii) a single HIMU anomaly is present underneath Macquarie Island. Here, we will test these models via 40Ar/39Ar dating and detailed elemental and Sr-Nd-Pb isotopic analyses across 1200 km of the MRC. The results resolve the nature of the upper mantle at the Australia-Pacific plate boundary and have important implications for the HIMU reservoir in this region.

Keywords: HIMU, MORB, Macquarie Ridge, ^{40}Ar/^{39}Ar geochronology, Isotopes

A COMPREHENSIVE MICROSCOPIC AND GEOCHEMICAL APPROACH TO IDENTIFY MELANOSOMES AND KERATIN IN A FOSSILISED FISH EYE FROM THE FUR FORMATION, DENMARK

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Fossilised pigments are significant in yielding many aspects about the ecology of ancient life. It has been assumed that the tiny microstructures observed in exceptionally well-preserved fossils are associated with biofilms made by bacteria. However, recent studies have provided clear and convincing evidence, both morphologically and chemically, that these microstructures are melanin-bearing melanosomes, colour-bearing organelles, refuting a misinterpretation as bacterial biofilms. By applying time-of-flight secondary ion mass spectrometry (ToF-SIMS), molecular content of putative melanosome from a fish eye fossil from the early Eocene of Denmark were analysed and showed a close agreement of the mass spectra compared to a natural melanin standard [1]. Trace metal abundances proved that copper, as organometallic compounds, is present in eumelanin, providing a proxy for determining the density and distribution of eumelanin [2]. Other elements, such as Ca and Zn, also showed a strong correlation with the melanin pigment. Identification of keratinous proteins in fossil matrix which these microbodies are embedded in also supports the assignment of these microbodies as melanosomes [3]. However, the source of the organically bound trace metals is still under debate. Also, recent studies have shown that epidermal keratin can decay easily during microbial activity and diagenetic process [4]. Little research has been done on the chemical processes during melanosome preservation and the degradation process of keratinous protein.

Keywords: molecular fossil, melanin, keratin

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HEAVY METAL INCORPORATION IN FORAMINIFERAL CALCITE: MULTI-ELEMENT ENRICHMENT CULTURE EXPERIMENTS WITH *AMPHISOROUS* SP.

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Large benthic foraminifera (LBF) are important marine calcifiers and are potential candidates to reconstruct the environmental signals. Live *Amphisorous* sp. foraminifera were collected from the Rottnest Island located approximately 18 km off the coast of Western Australia, for multi-element enrichment culture experiments.

In the first phase, our goal was to observe the heavy metal incorporation in the tests of *Amphisorous* foraminifera, for which we performed a short-term spiking culture experiment. Thirteen samples were handpicked and cultured individually in Petri dishes for 12 weeks before the start of the spiking-experiments. The spike concentration with heavy metals Cd, Cu, Pb, Mn, Ni and Zn, was prepared at double the 80% level of protection of species in marine water as mentioned in the Australian and New Zealand guidelines for fresh and marine water quality [1]. The samples were changed to normal filtered seawater after two weeks and cultured further for a period of two weeks before performing laser ablation studies on their tests.

The geochemical data, Te/Ca ratios, shows increased concentration of heavy metals in their tests for the spiked-culture period. Long-term spiking culture experiments are currently in progress to determine the partitioning coefficient of the heavy metals from the seawater to the calcareous tests of the *Amphisorous* foraminifera.

Keywords: *Amphisorous* sp., Heavy metals, Culture, Spike, Rottnest

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EXTRACELLULAR POLYMERIC SUBSTANCES OF MICROBIAL MATS FROM SHARK BAY, WESTERN AUSTRALIA

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Microbial mats are organosedimentary biofilm communities and analogues of the earliest life on Earth that accumulate as a consequence of microbial communities producing extracellular polymeric substances (EPS) that trap and bind sediments and minerals. By producing EPS, microorganisms engineer their immediate environment with respect to many physicochemical characteristics. EPSs are most commonly composed of polysaccharides and proteins but also include lipids. Shark Bay offers a large diversity of modern microbial mats that are affected by a range of different physicochemical factors. By way of example, research has shown that microbes will excrete variable amounts and types of EPSs depending on the salinity of their environment [1]. In order to investigate the chemical composition of EPS from 3 contrasting Shark Bay microbial mats, we chemically characterised EPS by a variety of non-destructive (i.e. Fourier-transform infrared (FT-IR) and Nuclear magnetic resonance (NMR) spectroscopy) and destructive (i.e. chemical degradation of EPS for Gas chromatography mass spectrometry (GCMS) and various pyrolysis (Py) methodologies. Additionally, metatranscriptomes were sequenced to investigate expressed functional genes associated with EPS cycling and production.

Keywords: Shark Bay, microbial mats, extracellular polymeric substances, salinity

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MICROBIAL COMMUNITY DYNAMICS OF SUBSURFACE PETROLEUM ENVIRONMENTS IN THE NORTH WEST SHELF, WA

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Petroleum reserves in Western Australia's North West Shelf are significant energy resources for the Australian economy [1], but biodegraded crude oil deposits complicate extraction and purification processes [2]. Abundant geochemical studies have been carried out on petroleum biodegradation in the NWS [3,4], but there is a dearth of microbial ecology data pertaining to the same production sites. Subsurface petroleum environments are resident to anaerobic microbial communities that degrade petroleum compounds as a function of their metabolic activities [5]. Microbial growth and biodegradation rates are mainly controlled by reservoir temperature, but also dynamically influenced by salinity, fresh oil recharge, nutrient availability, fluid migration, and volatile intermediates [6]. Microbial communities also work within syntrophic consortia responsible for multiple stages of petroleum degradation [7], which ultimately discharges methane as a terminal product [8]. This study aims to characterise the microbial community dynamics in subsurface environments in relation to petroleum degradation, which could be further applied to secondary extraction of crude oil, as well as methane production from degradation of residual crude oils. Microbial diversity and function are analysed by metagenomics and metatranscriptomics, while organic geochemical methods and compound-specific isotope analysis (CSIA) are used to characterise metabolite abundances and degradation pathways. Metal and inorganic components are also analysed to characterise influences of nutrients and other volatiles. Finally, anaerobic incubation experiments are being conducted with various substrate and media inoculations to further characterise microbial community dynamics under controlled conditions, as well as their viability for microbially enhanced oil recovery and methane production.

Keywords: North West Shelf, biodegradation, petroleum, methane, subsurface, microbial community dynamics, anaerobic, metagenomics, metatranscriptomics

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ISOMER DISTRIBUTIONS AND Δ^{34}S VALUES OF ORGANOSULPHUR COMPOUNDS IN BIODEGRADED OILS FROM PEACE RIVER, ALBERTA BASIN, CANADA

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The heavy S-rich oils of the western Canada oil sand belt were primarily formed by microbial degradation. Their composition can vary with the degree of biodegradation, but also widely due to the interplay of several other key factors (e.g., different sources or thermal maturity, secondary charging, in-reservoir compartmentalisation). This complexity can alter some traditional hydrocarbon based biodegradation tendencies and a multi parameter approach (e.g., Manco Number, MN2) was considered necessary to reliably assess the biodegradation levels of these oils [1]. To investigate the potential impacts of biodegradation on organosulphur, we have measured the distribution and δ^{34}S values of alkylated thioaromatic compounds detected in progressively biodegraded samples from two Peace River oil-legs reflecting different biodegradation gradients (Biodegradation levels well A = 3-4; well B = 5-7). The concentrations of all C_1-C_3 alkylated BTs and DBTs declined sharply through each well consistent with biodegradation, and varied rates of decline between selected isomers (e.g., 3&4-mBT >> 2-mBT; 4-mDBT >> 1-mDBT/2&3-mDBT; 4-eDBT >> 1,3-dmDBT) may indicate their different susceptibilities to biodegradation. The S-isotopic measurements showed a general ^{34}S enrichment of alkyl BTs (e.g., up to 6‰ for 2,7-dmBTs) in oils of well B (Nb., Alkyl BT concentrations of well A oils were too low for δ^{34}S measurement) consistent with the microbial uptake of the smaller ^{32}S. In contrast, there was little variation in the δ^{34}S values of alkyl DBTs measured in the oils of both wells suggesting negligible S-isotopic fractionation with the biodegradative reduction of these higher molecular weight organosulphur compounds.

