GESS

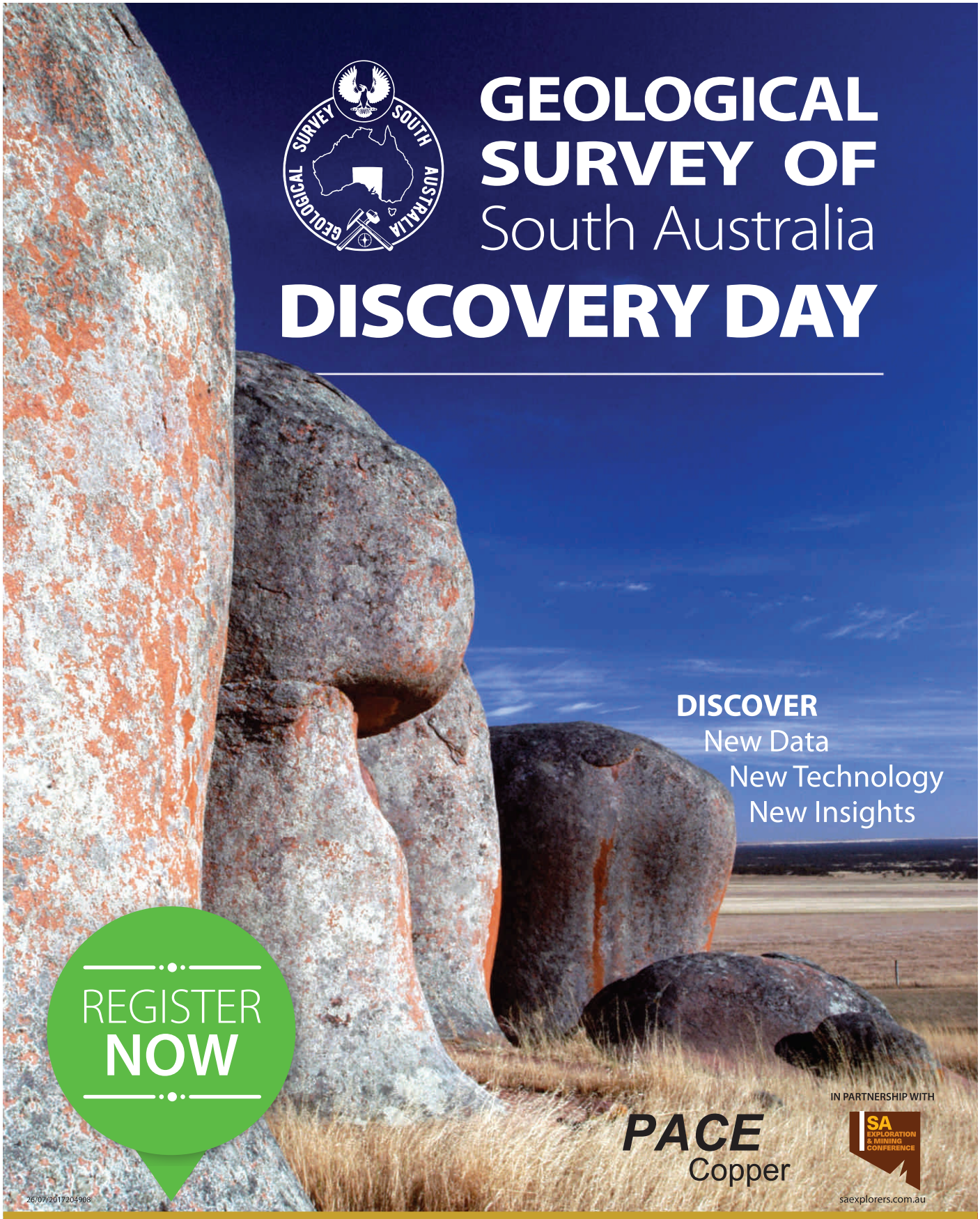
GSA Earth Sciences Student Symposium

SA

Geological Society of Australia
Earth Sciences Student Symposium
South Australia

24th November, 2017

PROGRAM AND ABSTRACT VOLUME



ADELAIDE CONVENTION CENTRE

Thursday • 7 December • 2017

www.minerals.dpc.sa.gov.au/gssa_dd

SOUTH AUSTRALIA

Government of South Australia

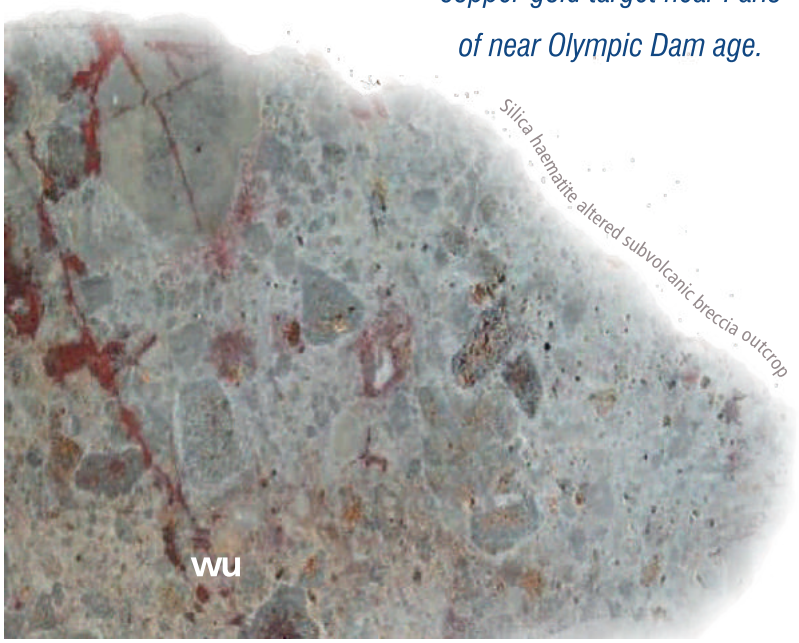
CONTENTS

South Australian focus:

- *Moving the Paris Silver Deposit towards development*
- *Emerging Greenfields Mineral Potential*
- *Data-rich and research savvy jurisdiction*

Aiming to revitalise South Australias minerals discovery rate with breakthrough ideas tested by collaborative and co-ordinated research.

For example:
The Nankivel porphyry copper-gold target near Paris of near Olympic Dam age.



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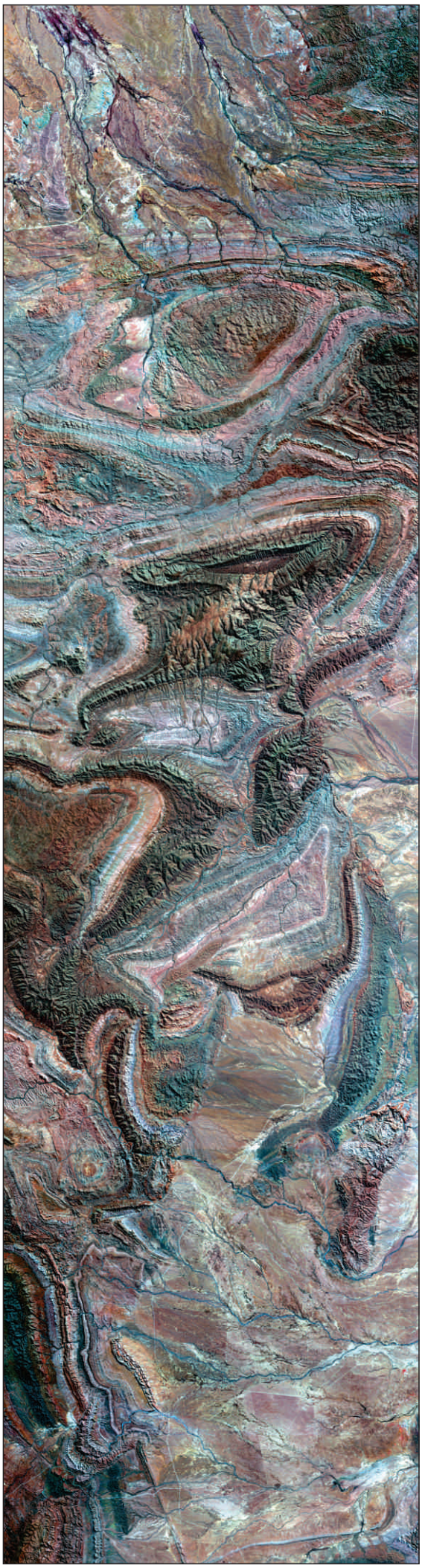
INVESTIGATOR RESOURCES LIMITED

New Thinking, Real Discoveries.