Keywords: Peace River; Alberta oil sands; benzothiophenes; dibenzothiophenes; compound specific sulphur isotope analysis

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STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE MIOCENE LIMESTONES FROM THE CAPE RANGE ANTICLINE

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Outcrops of Miocene limestones are widespread along the coast of northwest Western Australia. This outcrops belong to the carbonate system overlying the petroleum reservoirs of the Northern Carnarvon Basin. Despite their economic importance and their value for constraining the Miocene palaeoclimate history of Australia, their detailed depositional history is still poorly understood.
This study is based on field, well and seismic data. It aims to revise the ages of this limestones in the Cape Range Anticline, to correlate the outcrops with offshore sequences in the Exmouth sub-basin and to update the existing depositional model. The Miocene limestones were deposited in four phases: (1) Warm open shelf with extensive seagrass meadows, (2) Warm open shelf with tidal flat, (3) Rimmed shelf with an extensive lagoon and coral patch reefs, and (4) Warm mixed carbonate-siliciclastic shelf.
This four phases can be correlated with global and regional events: the tidal flat formed during the major sea level fall associated with the Miocene Climatic Optimum (MCO), the corals proliferate during the progressive global cooling following the MCO, and the onset of siliciclastic influx coincides with climatic changes in Western Australia.

Keywords: Miocene, carbonates, Carnarvon Basin, Miocene climatic optimum

MULTIPLE SULPHUR ISOTOPES AS INDELIBLE TRACERS OF ORE-FORMING PROCESSES IN MAGMATIC AND HYDROTHERMAL MINERAL SYSTEMS

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In the past decade, the investigation of multiple sulphur isotopes applied to mineral systems has been radically revolutionised through the discovery that isotopic anomalies due to mass-independent fractionation (MIF) of sulphur are chemically conservative and nearly indelible. Thus, they represent excellent tracers of geological and ore forming processes. Consequently, MIF signatures have been utilised to fingerprint the sources of sulphur and metals in a large variety of mineral systems. For instance, largely positive $\Delta^{33}S$ anomalies in Archean orogenic gold mineralisation testify the relevant input of sedimentary-derived sulphur to the gold-bearing fluids. Whereas variable $\Delta^{33}S$ signatures in komatiite-hosted deposits define a genetic framework that associate negative $\Delta^{33}S$ signature with the assimilation of exhalative material proximal to vents, positive $\Delta^{33}S$ signatures are thought to be associated with more distal systems, where thermo-mechanical erosion of distal sulphidic shales is the prevalent ore forming process.

Through a series of new studies, we demonstrate that further insights can be revealed by combining MIF signatures with the more traditional $\delta^{34}S$ signatures as well as detailed microchemical analysis. In komatiite-hosted deposits, the isotopic effects originated from crustal assimilation can be resolved from those derived from either magmatic devolatilisation of sulphur, or imparted by multiple hydrothermal events. In orogenic gold systems, the specific $\delta^{34}S$ signatures and sulphide trace element compositions can uniquely fingerprint the deposition mechanisms. We suggest that through this integrated approach, multiple sulphur isotope analyses provide more reliable and robust insights to improve the current understanding of ore-forming processes.

Keywords: Sulphur isotopes, Sulphides, Archean, Mineral systems, Magmatic, Hydrothermal

ALKALINE MAGMATISM AS A PROBE INTO THE MANTLE UNDER THE YILGARN CRATON, WA

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The Archean Yilgarn Craton of Western Australia is a world-class metallogenic province, hosting numerous volcanogenic massive sulphide systems enriched in base metals, komatiite-associated nickel-sulphide mineralisation and orogenic Au deposits. However, at the regional scale mineralised camps are not evenly distributed across the craton but are preferentially concentrated in specific areas, which may be controlled by the architecture of the underlying lithospheric mantle. The PGE-Au signature of deeply sourced alkaline magmas may provide key insights into the metallogenic fertility of the craton and help on the prediction of the spatial setting of different mineral systems.

As these alkaline systems were most likely generated by smaller degrees of partial melting of the mantle (most likely at different depths), it is argued that the observed variable PGE signature may reflect an inherited difference in the metallogenic endowment of the source. This piece of evidence needs to be reconciled with the fact that most alkaline magmas from the Yilgarn Craton appear to be anomalously enriched in Au. Alkaline magmas that contain enriched AU contents have high SO_3 (≤ 2.0 wt.%) and F (≤ 1.5 wt.%), which is correlated with the high F (≤ 5.1 wt.%). and SO_3 (≤ 2.0 wt.%) contents in apatite. It is argued that F and SO_3 may play a crucial role in the primary transport and concentration processes of gold in the mantle source of these magmas.

Keywords: geochemistry, the Yilgarn Craton, alkaline magmatism, platinum group element, apatite, volatile elements

CRUSTAL GROWTH BASED ON IN-SITU ZIRCON SHRIMP U-PB GEOCHRONOLOGY AND HF-O ISOTOPES FROM PROTRACTED MAGMATISM IN SOUTHERN GOIÁS MASSIF, CENTRAL BRAZIL

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The Goiás Massif represents an Archean crust of uncertain origin active during the Palaeoproterozoic and Neoproterozoic. A combined study of whole rock geochemistry, in-situ zircon U-Pb SHRIMP geochronology and Hf-O isotopes reveals changes in tectonic setting and source in the southern Goiás Massif, and along its western and eastern margins, through time. The Archean TTGs (ca. 2740-2830 Ma) characterise typical volcanic arc setting involving tholeiitic oceanic arcs and subduction of oceanic crust with overlapping juvenile mantle-like Hf-O isotopic compositions. The emplacement of the Itapuranga and Rio Caiapó granites (ca. 610-630 Ma), coeval with regional peak metamorphism, is characterised by Hf-O isotopic values that suggest reworking of older crust and a supracrustal contribution. The Serra Negra granite (ca. 530 Ma) displays Palaeoproterozoic (2090 Ma) inheritance, mantle-like δ18O isotopes and juvenile εHf. The first record of an intrusive rock in the Faina greenstone belt is represented by the Pink Syenite (~2070 Ma), which has Archean inheritance (~2880 Ma), mantle-like δ^{18}O signature and juvenile εHf values. Similarities between the Serra Negra and Pink Syenite, e.g., U-Pb ages and associated inheritance, mantle-like δ^{18}O signature, and juvenile Hf values (εHf ~ 0), suggest that both are likely associated with deep melting of re-fertilised source within convergent margin. The data indicate different processes were involved during these magmatic events, with generation of new crust mostly at ca. 2.8, whereas 2.0 Ga and 0.6 Ga magmatism are associated with orogenesis in the Palaeoproterozoic and Neoproterozoic, during the Transamazonian (Eburnean) and Brasiliano (Pan-African) events, respectively.