WELCOME TO GESSS SOUTH AUSTRALIA 2017

Welcome to the inaugural Geological Society of Australia Earth Sciences Student Symposium South Australia (GESSS-SA). We are pleased to have you join us at the Tonsley Drillcore Library for a day that will showcase the best of South Australia's student research.

This conference is an opportunity for Honours, Masters and PhD students from South Australian universities to come together and present their Earth Science related research. This experience is valuable for students who wish to develop their communication and networking skills, with their peers and professional geoscientists.

We are excited by the quality of research that will be presented at this conference, with topics covering palaeontology, geophysics, tectonics and isotope geochemistry. We are impressed by the global reach of research by South Australian students, who are collaborating and conducting research in all corners of the globe (more on page 11).

We sincerely thank our partners for their support in making this year's conference possible, and we hope to continue these 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 future GESSS-SA events.

We hope you enjoy GESSS-SA 2017!

Thank you,
GESSS-SA 2017 Organising Committee

Minotaur Exploration Limited
迈诺拓勘探公司

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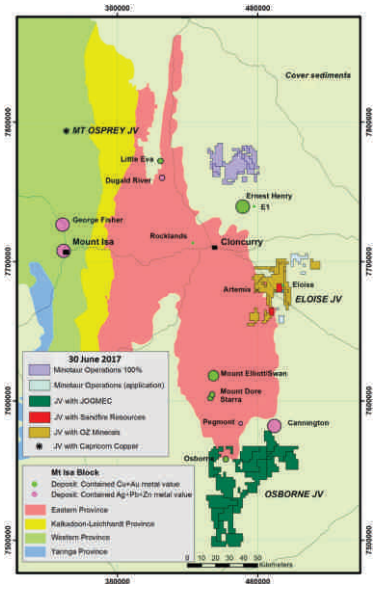
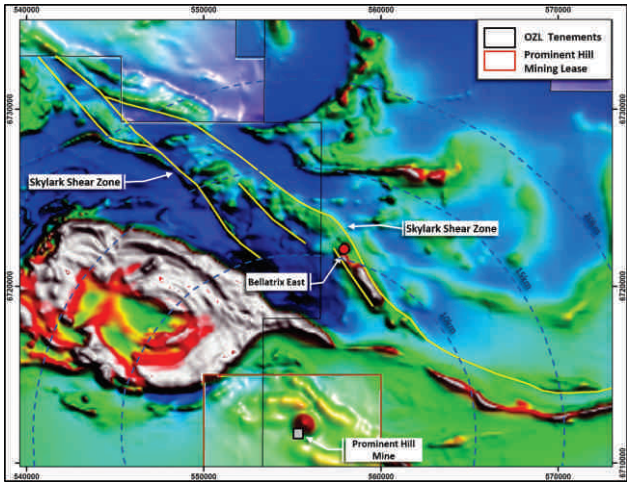
MINOTAUR EXPLORATION

Copper – Gold Explorer
铜 – 金勘探
ADELAIDE, AUSTRALIA
阿德莱德 澳大利亚



Copper – Gold Exploration Mt Isa region
伊莎山地区铜—金矿勘探



Copper – Gold Exploration Olympic Dam region
奥林匹克大坝地区铜—金矿勘探

Minotaur undertakes copper-gold exploration with Joint Venture partners funding for project equity
迈诺拓公司保证投资合作方在铜–金勘探项目上的公平性

GESSS SOUTH AUSTRALIA 2017 ORGANISING COMMITTEE

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University of Adelaide

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University of Adelaide

Kailah Thorn, Program and Abstracts
Flinders University

GENERAL INFORMATION

SOCIAL MEDIA

We encourage delegates to use the hashtag **#GESSSSA** on Facebook, Instagram and Twitter to share your experience of the day!

The Geological Society of Australia

The geological society of Australia (GSA) gives members an outstanding opportunity to keep in touch with scientific developments, present the results of their work, and contribute to discussions on vocational and scientific topics.

www.gsa.org.au

The next major GSA conference will be run in conjunction with other Australian earth science societies, for further information visit:

www.agcc.org.au

AGCC Australian Geoscience Council Convention

BIG ISSUES AND IDEAS IN GEOSCIENCE

14–18 OCTOBER 2018 | Earth Science Week

Adelaide Convention Centre

Registration

Registration will open at 8:30 am. Please ensure that you have registered online, as unfortunately we won't be accepting late registrations.

Oral presentations

Please ensure you have uploaded your presentation (powerpoint or PDF format) to the computer and checked over it prior to your session starting.

Posters

Please arrive early to ensure adequate time to set up your poster in the morning. Volunteers and committee members will be able to assist with this.

Catering

Morning tea, lunch and afternoon tea will be served. Drinks will also be served during the poster session.

Conference dinner

The conference dinner will be held at the Tonsley Hotel at 6:30 PM after the poster session. Please see a committee member ASAP if you have not registered for the dinner, and wish to attend.

Photography acknowledgements

GESSS-SA conference banner: Alan Collins
Cover photos from social media photography competition: Jonathan Berthiaume, Georgy Falster, Heather Duff, B. Kay, Alan Collins, Mitchell Bockmann and Richard Lilly

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Contact:
President: bradley.cave@student.adelaide.edu.au
Vice President: mitchell.bockmann@student.adelaide.edu.au

Perpetual Trophy for best Oral Presentation (to be awarded annually)

$200 Taylor and Francis gift voucher for best contribution (poster or oral) to GESSS-SA

Rock coasters (category TBA)

- Ediacaran Stromatolite from the Flinders Ranges, SA; or
- Actinolite-biotite-tremolite schist

Generously donated by Jonathan Berthiaume

Winner of the social media photography competition will be announced at GESSS-SA

Other prizes will be revealed in the lead up to GESSS-SA

SOUTH AUSTRALIAN STUDENTS – GLOBAL SCIENTISTS

Collaboration is important for scientific advancement, and is critical for students and early career researchers to broaden their professional networks. South Australian students attending this conference are actively involved in collaborative research with over twenty countries and from every continent!