Keywords: U-Pb geochronology, Hf-O isotopes, crustal growth, Goiás Massif, Transamazonian orogeny, Brasiliano orogeny

TRACE ELEMENT COMPOSITION OF SUB-MICROMETRE MONAZITE INCLUSIONS IN ULTRA-HIGH TEMPERATURE METAMORPHIC RUTILE

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Rutile and monazite are routinely used for U-Th-Pb geochronology and provide valuable information on the timing of crystallisation and metamorphic events. However, the accuracy of this information is reliant on our understanding of the U-Th-Pb decay system and the assumption that elements do not migrate after formation. Recent studies on the effect of high temperature metamorphism on zircon [1, 2] and monazite [3] showed that Pb and other trace elements can be concentrated as nanoscale inclusions.

For this study, rutile from the Napier Complex, East Antarctica, was characterised at the nanoscale to gain information about trace element mobility during ultra-high temperature (UHT) metamorphism. The Napier Complex has recorded the highest known metamorphic temperatures (>1150°C) in the continental crust. The samples consist of garnet-rich orthogneiss in which rutile resides as accessory phase mineral. For this contribution, Atom Probe Tomography (APT) and correlative techniques including Backscattered Electron (BSE) imaging, Electron Backscatter Diffraction (EBSD) mapping and Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS), were used to characterise the rutile grains.

The correlative analysis revealed the presence of 0.5 - 1 µm monazite inclusions in rutile. APT analysis of the sub-micrometre monazite revealed nanoscale segregations of Ca and Si. The presence of monazite inclusions in rutile provides a unique opportunity to use two well established geochronometers and allows us to evaluate the partitioning of incompatible elements including Pb, Th and LREE.

Keywords: Rutile, monazite inclusions, atom probe tomography, geochronology, incompatible elements

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A BUSINESS CASE FOR GOLD EXPLORATION: COMBINING GEOSCIENTIFIC, ECONOMIC AND FINANCIAL ANALYSIS TO DEVELOP AN EXPLORATION TARGETING MODEL FOR THE SANDSTONE GREENSTONE BELT

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Despite increased expenditure, discovery of new mineral deposits has slowed dramatically since the beginning of the 21st century. Targeting below deeper, more complex cover is recognised as key to opening up new search-spaces and re-invigorating exploration success. Existing techniques and technologies are reaching maturity as direct-detection exploration methods are costly and have limited success when targeting beneath cover. Thus, the application of a conceptual based approach to exploration targeting is required. The Mineral Systems Concept provides a framework within which the critical elements of the system can be defined and incorporated into an exploration targeting model. However, modelling of mineral systems remains in its infancy, with only qualitative models being applied to whole-system modelling.

The effective translation of the Mineral Systems Concept into robust exploration targeting models is defined as a significant research challenge by several authors. The intention in this project is to formulate an integrated quantitative mineral-systems model through the following steps: Assessment of the critical elements within the orogenic gold-mineralising system of the Sandstone Greenstone Belt, WA [1]; application of existing exploration tools, including a mineral endowment assessment [2] and mineral prospectivity analysis, to define maturity and map mineral distribution; and review gold exploration and corporate strategy in WA.

A quantitative whole-system model, linking mineral prospectivity to metal endowment, can provide key information to guide exploration decision making by attributing a risk-adjusted dollar value to each target, allowing a clear business case to be built for the exploration project.

Keywords: Exploration Targeting, Mineral Systems Concept, Mineral Endowment Assessment, Mineral Prospectivity Analysis, Orogenic Gold, Sandstone Greenstone Belt, Yilgarn Craton

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BUILDING THE GEOLOGICAL FRAMEWORK OF THE KANOWNA BELLE DEPOSIT FOR A METHODICAL SULPHUR ISOTOPE APPLICATION

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Archean orogenic gold deposits are structurally controlled systems that have been researched extensively. However, their genetic model remains controversial. A major problem lies in the inconclusive nature of the source of its hydrothermal fluids as well as its gold and sulphur. Furthermore, it is a matter of debate whether these deposits formed during a protracted period consisting of multiple deformation events or over a shorter period within a single critical deformation event. These problems severely limit our capacity to predict the localisation of mineralised systems.

To address these questions, we focused on the polyphased Kanowna Belle deposit as a natural laboratory. The Kanowna Belle deposit consists of 5 different deformation events (DE to D4). In this framework, the initial extensional deformation (DE) is followed by four different contractional episodes: 1.) D1 deformation; 2.) D2 NE-SW contraction; 3.) D3 N-S contraction; 4.) D4 ENE-WSW contraction. Each deformation controls the emplacement of different veins that are separated based on their cross-cutting relationships and structural context. Our next objective is to apply selective sulphur isotope analysis to monitor the source and evolution of hydrothermal fluids, and geochronology to constrain the timing of the hydrothermal fluid generation. Both techniques will be applied based on our constructed geological framework.

Keywords: Archean orogenic gold, sulphur isotopes, deformation events

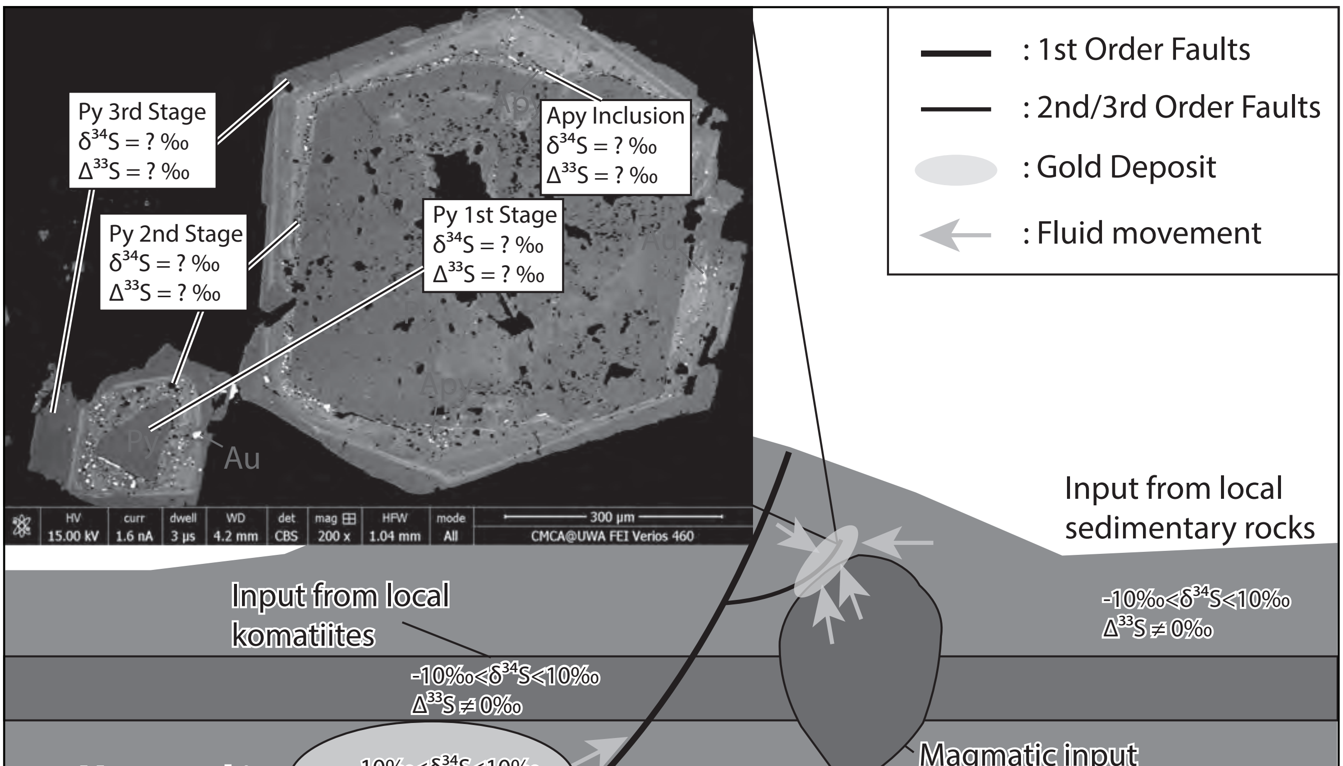

Figure. Conceptualisation of sulphur isotope signatures relating to gold deposit source