POSTERS

Name	Title	Pres no.	Pg
Brandon Alessio	ON YODERITE: USING CALCULATED PHASE EQUILIBRIA TO INVESTIGATE ITS RARITY IN THE GEOLOGICAL RECORD OF WHITESCHISTS	1	25
Rachel Atkins	THE GEOCHRONOLOGY OF THE BOUCAUT VOLCANICS	2	28
Jacob Blokland	PIECES OF THE PENGUIN PUZZLE: INSIGHTS FROM A NOVEL BASAL PALEOCENE PENGUIN, CHATHAM ISLAND, NEW ZEALAND	3	29
Larissa Collins	COLD SUBDUCTION ON THE AVALONIAN MARGIN	4	35
Natalie Debenham	THE INFLUENCE OF REVERSE-REACTIVATED NORMAL FAULTS ON NATURAL FRACTURE GEOMETRIES AND CHRONOLOGIES IN SANDSTONES: A CASE STUDY AT CASTLE COVE, OTWAY BASIN	5	36
Heather Duff	DEVELOPING NEW TOOLS FOR PALEOECOLOGICAL FOREST RECONSTRUCTIONS	6	37
James Hall	TWO BILLION YEARS OF THERMAL EVOLUTION IN THE NORTHERN GAWLER CRATON, SOUTH AUSTRALIA	7	42
Daniel Howlett	120 MYR OF EPISODIC MID-CRUSTAL METAMORPHISM AND FLUID-ROCK INTERACTION DURING THE ALICE SPRINGS OROGENY; THE STRANGWAYS RANGE, CENTRAL AUSTRALIA	8	45
Christopher Kemp	PRECIPITATION IN AUSTRALIA DURING MIS3: AN ANALYSIS OF PUBLISHED PALAEOCLIMATE DATASETS	9	49
Ellen Mather	FLIGHTLESS RAILS (AVES: RALLIDAE) FROM THE EARLY MIOCENE ST BATHANS FAUNA, OTAGO, NEW ZEALAND	10	50
Claire Murphy	RECONSTRUCTION OF LATE PLEISTOCENE TO HOLOCENE PALAEOENVIRONMENTAL CHANGE AT BASIN LAKE, FRASER ISLAND	11	52
Alicia Pollett	USING NEW GEOPHYSICAL DATA TO CONSTRAIN THE LITHOSPHERIC RELATIONSHIP BETWEEN THE GAWLER CRATON AND MUSGRAVE PROVINCE	12	53
Lily Reid	CHARACTERISTICS OF A JUVENILE POPULATION OF *DICKINSONIA COSTATA* FROM THE FLINDERS RANGES	13	54
Lachlan Richards	BRITTLE VS DUCTILE DEOFRMATION IN SALT DETACHMENTS: AN EXAMPLE FROM THE SALT RANGE, PAKISTAN	14	55
Yuexiao Shao	CALCIUM AND STRONTIUM ISOTOPE CYCLING IN COASTAL LAGOON-ESTUARINE ENVIRONMENTS, SOUTH AUSTRALIA: IMPLICATIONS FOR WATER MIXING, CARBONATE FLUXES AND FISH MIGRATION	15	56
Alastair Stark	RAMIFICATIONS FOR STRUCTURAL PERMEABILITY WITHIN THE PERTH BASIN: ANALYSIS OF CALCITE TWIN DATA & IN-SITU STRESSES.	16	57
Kailah Thorn	DATING AUSTRALIAN SKINK DIVERSIFICATION: FOSSIL SPHENOMORPHUS AND EGERNIA GROUP SKINKS FROM RIVERSLEIGH WORLD HERITAGE AREA (QUEENSLAND, AUSTRALIA)	17	61
Jessie-Briar Treloar	BASELINES FROM SUBFOSSILS: WHAT SMALL MAMMALS ROAMED THE FLINDERS RANGES BEFORE EUROPEAN SETTLEMENT OF AUSTRALIA?	18	62
Naomi Tucker	A TRIPARTITE APPROACH TO UNEARTHING THE DURATION OF HIGH TEMPERATURE CONDITIONS VERSUS PEAK METAMORPHISM: AN EXAMPLE FROM THE BUNGER HILLS, EAST ANTARCTICA	19	64
Jan Varga	THE ROLE OF FLUID–ROCK INTERACTION AND MELT PRODUCTION IN INTRAPLATE MOUNTAIN BUILDING: THE HARTS RANGE, CENTRAL AUSTRALIA	20	66
Georgina Virgo	THE ELATINA FORMATION, PICHI RICHI: IMPLICATIONS FOR SNOWBALL EARTH	21	67
Bo Yang	SPATIAL AND TEMPORAL VARIATION IN DETRITAL ZIRCON AGE PROVENANCE OF THE HYDROCARBON-BEARING UPPER ROPER GROUP, BEETALOO SUB-BASIN, NORTHERN TERRITORY, AUSTRALIA	22	69

GESSS-SA 2017 PROGRAM

8:30	Registration opens	**Pg**
9:00	Acknowledgement of Country and opening address	
9:10	Keynote: **Alice Clement:** The Late Devonian Gogo Formation Lägerstatte and its spectacularly-preserved 3D fossil fish fauna	34
	SESSION 1: PALAEONTOLOGY (CHAIR: KAILAH THORN)	
9:30	**Ray Chatterji**: A quantitative analysis of skull growth and evolution in sea turtles (Testudinata: Chelonoidea)	33
9:45	**Jacob van Zoelen**: Digitally reconstructing the skull of the extinct marsupial *Nototherium inerme* (Diprotodontidae) and inferring diet using multidisciplinary analyses	65
10:00	**Sam Arman**: Dietary diversity in Pleistocene Kangaroos of South-eastern Australia	27
10:15	**Amy Tschirn**: Palaeobiology of *Madakoala devisi* (Phascolarctidae) using novel specimens from Lake Pinpa, South Australia	63
10:30	**Diana Fusco**: Digging deep – the late Quaternary fossil fauna of Cathedral Cave, central eastern Australia	40
10:45	**Poster Presentations 1–6**	
10:50	Morning Tea	
	SESSION 2: METAMORPHIC GEOLOGY (CHAIR: BRANDON ALESSIO)	
11:15	**Megan Williams**: Thorium distribution in the crust: outcrop and grain scale approaches	68
11:30	**Kieran Meaney:** The tectonic development of the Paleo-Mesoproterozoic Barossa Complex, Gawler Craton, South Australia	51
11:45	**Renee Tamblyn:** Metamorphic conditions of blueschist from mud volcanoes in the Mariana Trench	58
12:00	**Xiao-Fang He**: On the utility of mafic granulites to address the controversy over metamorphic p–t–t evolution of the Highland Complex, Sri Lanka	43
12:15	**Kiara Bockmann:** Thermochemical hotspots in the crust	30
12:30	**Poster Presentations 7–12**	
12:35	Lunch	
	SESSION 3: GEOCHRONOLOGY AND GEOCHEMISTRY (CHAIR: SHEREE ARMISTEAD)	
13:30	**Jack Gillespie**: Beyond zircon: one billion years of tectonic history resolved by apatite double dating of the western Siberian margin	41
13:45	**Gilby Jepson**: Deciphering central Asian mountain building; a thermochronology approach	46
14:00	**Nicholas Fernie**: Apatite fission track thermal history of the Bole-Nangodi shear zone (northern Ghana, west African Craton): insights into equatorial Atlantic rifting	39
14:15	**Bradley Cave**: U-Pb Geochronology and Trace Element Analysis of Apatite and Calcite from the Ernest Henry Deposit, NW Queensland	31
14:30	**James Hewett:** Distribution of gold and the relationship to pyrite trace element geochemistry at the Ernest Henry Deposit, Queensland	44
14:45	**Poster Presentations 13–18**	
14:50	Afternoon Tea	
	SESSION 4: PALAEOCLIMATE (CHAIR: SIAN HOWARD)	
15:15	**Haidee Cadd**: A multi-proxy assessment of millennial scale climate variability and environmental change in sub-tropical Australia	32
15:30	**Georgina Falster:** Environmental implications of oxygen isotopes in Australian land snail shells	38
15:45	**Christopher Kemp**: A new ~230,000 year Australian record: Fern Gully Wetland, north Stradbroke Island	48
	SESSION 5: HYDROGEOLOGY (CHAIR: ROMANA DEW)	
16:00	**Chris Li:** Improving next-generation hydrogeological models with nuclear magnetic resonance and electromagnetics	47
16:15	**Kelsey Tarabini:** Assessing the use of temperature time series to quantify ground water recharge	59
16:30	**Nathan Teder:** Wind driven upwelling off the Gippsland coast	60
16:45	**Tom Anderson:** Hydrogeological sensitivity to drought conditions in a perennial creek system, Mt Lofty Ranges, South Australia	26
17:00	**Poster Presentations 19-22**	
17:05	Closing remarks	
17:10	Drinks and poster session	
17:45	Awards presentation	

PARTNERS

The Geological Survey of South Australia

Venue Partner

Government of South Australia
Department of the Premier and Cabinet

Geoscience data maximising opportunities for mineral exploration and discovery

The Geological Survey of South Australia (GSSA) acquires and delivers precompetitive geoscience data to reduce the risks associated with mineral exploration in the state.

The *GSSA Discovery Day 2017* showcases the latest innovative work of the GSSA and key collaborators, including the Deep Exploration Technologies Cooperative Research Centre (DET-CRC), CSIRO, the University of South Australia and the University of Tasmania.

The program covers four themes, based on the national geoscience initiative, UNCOVER:

- Mineral systems: new ideas, samples and technology
- South Australian commodities and characterising the cover
- Lithospheric architecture: new views of cratonic South Australia
- Distal mineral footprints

Keynote addresses:

- Sandi Occhipinti (Centre for Exploration Targeting, University of Western Australia) – *Multiscale targeting: a mineral systems toolbox*
- Colin Card (Saskatchewan Geological Survey) – *Lessons from the Athabasca Basin: uranium in basement and basin*
- Kathy Ehrig (BHP) – *How close to Olympic Dam do you need to be to know you are close to Olympic Dam?*

Other addresses include:

- Preliminary results of the Coompana drilling project
- Overviews of South Australia's mineral commodities
- Crustal boundaries of the Gawler Craton
- Alteration and geochemical features of the eastern Gawler Craton

The *GSSA Discovery Day 2017* Exhibition will feature opportunities to:

- See the DET-CRC Coiled Tubing Drill Rig on the floor of the Convention Centre
- Inspect some of the new drill core from the Coompana drilling program
- See the regolith rock display and new regolith mapping
- View new results and equipment from AusLAMP Magnetotellurics deployment

Discovery Day is an opportunity to discover new data, obtain new insights and new opportunities – and to make connections within the South Australian geoscience community.

GSSA Discovery Day is followed by the South Australian Exploration and Mining Conference (SAEMC) www.saexplorers.com.au on Friday 8 December at the Adelaide Convention Centre. The conference provides updates on significant mineral exploration and mining developments and new insights into emerging projects in the state, with the associated exhibition including poster presentations by under-graduate and post-graduate students.

In addition to the technical presentations, SAEMC presents opportunities for networking to explore business opportunities within the resource sector and engage with service providers.

Investigator Resources

Diamond Partner

A research-based approach to minerals discovery

In keeping with its name, Investigator Resources Limited is a South Australian-focussed minerals explorer that applies innovative ideas and techniques to its targeting. Despite its small size, the company has manoeuvred itself into large discovery territory. Investigator has recognised two new deposit styles in the Gawler Craton during the past six years — epithermals and porphyries of interpreted Olympic Dam age at the Paris silver project and Nankivel copper-gold prospect nearby.

There is a need for Australia to reboot the country's discovery rate by challenging stale dogma with co-ordinated research. In doing its bit, Investigator has been a strong supporter of the national Uncover initiative, the local “Source to Spectrum” ARC Linkage project and research collaborations with several PhD students and the Geological Survey of South Australia ('GSSA') on the Paris and Nankivel mineral systems.

One such development by the University of Adelaide led to the government's use of magneto-tellurics ('MT') to remap the Olympic Dam iron-oxide copper gold ('IOCG') metallogenic corridor, now interpreted to extend towards the Paris-Nankivel area.

Investigator's research model proposes a 300-kilometre-wide volcanic 'caldera' basin of Gawler Range Volcanics ('GRV'). Olympic Dam and Paris-Nankivel are on the respective northern and southern faulted margins. By applying accurate dating done by the GSSA and review of historic drill holes, the hypothesis has the highly explosive fluorine-rich event generating a distinctive marker unit between the Lower and Upper GRV. This may laterally link the OD IOCG belt to the Paris-Nankivel mineralisation at the same time of around 1589Ma.

Investigator's discoveries and interpretations challenge accepted views that porphyry deposits cannot concurrently form in the same setting as IOCG deposits. Collaborative research is underway with the GSSA and universities for more geochemical and accurate dating work in the Paris-Nankivel field. Initial results are positive for the model with preceding subduction-related intrusives becoming more likely at Paris-Nankivel.

The model also upgrades the prospectivity of the intervening MT corridor where Investigator has proposed the Maslins copper-gold target as a candidate for the next generation of IOCG discoveries.

It may take years or even decades for all the science to come in and establish whether the new thinking is entirely correct, but Investigator as a first-mover has immediately acted on the exciting ideas. These are likely to greatly improve the odds of major discoveries when backed by the latest science and determined exploration in the field.

Minotaur Exploration

Diamond Partner

Minotaur Exploration Ltd (ASX:MEP) is an ASX-listed mineral exploration company - a dedicated copper-gold explorer with a focus on Iron Oxide Copper-Gold (IOCG) style targets and Iron Sulphide (ISCG) variants. Our research is directed to locating 'blind' deposits that underlie thick sequences of cover rocks, relying on a variety of geophysical techniques to 'see' through the cover, into basement formations to pinpoint targets worthy of drill testing. Regions of focus within Australia for IOCG and ISCG style mineralisation include the Cloncurry terrane of western Queensland and South Australia's Gawler Craton.

Minotaur is in the midst of a period of intense exploration activity at three such projects, viz: drilling of ISCG targets south of the Eloise copper-gold mine (Cloncurry); drill testing of newly generated ISCG targets along the Skylark Shear Zone north of the Prominent Hill IOCG mine (Gawler Craton); and target generating geophysical surveys south of the Osborne copper-gold mine (Cloncurry). The Company continually researches new project opportunities in these districts, and elsewhere. A diversity of projects, project partners, geological domains and regulatory jurisdictions are considered critical to providing the Company with a risk-balanced approach to the business of on-the-ground exploration.

At each of Eloise and Prominent Hill Projects, initial Proof of Concept of new ISCG models has been achieved with intercepts of pyrrhotite-chalcopyrite mineralisation intersected by recent drilling. Fine tuning of the targeting methodologies and associated drill testing are now underway with the aim of proving the presence of economic grades of copper and gold.

Minotaur also holds development-ready resources of industrial minerals – kaolin, halloysite, and gypsum where ongoing research partnerships into new technology applications, such as natural nanotube replacement of carbon nanotubes, are seeking new commercialisation opportunities.

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We are a Modern Mining Company creating value through operating a lean business with a copper core, a customer focus and having multiple assets.

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- West Musgraves, an earn-in exploration project in the Musgraves Province of Western Australia
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Find out more about what we do at www.ozminerals.com

Burea Veritas

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Bureau Veritas Minerals are industry leaders in the provision of high quality laboratory services, specialising in geoanalytical testwork, mineral processing, extractive metallurgy, mineralogy, spectral analysis and more.

We have extensive operations throughout Australia providing services to the exploration & mining industry for a broad range of resources and commodities.

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DET CRC

Topaz Partner

A revolutionary new drill rig that could revitalise Australia's mining industry – The RoXplorer® – has excelled in its second major field trial, readying it for licencing and potential commercialisation later this year.

The prototype coiled tubing (CT) drill rig, developed by the Deep Exploration Technologies Cooperative Research Centre (DET CRC), underwent the trial during May and June 2017 in the Murray Basin near Horsham, Victoria.

View the results of these trials via the DET CRC website here - http://detcrc.com.au/2017/september-2017-det-crc-technical-press-release-roxplorer-coiled-tubing-drill-rig-successfully-drills-consolidated-unconsolidated-cover-rocks-basement-delivers-representative-sample/

Olympus

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Olympus is a world-leading manufacturer and distributor of high quality analytical, optical and precision engineering products, for geochemical, scientific and industrial applications. The Olympus industrial leading edge testing technologies include X-ray fluorescence, X-ray diffraction, remote visual inspection, ultrasonic testing and microscopy. Olympus products provide reliable, economical inspection systems that enhance safety, security, and productivity for our customers.

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Ph 1300 132 992

The Environment Institute

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The Environment Institute exists to deliver outstanding research across environmental sciences.

By understanding patterns and processes to derive solutions, we help enable decision-making that can meet todays and future needs.

This work is being carried out against a background where the current state of the environment is an international priority. This requires us to develop and implement solutions for its health, our wellbeing and to sustain our economy.

To help do this the Institute puts water, climate and earth scientists together with biodiversity, marine, landscape and genetics work, and more. We are doing this at a time when our capabilities to research and understand the issues we face are growing exponentially.

Petroleum Exploration Society of Australia (PESA)

Topaz Partner

The Petroleum Exploration Society of Australia is a non-profit association of individuals involved in the exploration of oil and gas.

The purpose and objectives of PESA are:

- to promote professional and technical aspects of the upstream petroleum industry throughout Australia by providing a medium for gathering individuals interested in oil and gas exploration
- To present views and discuss technical and professional matters relating to the upstream petroleum industry
- to foster and provide continuing education for the benefit of members
- to maintain a high standard of professional conduct on the part of its members
- to promote and encourage university research in petroleum exploration geoscience through Federal and State Branch scholarship programs

For more information visit: www.pesa.com.au

Site Map

1 Administration Building

Innovyz & CoHABCo-working Space
Mitsubishi Motors Australia Ltd
SAFKI Medicare Local
Signostics
Tonsley Project Office

2 Bedford Medical Centre

3 Flinders @ Tonsley - T1

School of Computer Science, Engineering & Mathematics
Centre for Nanoscience & Technology
Flinders Partners
Hills Limited
New Venture Institute
Medical Device Research Institute