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CHARACTERISATION OF SHOCK DEFORMATION AT THE SPIDER IMPACT STRUCTURE, WESTERN AUSTRALIA

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The Spider impact structure is ~13 x 11 km in diameter and is located 430 km NE of Broome in the Kimberley, Western Australia. The impact is suggested to have been oblique based on the unusual morphology of faulted metasedimentary rocks in the central uplift. Rocks include the Pentecost (1704±14 to 1774±9 Ma) and Warton (1704±7 to 1786±14 Ma) sandstone radiating out from the central uplift [1, 2]. Here we present a study of shock deformation in quartz, zircon and xenotime from shatter cones in metasandstone collected from the Spider structure. Quartz grains contain planar fractures (PFs), feather features (FFs) and planar deformation features (PDFs). PDFs are abundant throughout all sections and are orientated predominantly along (0001) indicating the samples experienced pressures of ~10 GPa. The PDFs and PFs indicate that the samples experienced strong deviatoric stress and the FF orientations within samples allow the principal axis of stress to be determined. Zircon and xenotime grains within 7 thin sections were analysed by EBSD. Xenotime overgrowths on zircon grains were observed, some overgrowths contain {112} deformation twins in up to two orientations. Zircon grains also contain {112} deformation twins which occur at pressures of ~20 GPa. Samples from the centre of the uplift are extremely heterogeneous with quartz indicating lower pressures of ~10 GPa while accessory phases indicating pressures of ~20 GPa, showing that porosity and impedance mismatching is incredibly important when trying to determine shock isobars within impact structures.

Keywords: shock deformation, impact cratering, zircon, Spider Impact Structure

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THE BRYAH AND PADBURY BASINS FROM AN INTEGRATED GEOPHYSICAL AND GEOLOGICAL ANALYSIS

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The northern margin of the Yilgarn Craton was setting of a continental rift during the Palaeoproterozoic that lead to the formation of the Bryah Group (2027-2000 Ma), and deposition of the Bryah Sub-Basin within the Yerrida Basin [1]. Contractional movements attributed to the Glenburgh Orogeny (2005-1960 Ma) resulted in the formation of the foreland peripheral Padbury Basin, and deposition of the Padbury Group (1996-1820 Ma). In this study, potential field data were used to characterise the basins structural framework, as well as the rift-related mafic magmatism, which is coincident with an east-northeast trending very high gravity anomaly. Geological mapping and drill core observations were also used to constrain the interpretations. An integrated analysis of the shallow and deep gravity and magnetic anomalous sources assisted the investigation of faults, such as the growth Goodin Fault, which represents a large-scale rift-boundary fault. Further, the potential field analysis reveals the mafic magmatism within the rift extending to depths up to ~ 6 km, and show possible shallow magmatic spreading centres. The investigation of the mafic magmatism and the basins structural framework is also particularly important to aid VMS and orogenic gold exploration models in the basins. Deep structures and subvolcanic channels play an important role in VMS mineral system analysis, while the identification of reactivated and overprinted structures is crucial for gold exploration.

Keywords: Geophysical mapping, Potential field methods, Bryah Sub-basin, Padbury Basin, Capricorn Orogen

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A GAUSSIAN PROCESS REGRESSION MODEL FOR 3D GEOCHEMICAL INTERPOLATION SUPPORTED BY GEOPHYSICAL INVERSION MODELS

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3D geochemical subsurface models, as constructed by spatial interpolation of drill core assays, are valuable assets across multiple stages of the mineral industry's workflow. However, the accuracy of such models is limited by the spatial sparsity of the underlying drill core, which samples only a small fraction (≤0.01%) of the subsurface. This limitation can be alleviated by integrating additional collocated and correlated 3D models into the interpolation process, such as the 3D rock property models produced by modern geophysical inversion procedures. We propose a Gaussian process regression model for 3D geochemical interpolation, where custom kernels are introduced to integrate collocated 3D rock property models while addressing the trade-off between the spatial proximity of drill cores and the similarities in their collocated rock properties, as well as the relative degree to which each supporting 3D model contributes to interpolation. The proposed model was evaluated for 3D modelling of magnesium concentration in the Kevitsa Ni-Cu-PGE deposit based on drill core assays and four 3D geophysical inversion models. It was found that incorporating the inversion models improved the regression model's likelihood over spatial interpolation alone at moderate spatial scales (approx. 100 m). Implementation used the recent machine learning package GPFlow, which leverages advances in graphical processing to compute the full 3D model in minutes.

Keywords: Gaussian process regression, geophysical inversion, spatial modelling, geochemistry

CARBONATE-SULPHIDE REPLACEMENT PROCESSES—ARTEMIS CU-AU PROSPECT, QUEENSLAND

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Massive polymetallic mineralisation at the Artemis Cu-Au prospect located within the Eastern succession of the Mount Isa Inlier, NW Queensland, discovered by Minotaur Exploration Ltd. in 2014, displays a complex association of sulphides and carbonates. The ore mineralisation is hosted in a vertical, few meters wide, N-S trending marble unit that is enveloped by staurolite muscovite schist and garnet-bearing calc-silicate hornfels. The sulphide assemblage consists of pyrrhotite, sphalerite, chalcopyrite, galena, arsenopyrite, cobaltite, cubanite, bismuth ± Ag-sulphides, gold, and costibite; in decreasing order of abundance. Calcite is the dominant gangue mineral and it is frequently intergrown with siderite. Textural analyses reveal two processes: (i) early, replacement of carbonates by sulphides as the main ore-forming process; (ii) subsequent, replacement of the sulphides by secondary siderite and calcite. Therefore, Artemis provides an excellent opportunity to study carbonate-sulphide dissolution and precipitation processes.

Micro-XRF maps show homogeneous distribution of Fe and Mn in sphalerite; on average 9.1 wt.% Fe and 0.5 wt.% Mn. EPMA analyses of carbonates revealed an average content of 1.5 wt.% Mn, and 0.5 wt.% Fe in calcite, while siderite contains an average of 4.0 wt.% of Ca, 1.9 wt.% of Mn, and up to 1.3 wt.% of Zn. The microscale investigations of abundant sulphidation and carbonatisation processes manifested in the Artemis mineralisation help to elucidate the role of CO2-rich fluids in metal mobilisation and subsequent sequestration in skarn, manto- and/or Mississippi Valley-type deposits.