4 Flinders Pod – T2

5 Mitsubishi Motors Australia Ltd

6 Siemens

7 State Drill Core Reference Library

8 SIEC -(Sustainable Industries Education Centre)

Hegs Pegs
OPCE Training Facility
TAFE SA
Zen Energy Systems

9 Line Zero

10 Town Square + Retail Precinct

11 Western Plant - Mitsubishi Motors

12 Western Plaza (Stage 1)

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P Carpark
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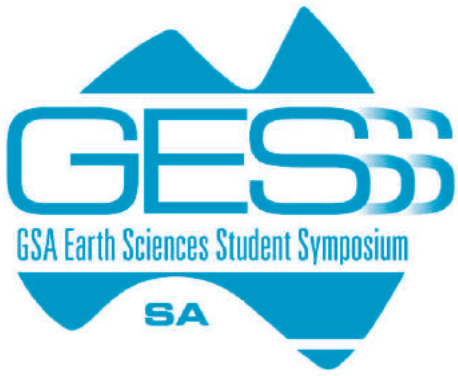
SOUTH AUSTRALIA
Government of South Australia

ABSTRACT VOLUME



ON YODERITE: USING CALCULATED PHASE EQUILIBRIA TO INVESTIGATE ITS RARITY IN THE GEOLOGICAL RECORD OF WHITESCHISTS

Brandon L. Alessio[1], David Kelsey[1]

[1]Centre for Tectonics, Resources and Exploration (TRaX), Department of Earth Sciences, The University of Adelaide, SA 5005, Australia

Email address: brandon.alessio@adelaide.edu.au

We present a new activity–composition model for yoderite for use in the latest internally consistent thermodynamic dataset used by THERMOCALC, for calculations primarily in $MgO–Al_2O_3–SiO_2–H_2O–O$ system, where O is a proxy for Fe_2O_3. *P–T* grids calculated with our model in the MASH and MASHO system feature invariant points and univariant reaction bundles that are consistent with existing experimental results. Using this new model we have explored the stability of yoderite in whiteschists, a rare type of high pressure rock that conforms closely to the MASHO system. Using a series of calculated models in which composition varies, we show that yoderite stability is a function of bulk rock SiO_2, MgO, and Al_2O_3, where the most important component for stabilising yoderite is a function of pressure and temperature. The rarity of yoderite in naturally occurring whiteschists is largely related to these compositional factors, with most whiteschists having rock compositions that are too SiO_2-rich and Al_2O_3-poor to allow yoderite formation. However, in addition to compositional factors, the calculated *P–T* stability field of yoderite occurs over thermal gradients that are generally too high to occur in modern-style subduction zones. As nearly all known whiteschist occurrences are Phanerozoic in age, the near complete absence of yoderite in late-Neoproterozoic–Phanerozoic whiteschists may be at least partially due to modern subduction systems failing to produce the hotter thermal gradients needed to stabilize yoderite. The provision of this new *a–x* model for yoderite allows for more rigorous *P–T–X* investigations of all whiteschists.

Keywords: Yoderite, THERMOCALC, Whiteschist, pseudosection

HYDROGEOLOGICAL SENSITIVITY TO DROUGHT CONDITIONS IN A PERENNIAL CREEK SYSTEM, MT LOFTY RANGES, SOUTH AUSTRALIA

Thomas A. Anderson[1], Erick A. Bestland[1], Lesja Soloninka[1], Ilka Wallis[1], Peter Kretschmer[2], Markus M. Pichler[1], Edward W. Banks[1]

[1]College of Science and Engineering, Flinders University, Adelaide 5001, Australia
[2]Department of Environment, Water and Natural Resources (DEWNR), 5000, Australia
Email address: tanderson@flinders.edu.au

Understanding the hydrological sensitivity of perennial streams to drought conditions is essential to prepare for the associated post-drought hardships that are inevitable South Eastern Australia. These types of streams, which are defined as having continuous surface flow throughout the year, except in cases of severe drought, are critically important to the freshwater ecosystem stability. This is because they provide important ecological refuge during periods of low rainfall and surface runoff. The record breaking drought conditions that occurred between 1997 and 2006 has provided a rare opportunity to investigate hydrological sensitivity of perennial streams. Hydrological and hydrogeological data from Scott Creek Catchment, a perennial stream within a heterogeneous fractured rock aquifer in the Mt Lofty ranges of South Australia was reported. A conceptual model was developed to investigate the hydrochemisty in surface water and groundwater at this location. Statistical analysis of flow and salinity data of Scott Creek over a 27 year period, from 1989 to 2016 was undertaken. Surface water samples were collected on a monthly interval before and after the experienced drought conditions at a continuously monitored gauging station at the base of the catchment. Additional samples were collected longitudinally at 19 locations along the river and at 54 groundwater monitoring bores over a 3 year period. These samples were analysed for major and trace elements, stable isotopes of water and stable isotopes of strontium. The results indicated that groundwater from specific geological strata discharged into the creek. The findings determined that the severity of drought conditions imposed a dominant groundwater input signature to the stream's chemical composition. This has enabled contributions to the stream at particular locations within the catchment to be determined. Therefore, compartmentalising the mechanisms responsible for the chemical composition of these types of streams can assist in managing water sources now and into the future.

Key words: Salinisation, groundwater/surface-water interactions, strontium isotopes, environmental tracers, geostatistics

DIETARY DIVERSITY IN PLEISTOCENE KANGAROOS OF SOUTH-EASTERN AUSTRALIA

Samuel D. Arman[1] and Gavin Prideaux[1]
[1]College of Science and Engineering, Flinders University, South Australia 5042, Australia
Email address: samuel.arman@flinders.edu.au

Kangaroos (family Macropodidae) are the dominant vertebrate herbivores of modern Australia, and were even more diverse and abundant during the Pleistocene. There were two main lineages: sthenurine kangaroos, which have mostly been considered dicot leaf browsers, and macropodine kangaroos, considered predominantly grazers. The reliance of sthenurines on browse has been implied by some as a principal reason for their extinction through climate change. Hypotheses regarding these adaptations though are based almost entirely on morphology, rather than more direct dietary inference.

Here we investigate the diets of kangaroos through Dental Microwear Texture Analysis. This method operates by considering the impacts that food make on tooth enamel as animals chew their food. Physical characteristics of different foods, alongside grit adhering to, and phytoliths within foods, alter markings produced on tooth enamel during occlusion. To analyse these markings, high-resolution 3D scans are taken of the molar wear facets. Algorithms are applied to scans to quantify differences in surficial characteristics, and have been shown in numerous mammalian groups to distinguish between species with different diets. In addition general linear mixed-modelling was used to incorporate intraspecific factors into models of differences between species. This method includes factors in models only when they can improve the ability of the model to describe the data. Models generated indicated a small number of factors, including facet scanned and ecoregion of specimen origin to have the greatest effect on microwear data. Most important, however, appeared to be the inclusion of each specimen modelled as a random effect, likely to encapsulate natural inter-individual variation.

Diets of the diverse middle Pleistocene macropodid fauna sampled in the Victoria Fossil Cave assemblage, were compared with a large extant baseline, to consider diets of Pleistocene kangaroos. We find that sthenurine species were predominantly browsers, but that some were strict browsers while others had mixed diets. Pleistocene macropodines also evince more mixed feeding microwear signatures than their modern counterparts, which may reflect significant dietary plasticity in response to environmental change. It seems unlikely that broad changes in climate or flora can alone account for the extinction of all species of sthenurine kangaroos given the dietary breadth of the group and the range of habitats and regions that they occupied.

Keywords: Palaeontology, Palaeodiet, Dental Microwear, Quaternary, Macropodidae

THE GEOCHRONOLOGY OF THE BOUCAUT VOLCANICS

Rachel A. Atkins[1], Sheree E. Armistead[1], Alan S. Collins[1], Grant Cox[1], Solomon Buckman[2]
[1]Department of Earth Sciences, School of Physical Sciences, The University of Adelaide, SA 5005, Australia
[2]Department of Earth and Environmental Sciences, University of Wollongong, Northfield Avenue, Wollongong, NSW 2522
Email address: a1704558@student.adelaide.edu.au

The Boucaut Volcanics are an isolated outcrop located in the Flinders Ranges, consisting of rhyolitic and basaltic rocks. Previously, the geochronology of the volcanic rocks had been broadly constrained to the Cryogenian Period, with a reported age of c. 777 Ma. However, the age obtained for this unit was poorly constrained as it was not accompanied by published isotopic data. Therefore, the Boucaut Volcanics are yet to be robustly dated. Constraining the regional stratigraphy of the Flinders Ranges region is dependent on the precise age of the volcanics. Zircons are an excellent geochronological material used to date rocks by their U-Pb decay system. We have used zircon U-Pb geochronology and zircon trace element geochemistry (LA-ICP-MS) from a rhyolite sample from the Boucaut Volcanics to constrain the timing of crystallisation of these volcanics. These new data will provide further age constraints for the regional stratigraphy of the Flinders Ranges.

Keywords: Boucaut Volcanics, U-Pb geochronology, LA-ICP-MS, Flinders Ranges

PIECES OF THE PENGUIN PUZZLE: INSIGHTS FROM A NOVEL BASAL PALEOCENE PENGUIN, CHATHAM ISLAND, NEW ZEALAND

Jacob C. Blokland[1], R. Paul Scofield[2], Alan J. D. Tennyson[3], Catherine M. Reid[1]
[1]Department of Geological Sciences, University of Canterbury, Christchurch 8140, New Zealand
[2]Canterbury Museum, Rolleston Avenue, Christchurch 8050, New Zealand
[3]Museum of New Zealand Te Papa Tongarewa, P.O. Box 467, Wellington, New Zealand
Email address: jacob.blokland@gmail.com/ jacob.blokland@pg.canterbury.ac.nz

The origin and radiation of crown group birds during the Late Cretaceous and Early Cenozoic is a subject of ongoing debate in palaeontology and molecular biology [1, 2]. Numerous skeletal remains recovered *in situ* from the late Early to Middle Paleocene Takatika Grit of Chatham Island, New Zealand, are among the oldest known fossils attributed to the penguin clade (Sphenisciformes). These fossils are thus of significant relevance to the understanding of archaic penguins, as well as early neoavian waterbird evolution, and neornithine radiation in the aftermath of the K/Pg mass extinction. The penguin fossils are represented by several specimens of a single taxon, two of which were subject to X-ray computed tomography and subsequent examination using *Materialise Mimics* software, to allow for virtual manipulation of the fossils in a three-dimensional space. Morphologies of selected elements were compared to those of extinct and extant bird relatives using morphometric and Principle Component Analysis. Additional morphological character scoring of the fossils was conducted, which was assimilated into an updated phylogenetic matrix of Sphenisciformes (8426 characters, 81 taxa), to consider the fossils in the context of a phylogenetic framework. As a medium-sized, novel penguin taxon, these fossils are phylogenetically more derived than *Waimanu*, but are still recovered in a relatively basal position in Sphenisciformes. Interpreted as one of the most primitive known wing-propelled divers amongst Sphenisciformes, morphologies observed in these fossils are consistent with a model of penguin evolution in which early penguins diverged from volant ancestors and specialised for the aquatic environment [3]. This novel Chatham Island taxon adds to the growing number of Paleocene penguins, and would have existed at the same time as *Waimanu* [4], and the recently recognised giant penguin from Waipara Greensand [5]. Morphological disparity between taxa additionally provides evidence of a relatively large diversity of penguin taxa in the Eastern New Zealand region, during the late Early to Middle Paleocene, supporting claims [5] that the origin of the penguin clade may be older than suggested molecular divergence estimates of the Middle Paleocene [6, 7].

Keywords: Palaeontology, Fossil birds, Sphenisciformes, *Waimanu*, Takatika Grit, Chatham Islands

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THERMOCHEMICAL HOTSPOTS IN THE CRUST

Kiara L. Bockmann[1], Martin Hand[1], David E. Kelsey[1], Laura J. Morrissey[2], Megan A. Williams[1]
[1]Department of Earth Sciences, University of Adelaide, Adelaide, SA 5005, Australia
[2]School of Natural and Built Environments, University of South Australia, GPO Box 2471 Adelaide, SA 5001 Australia
E-mail address: kiara.bockmann@adelaide.edu.au

High-temperature–low-pressure (HT–LP) crustal geologic environments that reach granulite-facies conditions have extreme energy requirements that sustain rapid changes in temperature with depth. Generally these requirements either demand that the lithosphere had been significantly thinned, that metamorphism was accompanied voluminous magmatism or that high geothermal gradients were generated during rapid exhumation of hot, deeply buried rocks. However, it is beginning to be recognised that in some regions the concentration of heat producing elements contained in metasedimentary and granitic reservoirs may be sufficiently high to generate high grade metamorphism at comparatively shallow depths [1, 2]. Furthermore, high geothermal gradient terranes largely heated by internal heat sources will only cool significantly if they are exhumed, meaning that metamorphism resulting from this type of heating can potentially continue for huge periods of time.

One of the challenges in deciphering the duration of long-lived, high-grade metamorphic events is that within the high-grade areas the prograde evolution and geochronology are largely destroyed or obscured. The records held by accessory minerals that are often used for dating are biased towards the end of thermal evolution, due to their physiochemical behaviours governed largely by melt crystallisation.

This study is focussed on the Reynolds Range in central Australia, which records metamorphism from greenschist to granulite facies and is characterised by higher than average crustal heat flow. The geochronology and geochemical data obtained in this study, as well as previous studies in this area, suggests that HT–LP anatectic conditions were maintained here for a period greater than 100 Ma, and that radiogenic heating may largely be behind this extended period of metamorphism.

U-PB GEOCHRONOLOGY AND TRACE ELEMENT ANALYSIS OF APATITE AND CALCITE FROM THE ERNEST HENRY DEPOSIT, NW QUEENSLAND

Cave W. Bradley[1], Lilly. Richard[1], Glorie. S[1]
[1]Department of Earth Sciences, Mawson Building, University of Adelaide, SA 5005, Australia.
Email address: bradley.cave@student.adelaide.edu.au

The Ernest Henry deposit represents the largest known Iron Oxide Copper Gold (IOCG) deposit in the Eastern Succession of the Mount Isa inlier, NW Queensland. The orebody consists of a structurally controlled pipe-like breccia hosted in complexly altered Proterozoic volcanics. The breccia hosted ore-assemblage of chalcopyrite and free gold includes calcite and accessory apatite. At depth, the orebody is divided into two distinct lenses by a low-grade zone termed the Interlens. This structurally controlled, deformed package is host to coarse-grained apatite, which is brecciated by a mineralogy comparable to economic mineralization. The U-Pb geochronology via the in-situ laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) method allows for the U-Pb dating of apatite and calcite [1][2], whilst providing the opportunity to examine the trace element composition of the minerals, which can be used to constrain the source of the minerals and metasomatic processes [3].

This study has generated evidence that the apatite from the Interlens formed at 1581 ± 16Ma, consistent with regional peak metamorphic conditions and D_2 deformation during the Isan Orogeny. Ore-stage apatite sample produced an age of 1529 ± 39Ma, coeval with the accepted date for sulphide mineralisation and a later D_3 deformation event. Trace element analysis on apatite indicate metasomatism and coupled dissolution re-precipitation reactions were induced by a Na and/or Ca rich fluid, possessing varying amounts of Cl and S.

The U-Pb calcite dating method used in this study is viable for future use, however calcite from the Ernest Henry deposit is unsuitable for U-Pb dating as it is dominated by common lead. Trace element analysis of calcite geochemically links calcite from the Interlens to calcite from the nearby E1 deposit. This is the first time that the paragenetic events in the two deposits have been directly linked through geochemistry and demonstrates that the hydrothermal system responsible for the later calcite generation extends spatially for at least 8km.

Key words: Ernest Henry, Apatite, Calcite, U-Pb geochronology, IOCG, Trace Elements, Metasomatism.

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A MULTI-PROXY ASSESSMENT OF MILLENNIAL SCALE CLIMATE VARIABILITY AND ENVIRONMENTAL CHANGE IN SUB-TROPICAL AUSTRALIA

Haidee R. Cadd[1,2,3], Jonathan Tyler[1], John Tibby[2], Cameron Barr[2], Melanie Leng[3], Jeff Baldock[4]
[1]Department of Earth Sciences, The University of Adelaide, SA, Australia
[2]Department of Geography, Environment and Population
[3] NERC Isotope Geosciences Facilities, British Geological Survey, Nottingham, Centre for Environmental Geochemistry, University of Nottingham, Nottingham, UK
[4] CSIRO Agriculture, Urrbrae, SA, Australia
Email address: haidee.cadd@adelaide.edu.au

Terrestrial records that detail environmental and hydroclimate variability from mainland Australia that extend beyond the Last Glacial Maximum (LGM) are rare. This paucity of terrestrial archives is further hampered by poor age constraints and low sample resolution. Here we present a high-resolution, well-dated, multi-proxy sedimentary record covering the past ca. 100,000 years from Welsby Lagoon, North Stradbroke Island, south-eastern Queensland. The Welsby Lagoon chronology has been developed from 21 OSL ages and 20 ^{14}C dates and spans the regionally significant periods of Marine Isotope Stage (MIS) 3 and the LGM. Large scale centennial scale climate variations are evident in the carbon isotope ($\delta^{13}C$) and total organic carbon (TOC) records. Pollen based vegetation reconstruction, together with high resolution XRF elemental profiles and macroscopic charcoal are used to assess broader landscape scale environmental change in relation to human arrival and megafauna extinction. This record has the potential to provide an advancement in our understanding of millennial to centennial scale climate and ecological variability during significant time periods in subtropical Australia.