Keywords: Mount Isa Inlier, Cloncurry district, sulphides, carbonates, replacement reactions

SULPHUR SOURCES AND MAGMATIC SULPHIDE MINERALISATION IN THE FRASER ZONE: INSIGHTS FROM MINERAL PROSPECTS

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The Albany-Fraser Orogen is located along the southern and southeastern margin of Western Australia's Archean Yilgarn Craton, and comprises a number of discrete lithotectonic domains including the c. 1300 Ma Fraser Zone. The Fraser Zone is composed of voluminous sheeted mafic, ultramafic and minor granitic rocks that have intruded sulphur-bearing metasedimentary rocks of the Snowys Dam Formation. The zone has been considered prospective for nickel sulphide mineralisation since the discovery of the Nova-Bollinger Ni-Cu deposit in 2012. In order to better understand magmatic emplacement and formation of magmatic sulphide deposits within the Fraser Zone, we use in-situ multiple sulphur isotope geochemistry; a powerful tool allowing for the identification and sourcing of sulphur essential for mineralisation as well as the characterisation of any Archean sulphur input. Here we present new $\delta^{34}S$ and $\Delta^{33}S$ data from a range of mineral prospects within the Fraser Zone. Distinct ranges of sulphur isotopic signatures at each of the mineral prospects indicate variable degrees of assimilation of local metasediments of the Snowys Dam Formation. Despite an Archean source component in Fraser Zone magmas being suggested by radiogenic isotopes, sparse xenocrystic zircon, and whole rock geochemical modelling, Archean sulphur is absent, indicating a mechanism by which detrital Archean sulphur was stripped from sediments. These sediments were subsequently assimilated by Fraser Zone magmas. Our results indicate a coupling between variable assimilation of external sulphur by Fraser Zone magmas and the mineralisation present at the prospects studied.

Keywords: Fraser Zone, Octagonal, magmatic sulphides, sulphur isotopes, Archean

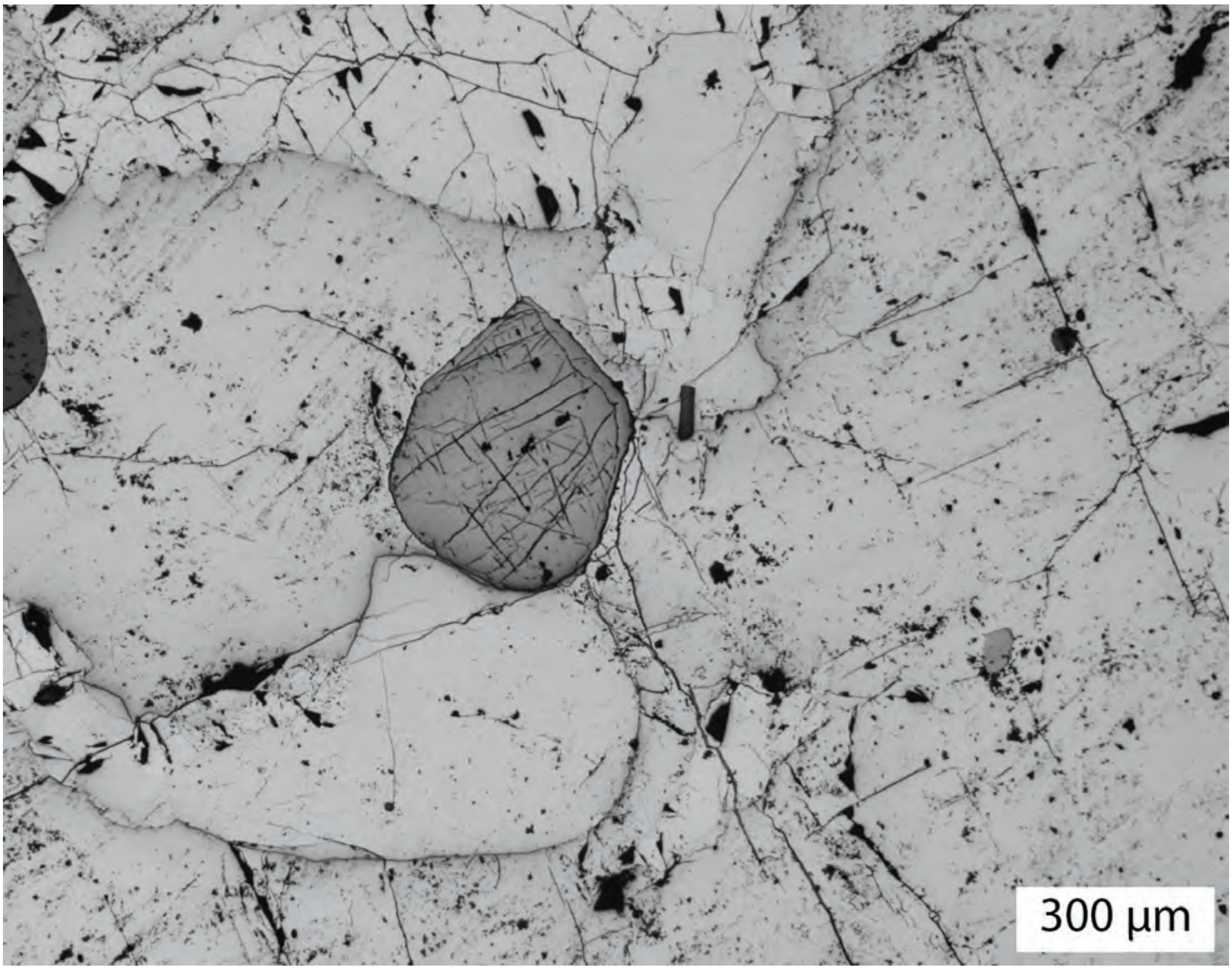

Figure. Reflected light image of cumulate magmatic sulphides from the Fraser Zone.

UNRAVELLING THE STRUCTURAL AND METAMORPHIC EVOLUTION OF THE GEORGETOWN INLIER (NE AUSTRALIA)

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Recent tectonic model suggests that the Mesoproterozoic Georgetown Inlier (GTI) in NE Queensland, records the continental collision between Laurentia and the North Australian Craton at ca. 1.6 Ga (Nordsvan et al., 2018: Pourteau et al., 2018). We test this record by combining analysis of fabrics and their defining paragenesis, with mineral chemistry data, thermodynamic modelling and geochronology.

Field and microstructural observations revealed 4 main foliations in the GTI. S3 (striking NW-SE) and S4 (E-W) foliations are recorded in both S-type granites and metasediments and are defined by greenschist facies assemblage. In D3 and D4 low strain domains, earlier foliations and paragenesis are preserved. S1 is a steep foliation preserved in the NW GTI and in S2 low strain domains. Garnet Lu–Hf geochronology and pressure–temperature estimation indicate prograde medium–P/T metamorphism at 1598 ± 6 Ma (Pourteau et al., 2018). S2 is a shallow HT-LP fabric defined by andalusite, locally replaced by sillimanite in the eastern area. S2 develops progressively (Bell & Rubenach, 1983) during emplacement of S-type granites (ca. 1560 - 1550 Ma). Consistent field observations suggest development of granite dome structure in the eastern part of GTI.

The first deformation phase is recorded at MT-MP conditions and represent the collisional stage of the orogeny. The D2/M2 overprinting event was recorded at HT-LP between 1.55 Ga and 1.4 Ga. This late-orogenic event is associated to granites emplacement and partial melting, suggesting it formed under an extensional regime. A late compressional event generates E-W macroscale folds under greenschist facies conditions.