Key words: paleoecology, paleoclimatology, megafauna, MIS3, pollen, isotopes, charcoal, wetland

A QUANTITATIVE ANALYSIS OF SKULL GROWTH AND EVOLUTION IN SEA TURTLES (TESTUDINATA: CHELONOIDEA)

Ray M. Chatterji[1,2], Mark N. Hutchinson[1,2], and Marc E. H. Jones[1,2]
[1]School of Biological Sciences, University of Adelaide, Adelaide, South Australia, Australia 5005
[2]Australia South Australian Museum, Adelaide, Adelaide, South Australia, Australia, 5005
Email address: ray.chatterji@adelaide.edu.au

Sea turtles have an extensive fossil record but the macroevolution of their life habits and ecology remain poorly known. The phylogenetic affinity of several fossil taxa is also uncertain. Progress on both these topics is hampered by limited knowledge of the variation within extant species. Sea turtles show marked changes in skull shape during post-hatching ontogeny, though this has not been explored amongst extinct taxa. Using a sample of over 30 skulls representing all 7 extant species at a variety of growth stages, X-ray computed tomography, and 3D geometric morphometrics, we investigated the ontogenetic shifts in skull morphology. General trends are similar to those seen in the ontogeny of skull shape of other tetrapod groups, with orbits showing negative allometry and trophic structures showing positive allometry. The extent of divergence away from the hatchling morphology varies among the species. We confirmed the findings of previous studies that *Dermochelys coriacea* is paedomorphic in many respects, adults retaining skull structure and proportions that are closer to those of hatchlings than is the case in other sea turtles. Among the typical, cheloniid sea turtles, we found that *Natator depressus* showed some paedomorphic features, while the skull of *Caretta caretta* displayed hypermorphosis. Heterochrony appears to play an important role in the evolution of sea turtle skull shape. The skull shape of hatchlings better reflected the molecular phylogeny of the group than did the skull shape of adults. These results suggest that the post-hatchling changes we observed in skull and jaw shape are driven by diet specialisation rather being constrained by phylogenetic relatedness. This dataset provides a framework to better asses the ecological and phylogenetic affinities of fossil sea turtles.

Key words: Chelonoidea, Geometric Morphometrics, Skull Shape,

THE LATE DEVONIAN GOGO FORMATION LÄGERSTATTE AND ITS SPECTACULARLY-PRESERVED 3D FOSSIL FISH FAUNA

Alice M. Clement[1,2], Kate Trinajstic[3], Per E. Ahlberg[4], & John A. Long[1]
[1] College of Science and Engineering, Flinders University, SA 5042, Australia
[2] Department of Sciences, Museum Victoria, VIC 3001, Australia
[3] Environment and Agriculture, Curtin University, WA 6102, Australia
[4] Department of Organismal Biology, Uppsala Universitet, Uppsala 752 36, Sweden
E-mail address: alice.clement@flinders.edu.au

The Late Devonian (Frasnian) Gogo Formation of northern Western Australia preserves an exceptional three-dimensional fauna containing fish and crustaceans from the "Age of Fishes". The vertebrate fauna is particularly well studied and especially diverse with close to 50 species described. Some highly significant recent discoveries include the oldest known vertebrate embryos, placoderm pelvic claspers used for internal fertilisation, the oldest transverse abdominal muscles, exceptional soft tissue preservation and a stem-tetrapod with limb bones and possible air-breathing capability. I herein discuss several of my current and ongoing projects working on the exceptional Gogo fossils.

The lungfish fauna is particularly diverse with 11 species described. As sister taxa (the closest living group) to tetrapods (all land animals), this group provide unique insight into our very own ancestors. The most recently described lungfish species, *Rhinodipterus kimberleyensis* Clement 2012, extended the known biogeographic range of this genus outside of Europe for the first time. Since then, *R. kimberleyensis* has been central to work investigating neural evolution, as well as the evolution of air breathing in lungfishes.

Other current projects include the description of the first coelacanth known from Gogo and an investigation into dentition in placoderms. Coelacanths are an enigmatic group that was once thought to have gone extinct 70 million years ago. Today there are just two extant species remaining since first appearing in the Early Devonian. A new taxon from Gogo represents only the seventh Devonian coelacanth known from extensive remains, and is only the second specimen preserved in 3D. The new specimen reveals unprecedented detail of the internal cranial anatomy and provides evidence of the early brain anatomy of this group.

Placoderms are a group of armour-plated fish that once ruled the seas but went extinct at the end Devonian. Long thought to be an evolutionary dead-end, recent work now suggests they are stem-gnathostomes from which all osteichthyans (bony vertebrates including ourselves) evolved. I am currently involved in a project that reveals evidence for tooth addition and resorption in placoderms, before it was present in the bony vertebrates. This is contrary to the historical view that placoderms did not possess 'true' teeth.

Key words: palaeontology, evolution, Devonian, early vertebrates, 3D modelling, microCT, gnathostomes, fossils

COLD SUBDUCTION ON THE AVALONIAN MARGIN

Larissa J. Collins[1], Renée J. Tamblyn[1], Martin Hand[1]
[1]Continental Evolution Research Group, (CERG) Department of Earth Sciences, The University of Adelaide, SA 5005, Australia
Email address: larissa.collins@adelaide.edu.au

Anglesey in North Wales is considered to contain the oldest exposures of lawsonite-glaucophane blueschist in the world, marking the first appearance of lawsonite in the geological record, and heralding the emergence of truly modern subduction thermal regimes. The blueschists formed in the late Neoproterozoic during subduction beneath Avalonia. Interlayered within the blueschist unit are rare lenses of garnet-bearing metapelite that form part of a lithological association with more voluminous garnet-free metapelites. Detrital U-Pb zircon geochronology of the metapelites indicates that deposition of the protolith occurred ~630-590 Ma ago. The dominant detrital zircon ages correspond to the age of arc magmatism along the inferred margin of Avalonia, suggesting that the bulk of the detritus was derived from erosion of the arc. The presence of less abundant older zircons that range in age up to 2Ga, suggest that the arc was built on an ancient continental margin. This suggestion is supported by Nd isotopic compositions of the metapelites, which indicate derivation from an evolved source.

The rare garnet metapelites contain the metamorphic assemblage garnet-muscovite-chlorite-albite-quartz-titanite-rutile in which coronas of rutile surround titanite. Mineral equilibria forward modelling of the metapelites indicates a prograde burial path that culminated with conditions around 400-450°C at pressures of 10-12kbar. These conditions give an average thermal gradient of around 40°C/kbar, which is comparatively warm for lawsonite-bearing rocks. This suggests the Anglesey lawsonite-bearing blueschists record the onset of global subduction thermal regimes in the late Neoproterozoic that can stabilise lawsonite, rather than simply being a fortuitous preservation of widely developed refrigerated metamorphic rock systems.

Key words: Anglesey, lawsonite, blueschist facies metapelite, geochronology, mineral equilibria forward modelling

THE INFLUENCE OF REVERSE-REACTIVATED NORMAL FAULTS ON NATURAL FRACTURE GEOMETRIES AND CHRONOLOGIES IN SANDSTONES: A CASE STUDY AT CASTLE COVE, OTWAY BASIN

Natalie Debenham[1], Simon Holford[1], Rosalind King[1], David Tassone[1]
[1]The University of Adelaide, SA 5005, Australia
Email address: natalie.debenham@adelaide.edu.au

Basin inversion is one of the most significant modes of compressional intraplate deformation and has fundamental implications for the prospectivity of petroleum producing basins. Inversion is mainly accommodated by the contractional reactivation and reversal of pre-existing extensional faults. Whilst there have been many previous studies of the large scale geometrical characteristics of fault reactivation during basin inversion, there is little data on the properties of damage zones associated with these faults. We present results from a detailed structural investigation of a well exposed fault system within the Otway Basin at Castle Cove, southeast Australia. Castle Cove provides excellent exposures of the Lower Cretaceous Eumeralla Formation, which is a porous and fine-grained volcanogenic sandstone. The Castle Cove Fault is a 30 km long, NE–SW striking fault. The fault initiated as a normal fault during the late Cretaceous and was subsequently reverse-reactivated during Miocene to Pliocene compression. We assess the influence of the fault displacement history on damage zone characteristics by undertaking detailed structural mapping and collecting structural data for 973 fractures. Structural mapping within the fault damage zone reveals a complex tectonic history recording both regional and local perturbations in stress and a total of 11 fracture sets were identified. Up to five of these fracture sets are geometrically related to the Castle Cove Fault. This study highlights the need to conduct careful reconstruction of the structural histories of faults that experienced complex reactivation histories when attempting to define off-fault fluid flow properties.