Keywords: Nuna, metamorphism, structural geology, Georgetown Inlier

THE IMPLICATION OF EARLY ARCHITECTURE FOR GOLD ENDOWMENT IN A LOW STRAIN ENVIRONMENT; THE YAOURÉ OROGENIC GOLD DEPOSIT, CÔTE D'IVOIRE

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The 1.5 Moz Yaouré gold mine is located in the Bouafle greenstone belt in central Côte d'Ivoire. The low aspect ratio of the belt area where the deposit occurs contrasts with the NE-SW trending arcuate Birimian granite-greenstone belts of the West African Craton. Country rocks in the Yaouré area occur in a poorly-deformed to undeformed state. Field data indicates that strike-slip faults bounding a 10km-scale intra-belt basin acted as key controls on the structural geometry of the gold deposit.

Gold mineralisation at Yaouré is polyphased. It first occurs within a conjugated set of strike-slips following the same orientations as the margins of a volcano-sedimentary basin present north of the deposit. These orientations are also borrowed by calc-alkaline dykes, emplaced prior shortening. A second mineralised event is marked by a thrusting episode crosscutting strike-slips, within which mineralisation occurs as an en echelon vein array associated with low to no displacement. The geometry and the kinematics study of the thrusts support a bulk incremental deformation under low differential stress leading to multiple slip increments and episodic fluid discharge. Although strike-slips and thrusts display different timing and hydrothermal alteration styles, they both developed during an E-W shortening event that corresponds to the regional belt main shortening event.

This study presents an unusual orogenic gold mineralisation setting in a poorly studied area and highlights the importance of early extensional tectonics as a controlling factor for the location of orogenic gold mineralisation.

Keywords: orogenic gold, early architecture, structural geology, West Africa

GEOCHEMICAL AND ISOTOPIC CHARACTERISATION OF HYDROTHERMAL ALTERATION AND GOLD MINERALISATION AT THE KAROUNI OROGENIC GOLD DEPOSITS: GUYANA, SOUTH AMERICA

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The Karouni gold deposits are located in north-central Guyana 35 km to the west of the 5 Moz Omai gold deposit. They are hosted in the 2.2-2.1 Ga Trans-Amazonian Province part of the Palaeo- to Neoproterozoic Guiana Shield [1]. Karouni consists of the Smarts and Hicks deposits, located 2 km apart along the NW striking Smarts-Hicks Shear Zone. Both deposits are hosted within greenschist facies mafic to ultramafic volcanic rocks and felsic intrusions. The style of hydrothermal alteration is lithology-dependent and is characterised by narrow selvages (4 to <1 m in width) which display a progression from chlorite-calcite-rutile to albite-dominated mineralogy in dolerite, whereas a chlorite-talc-chlorite-calcite assemblage dominates in high MgO basalt. It is anomalous among orogenic gold deposits for its distinct lack of potassic alteration. Gold is located within inclusions in disseminated pyrite associated with the proximal alteration zones, as coarse native gold within the quartz-carbonate veins and within Au-bearing telluride minerals. The dolerites formed a favourable chemical trap due to their high magnetite content suggesting sulphidation via redox reaction as a possible mechanism of gold deposition. Mass balance modelling of the proximal alteration shows strong trace element enrichment of W-Bi-Ag-Te-Mo-Pb all of which are correlative with gold. In-situ LA-ICP-MS trace element geochemistry of pyrite from of the gold bearing hydrothermal system within the deposits indicate a geochemically and isotopically homogeneous system. U-Pb dating of hydrothermal titanite associated with proximal alteration indicates a mineralisation age of 2084±14 Ma, corresponding to the late stages of the Trans-Amazonian Orogeny.

Keywords: Karouni, Guyana, Guiana Shield, Trans-Amazonian, Orogenic, Gold, Alteration, Geochronology

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PALAEOMAGNETISM OF A CA. 2.62 GA DYKE SWARM IN THE YILGARN CRATON, WESTERN AUSTRALIA, AND PALAEOGEOGRAPHIC IMPLICATIONS

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We report new palaeomagnetic data from a recently identified 2.62 Ga dyke swarm in the southwestern Yilgarn Craton, Australia. Among the 15 dykes sampled, 12 revealed stable, dual-polarity magnetic remanence that passed a reversal test. The mean direction of the remanence is WNW with an intermediate upward inclination. Although a baked contact test yielded inconclusive results, we interpret the remanence to be primary because: (i) the high unblocking temperature (560–580°C) of the characteristic remanent magnetisation (ChRM); (ii) the presence of single domain (titano)magnetite, which in some dykes is the main magnetic carrier; (iii) no pervasive overprint events has been reported in the study area; (iv) the dissimilarity of the ChRM direction with any younger palaeomagnetic direction expected in the area.

The Neoarchean–Palaeoproterozoic poles from the Yilgarn Craton, including our new one, together with coeval poles from the Zimbabwe Craton, extend the proposed Zimgarn (Zimbabwe-Yilgarn) connection back to ca. 2.6 Ga. However, the exact configuration of the Zimgarn supercraton is still unclear. The latitudinal motion constrained by our new pole and that of the ca. 2.41 Ga Widgiemooltha dyke swarm provides a lower bound of plate velocity at ~0.6 cm/yr for the Yilgarn Craton, which is comparable to present-day velocities of low-trench-effective plates such as the Eurasian Plate. It should be noted that this estimation of plate velocity does not consider true polar wander events since few of them were reported for this time interval.

Keywords: palaeomagnetism, palaeogeography, mafic dykes, Yilgarn Craton

SELF ORGANISING MAPS – A CASE STUDY OF BROKEN HILL

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Self-organising maps (SOM) is a type of unsupervised learning technique for analysis of multivariate data. SOM integrates multiple layers of data (Geophysics, Hymapper, soil chemistry etc.) to perform cluster analysis, resulting in unit categorisation (BMU cluster maps), whilst also highlighting relations between variables (U-matrix & component planes). The result is an intermediate product that allows end users to focus on the cause of the correlations within their datasets instead of trying to find them. Due to the rising quality of remote sensing data along with continued exploration over known deposits, multivariate data sets will be more frequent globally. Our work shows SOM can be used to simplify and streamline the data interpretation process on such datasets.

Using the exceptionally rich data set surrounding Broken Hill, Australia we evaluated the viability of applying SOM to regional mapping and exploration targeting. Our dataset was provided as part of the Frank Arnott Award by the Department of Primary Industries NSW. We then applied our own evaluation of the produced content and the impact of different input layers on the resultant SOM map. We also considered the applications of the quantisation error in data validation. SOM is then considered alongside other data science techniques, showing how current applications and interesting future directions.

This work placed 3rd internationally for the Frank Arnott Award at Exploration 17 and was also presented at AEGC 18 in Sydney [1], winning best student talk for mineral geoscience.

Keywords: SOM, Remote Sensing, Geophysics, Machine Learning, Broken Hill

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“SPOT” CALL: A COMMONLY RECORDED SOUND FROM AN UNKNOWN GREAT WHALE SPECIES

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Underwater passive acoustic recordings in temperate waters off Australia have regularly recorded a short duration (8 – 10 s), low frequency (23 – 26 Hz) tonal sound with a symmetrical bell-shaped envelope. When recorded nearby at high level the sound is often accompanied by higher frequency down sweeps (40 – 100 Hz) and is repeated at irregular intervals varying from 120 s to 200 s. It is termed the “spot” call due to its spot-like appearance on spectrograms of long time averaging. The spot call displays a decrease in fundamental frequency over years. Additionally, an almost instantaneous intra-seasonal jump in frequency from around 22 Hz to 28 Hz was also observed in 2006. The seasonal presence of the call varies according to recording location. Recordings made in some parts of the Southern ocean display a spot call chorus almost year round, with a peak in individual high intensity calls detected during the austral winter-spring. Although similar in appearance to the first unit of the Antarctic blue whale z-call, significant differences in fundamental frequency, the rate of decrease in fundamental frequency and spatial and seasonal presence are seen. We present evidence to suggest the spot call is not produced by an ABW, but rather another great whale species.

Keywords: passive acoustics, “spot” call, unknown whale species

DEFORMATION VELOCITIES OVER PERTH AREA DETERMINED USING INSAR TERRASAR-X DATA BASED ON DIFFERENT SBI-BASED APPROACHES

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In this study, we apply different Small Baseline Interferograms (SBI) techniques, namely small baseline subset (SBAS), time function (TimeFun), and Multiscale InSAR time series (MInTS) that are all incorporated in GIAnT package, to process X-band German TerraSAR-X data over Perth area, WA. The processing results are subsequently used to compare linear time-series calculated from these approaches. In the case of SBAS application, a linear trend is assumed and its parameters, i.e., an intercept and a slope, are obtained by least-squares fitting on pixel by pixel basis to SBAS time-series. In the case of TimeFun and MInTS, a time-dependent function in term of a linear rate of deformation only is used, and its parameter is calculated. For all cases, linear function parameters are used to compute linear time-series based on actual scenes acquired time and compared between each other. The InSAR Scientific Computing Environment (ISCE) is used to form individual interferograms prior to processing Multi-Temporal Interferometric SAR (MT-InSAR). The deformation velocities computed based on 4-year dataset show relatively small values, which vary within a range of a couple of millimetres per year. The result of vertical deformation is also compared with GNSS-derived surface deformation time-series at CGNSS stations showing relatively consistence between the two types of data.

Keywords: data processing, GIS, time-series, linear functions

A MINING AND EXPLORATION INDUSTRY PERSPECTIVE ON THE ENERGY TRANSITION

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The transition to renewable energy from fossil fuels will both fundamentally change the structure of minerals demand, and the process of mining. The mining and exploration sector in its current form may struggle to re-align mineral production to match these new demand patterns, whilst at the same time undergoing a significant shift in production technology. The 'CET Scenarios' Programme was established to investigate structural discontinuities, of this kind, in the future of mining. One discontinuity investigated was the energy transition [1,2,3,4,5,6,7]. Two scenarios were developed: one involving a voluntary and complete energy transition driven by industrial innovation and framed by concerns over sustainable development ('Wonderland'); and another with a forced and partial energy transition driven by government and framed by geopolitical (strategic) concerns over raw materials security ('1984'). Following the development of the scenarios further research was conducted into the interaction of the mining and exploration sector with the energy transition, sustainable development and resource security, with the aim of better informing corporate strategy. The strategic recommendations to the mining and exploration sector for re-aligning with changing, but unknown minerals demand patterns, and exploration and production technologies, included techniques for monitoring 'progress in transition', 'horizon scanning', market analysis, capabilities analysis, and ensuring strategic coherence. An emphasis was placed on developing creative, social, adaptable and varied thinking skills amongst mining and exploration sector professionals and researchers.

Keywords: mining, exploration, energy transition, renewables, batteries, electric vehicles, scenarios, future

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DAMMING THE NILE RIVER: GEOMORPHOLOGICAL AND SOCIO-ECONOMIC IMPLICATIONS

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Even though dams nearly produce 71% of the world's renewable energy, promote the water storage and regulate the streamflow, their effects on river morphology and fluvial processes, and also socio-economic impacts, have become increasingly of concern to water resources management during the last decade. The Nile River, arguably the largest river in the world, is shared with eleven countries, which complicate the exploitation of its precious resources. Since Uganda constructed the Bujagali dam in 2007 on the White Nile River and Ethiopia started to build the Grand Ethiopian Renaissance Dam (GERD) in 2011 on the Blue Nile River (the main tributaries of Nile River), the water supply and sedimentation flow to Egypt and Sudan, which highly depends on the Nile River system, could be severely compromised [1]. Thus, it is crucial to understand the way and degree of alteration in river dynamics due to damming and the associated socio-economic impacts in order to cope with the future water management. This research aims at employing geospatial tools (remote sensing and GIS techniques) to understand the geomorphological and socio-economic impacts resulting from damming the Nile River. Specifically, the study will: use multi-temporal Landsat images of the river before and after the construction of the dams to determine the spatial-temporal variations of the river channel morphology and to understand the causes, nature and rates in order to provide valuable information to the management of the Nile river resources.

Keywords: river geomorphology, Nile River, river channel changes, Remote Sensing, GIS, water resources

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THE RELATIONSHIP BETWEEN LARGE SCALE CLIMATIC CYCLES AND THE DISTRIBUTION OF ROSS RIVER VIRUS IN WESTERN AUSTRALIA: 2002-2016.

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Ross River Virus (RRV) is the most common mosquito-borne virus in Australia and there is much to study about the incidence and distribution of the virus and their relationship of large scale climatic cycles such as El Nino and La Nina with consideration to the Southern Oscillation Index (SOI) and the Indian Ocean Dipole (IOD). This study uses statistical analysis, hot spot analysis and spatial autocorrelation to indicate the strength of the relationship between these climatic variables and the number of distribution of RRV incidences. The results indicate that the changes in the SOI and IOD effect the relationship of the El Nino and La Nina climatic cycles with the number and distribution of RRV in Western Australia with confidence levels suggesting that there is a less than 1% chance that the clustered distribution is due to random chance.

Keywords: Ross River Virus, incidence, distribution, climatic cycles

GRAIN- VERSUS GRAIN BOUNDARY-BASED QUANTIFICATION OF SHAPE PREFERRED ORIENTATIONS IN NATURAL ROCK SALT

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Ductile deformation of rock salt produces foliations defined by a shape preferred orientation (SPO) of halite grains, which should play a significant role not only on deformation behaviour and microstructural development but also on seismic velocity anisotropy. The influences of SPO has not been sufficiently studied. To assess the influence of petrofabric characteristics such as grain size, ellipticity, alignment of grain boundaries, grain boundary shape and grain orientation it is necessary to be able to reliably quantify those characteristics and ultimately quantify the strength and geometry of the shape preferred orientation.

Analysing grain fabrics directly from images can be problematic for automated software. The commonly used way is to manually trace grain boundaries with a vector graphics software, combining reflected microscopy, SEM and EBSD data to identify and treat grain boundaries and cracks/fractures separately. The vector graphic maps are analysed with specialised software such as ImageJ and FracPaQ. The established method to quantify SPO is to define grains from which parameters such as the grain areas, equivalent circular diameter, and lengths, orientations, and ratios of long and short axes can be derived.

We present a completely new approach: SPO quantification via grain boundary property analysis from vector graphic maps. The segments that form the boundaries are analysed in terms of their length, orientation, abundance and distribution. Grain boundary-based SPOs are compared with grain-based SPOs, showing a broad equivalence. Further geometric relationships of an SPO are revealed by using line scan statistics of grain boundary intersections. This way, the directionally-dependent grain boundary density can be quantified, and a maximum and minimum grain boundary density direction identified, which is important when considering the effects of grain boundaries on acoustic wave attenuation. The line scan grain boundary analysis has potential in various fields. It is not only very useful to assess the strength of shape preferred orientation but might also provide data on grain boundary shape and thus on aggregate grain shape, accommodating deformation mechanisms and possibly grain growth dynamics.

Keywords: rock salt, seismic velocity anisotropy, shape preferred orientation quantification, FracPaQ

MULTI-SCALE ROCK CHARACTERISATION: SUPPORTING KNOWLEDGE INTEGRATION AND UNCERTAINTY REDUCTION FOR GEOLOGICAL MODELLING AND SIMULATION OF DEEP SILICICLASTIC RESERVOIRS

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Exploration and production of deep mineral and energy resources are limited by their prohibitive cost and associated risks, which is mostly due to uncertainties in the knowledge of the underground rock properties. In order to stimulate the resources industry, improvements in imaging the structure and understanding the properties of subsurface rocks should generate more cost-effective sweet-spot location and characterisation with lower risks. This entails developing new geophysical and geomechanical models using reliable input parameters carefully acquired in the laboratory or in the field. Indeed, the reliability of geophysical/geomechanical models is governed by input data quality and the associated uncertainties. The aim of this study is to improve the petrophysical and geophysical characterisation of subsurface stratigraphy and structure by developing a suite of novel and integrated analytical and experimental tools and protocols. The 2D, 3D and 4D (time dependency) characterisation from the micro-scale (mineral phases, pores, micro-cracks) to the macro-scale (centimetres to metres) will be improved using a quantitative and multi-scale digital rock physics approach. This project will focus on areas relevant for the energy and mineral resources sectors, with particular emphasis on siliciclastic reservoirs and time-dependent fluid migration within them. The impact at the macro-scale of rock facies, mineralogy, organic matter, texture, morphology, fluid content, and the distribution and connectivity of the different phases will be investigated quantitatively. The benchmark tools and protocols developed within this project are anticipated to be widely used in future projects related to energy and mineral resources recovery.

Keywords: uncertainty reduction, multi-scale characterisation, digital rock, geophysic, petrophysic

INTEGRATION OF GEOLOGICAL UNCERTAINTY INTO GEOPHYSICAL INVERSION USING LOCAL GRADIENT REGULARISATION IN THE YERRIDA BASIN

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Qualitative integration of geophysical and geological data has much potential to constrain the imaging of Earth's subsurface and to reduce interpretation uncertainty. We introduce a geophysical inversion scheme that incorporates geological uncertainty information into geophysical inversion. We utilize information extracted from a probabilistic geological model (PGM) to adapt the strength of the inversion's regularization accordingly with the level of geological uncertainty. The PGM is derived from Monte-Carlo simulations perturbing field geological measurements. It is therefore reflective of the range of possible geological scenarios while encapsulating geological uncertainty information. Consequently, the local regularization constraint that we propose agrees with the geology of the study area. This encourages model updates in geologically uncertain regions while supporting consistent changes where the geology is better known. We validate our approach on synthetic data and apply it to data from the Yerrida Basin (Western Australia). We use dip, strike and contact measurements with their uncertainty to derive the PGM, from which uncertainty information is extracted to calculate local regularization constraints for the inversion of gravity data. Our results show that this technique allow us to retrieve models where anomalies are more compact and exhibit higher density contrast, reducing ambivalent interpretation. These models are the product of the integration of a PGM in geophysical inversion, and are shown to be geologically and geophysically sound. We conclude that by allowing inversion to update the model more freely in geologically uncertain areas, our methodology is capable of focusing inversion and to reduce interpretation uncertainty.

Keywords: integration, geophysical inversion, probabilistic geological modelling, uncertainty, Yerrida Basin.

HIGH-PRECISION LEAD ISOTOPE SYSTEMATICS OF THE NIMBUS AND BENTLEY VHMS DEPOSITS IN THE EASTERN GOLDFIELDS IN THE YILGARN CRATON, WA

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INSIGHTS INTO THE MAGMATIC AND HYDROTHERMAL EVOLUTION OF THE BLACK SWAN SUCCESSION: EVIDENCE FROM MICROCHEMICAL AND SULPHUR ISOTOPE INVESTIGATION

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THE SULPHUR SOURCE AND FLUID EVOLUTION OF THE KUNDANA GOLD CAMP: MIXING DURING METAMORPHISM OR MANTLE INPUT?

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THE SOURCE OF PHOSPHORUS IN HIGH-GRADE IRON ORES OF JANGADA MINE, QUADRILÁTERO FERRÍFERO, BRAZIL

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TRACE ELEMENT MOBILITY ALONG RUTILE DEFORMATION TWINS DURING ULTRA-HIGH TEMPERATURE CRUSTAL METAMORPHISM

***Rick Verberne*[1,2], Steven M. Reddy[1,2], David W. Saxey[1], Denis Fougerouse[1,2], William D.A. Rickard[1], Chris Clark[2]**

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BIOMARKER DISTRIBUTION IN A CALCAREOUS SILTSTONE CONCRETION (DEVONIAN, HILLHEAD QUARRY, SCOTLAND)

***Madison Tripp*[1], Chloe Plet[2], Jessica H. Whiteside[3], Kliti Grice[1]**

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CRUST DELAMINATION POST 1.6 GA NUNA ASSEMBLAGE IN THE MT. ISA INLIER, QUEENSLAND, NE AUSTRALIA

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AN AUSTRALIAN SOURCE FOR PACIFIC-GONDWANA ZIRCONS: IMPLICATIONS FOR THE ASSEMBLY OF NE GONDWANA

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THE IMPLICATION OF EARLY ARCHITECTURE FOR GOLD ENDOWMENT IN A LOW STRAIN ENVIRONMENT; THE YAOURÉ OROGENIC GOLD DEPOSIT, CÔTE D'IVOIRE

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EL INDIO BELT MAGMATIC ZIRCON O-HF ISOTOPIC SIGNATURES

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HOW ROBUST IS ZIRCON CHEMISTRY? TRACE ELEMENT MOBILITY DURING SHOCK METAMORPHISM

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PALAEOENVIRONMENTAL AND PALAEOHYDROLOGICAL RECORDS FROM GROUNDWATER DOLOCRETE WITHIN THE FORTESCUE MARSH, PILBARA REGION OF NORTHWEST AUSTRALIA

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METASOMATIC REACTIONS IN BORNITE: INSIGHTS FROM HYDROTHERMAL EXPERIMENTS AND MICROSCOPIC AND MINERALOGICAL CHARACTERISATION

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POROSITY, PERMEABILITY AND MINERALOGICAL CHANGES OF BASALT CORES UNDER CO_2 RICH BRINE INJECTION CONDITIONS

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BASEMENT INHERITANCE CONTROLS ON NEOGENE REACTIVATION IN THE CASWELL SUB-BASIN, NORTH WEST SHELF OF AUSTRALIA

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GSA Earth Sciences Student Symposium WA

VENUE MAP

THE UNIVERSITY OF WESTERN AUSTRALIA

101. Winthrop Hall
103. Hackett Hall
104. Lawrence Wilson Art Gallery
106. Arts
131. Recreation & Fitness Centre
139. Reid Library
143. Octagon Theatre
144. Dolphin Theatre
225. Geography & Geology
241. Computer Science
245. Physics
272. Robert Street Building
606. Water Sports Complex
607. Boat Shed Matilda Bay

P Car Park Number

A. Registration
B. Woolnough Lecture Theatre
C. Webb Lecture Theatre
D. Tropical Grove (Lunch)
E. Water Sports Complex (Posters and Sundowner)