Keywords: Fault damage zone, reverse-reactivated fault, Castle Cove, Otway Basin

DEVELOPING NEW TOOLS FOR PALEOECOLOGICAL FOREST RECONSTRUCTIONS

Heather L. Duff[1], Francesca McInerney[1], Lucas A. Cernusak[2], Alexander Cheesman[2]
[1]School of Physical Sciences and Sprigg Geobiology Centre, University of Adelaide, Adelaide, 5005 Australia
[2]College of Science and Engineering, Centre for Tropical Environmental and Sustainability Studies, James Cook University, Queensland, Australia
Email address: heather.duff@adelaide.edu.au

The ability to identify forest architecture in the geologic past has implications for our understanding of palaeoecological processes. The degree of canopy closure (or density of foliage) effects surface albedo, atmospheric circulation and hydrologic cycling, which in turn, can influence terrestrial temperature and rainfall patterns[1]. Closed canopy forests are characterised by strong gradients in light intensity, which influence the chemistry and morphology of leaves. This study has used isotopic and morphological leaf traits from the modern closed canopy Daintree Rainforest in Queensland, which can also be measured from fossil leaves, to calibrate a multi-proxy tool that characterises the spatial distribution of light intensity. To quantify forest canopy closure, we measure leaf area index (LAI). We found that changes in carbon isotope ratios ($\delta^{13}C$), leaf mass per area (LMA), undulation index (UI) and cell area (CA) all have linear correlations with increasing LAI from the canopy to the understory. Therefore, these traits can be used as a proxy for reconstructions. However, the magnitude of responses varies between species. A portion of species are unresponsive in UI, therefore this proxy may not be suitable for all species. Traits of leaves from beneath a gap in canopy closure and those from a drought experiment, did not deviate from the general gradient seen with LAI. The leaf traits previously used to predict LMA (petiole width^2/ leaf area) did not correspond with measure LMA and did not produce results which characterise the gradient found within the Daintree rainforest[2]. However, they did predict the average LMA of a rainforest. Investigations into inter-trait variations demonstrate that $\delta^{13}C$, CA and UI correlate with LMA, and CA correlates with UI. Our results indicate several new leaf traits that can be used to identify the degree of shading in closed canopy forests in the fossil record, and demonstrate how light gradients drive variation within a forest.

Key words: paleobotany, carbon isotope ratios, canopy closure, rainforest, leaf cuticle

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ENVIRONMENTAL IMPLICATIONS OF OXYGEN ISOTOPES IN AUSTRALIAN LAND SNAIL SHELLS

Georgina M. Falster[1], Jonathan J. Tyler[1], Tobias Kluge[2]
[1]Sprigg Geobiology Centre, Department of Earth Sciences, The University of Adelaide, SA 5005, Australia
[2]Institute of Environmental Physics, Heidelberg University, Germany
Email address: georgina.falster@adelaide.edu

The oxygen isotope composition of precipitation ($\delta^{18}O_p$) in low-altitude areas of Australia is largely determined by rainfall amount[1,2]. Natural archives that preserve a $\delta^{18}O_p$ signature may therefore contain proxy information for past hydroclimate change. The $\delta^{18}O$ of terrestrial carbonate minerals ($\delta^{18}O_{carb}$) is one such archive, where $\delta^{18}O_{carb}$ reflects the temperature-dependent equilibrium fractionation between the source water (precipitation) and the carbonate mineral. One source of carbonate on land is snail shells: land snails precipitate their carbonate shell from bicarbonate dissolved in their body fluid, which in turn is derived from rain and dew that penetrates through the foot. The $\delta^{18}O$ of the snail shell ($\delta^{18}O_{shell}$) is therefore mainly controlled by $\delta^{18}O_p$, modulated by effects of evaporation at the soil surface, as well as the ambient temperature. Interpretation of the former two factors in terms of hydroclimate requires that the effect of temperature is deconvolved from the $\delta^{18}O_{shell}$ signal. A need therefore exists for independent estimates of temperature at the time of shell precipitation.

Carbonate 'clumped isotope' geochemistry is a new way of estimating the temperature of formation of carbonate minerals, and relies on the tendency for the heavy stable isotopes of oxygen and carbon to 'clump' together in a carbonate mineral. When carbonate precipitates in equilibrium, this tendency is temperature-dependent, and clumped isotope measurements can therefore be combined with $\delta^{18}O_{carb}$ to estimate the $\delta^{18}O$ of the carbonate source water.

Here we present the first investigation into the applicability of the carbonate clumped isotope thermometer to land snail shells from Australia, and discuss their utility as a hydroclimate proxy when combine with $\delta^{18}O_{shell}$ measurements. We combine eight new clumped isotope measurements on modern snail shells with $\delta^{18}O_{shell}$ measurements from a broad climatic gradient, and compare the results with observed climate data.

Key words: palaeoclimate, hydroclimate, carbonate, clumped isotopes

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APATITE FISSION TRACK THERMAL HISTORY OF THE BOLE-NANGODI SHEAR ZONE (NORTHERN GHANA, WEST AFRICAN CRATON): INSIGHTS INTO EQUATORIAL ATLANTIC RIFTING

Nicholas S. Fernie[a], Stijn Glorie[a,*], Mark W. Jessell[b], Alan S. Collins[a]
[a] Centre for Tectonics, Resources and Exploration (TRaX), Department of Earth Sciences, School of Physical Sciences, The University of Adelaide, Adelaide SA-5005, Australia
[b] Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia, Crawley, WA 6009, Australia
Email Address: nicholas.fernie@adelaide.edu.au

West Africa has been subjected to deformation and exhumation in response to Gondwana break-up. The timing and extent of these events are recorded in the thermal history of the margin. Apatite fission track (AFT) data were obtained from Palaeoproterozoic basement along the primary NE-SW structural trend of the Bole-Nangodi shear zone in northwestern Ghana. The results display bimodality in AFT age and length distributions, supported by differences in apatite chemistry (Cl and U concentrations). The bimodal AFT results and associated QTQt thermal history models provide evidence for two thermal events: (1) a Late Triassic – Early Jurassic thermal event, which may be related with the emplacement of the Central Atlantic Magmatic Province (CAMP) and (2) an Early Cretaceous cooling phase, which is thought to be associated with exhumation during the Early Cretaceous onset of rifting between West Africa and Brazil.

In addition, our data record differential exhumation of the crust with respect to the Bole-Nangodi shear zone, preserving older (CAMP) cooling ages to the south and younger (rifting) cooling ages to the north of the shear zone, respectively. This suggests that the Palaeoproterozoic BN shear zone has been reactivated during the Cretaceous as a result of deformation in the Equatorial Atlantic region of Africa.

Keywords: fission track thermochronology, Ghana thermal history, opening Atlantic Ocean, Central Atlantic Magmatic Province, West African Craton, fault reactivation.

DIGGING DEEP – THE LATE QUATERNARY FOSSIL FAUNA OF CATHEDRAL CAVE, CENTRAL EASTERN AUSTRALIA

Diana A. Fusco[1], Grant A. Gully[1], Kailah M. Thorn[1], Matthew C. McDowell[1] and Gavin J. Prideaux[1]

[1]Flinders University of South Australia, SA 5042, Australia.
Email address: diana.fusco@flinders.edu.au

The Wellington Caves, central eastern New South Wales, contain a ~4 million year palaeontological archive that extends from the Pliocene to the Holocene across multiple fossil sites. Fossils have been collected from Wellington Caves since the discovery of Australia's first extinct marsupial fossils at the caves in 1830. However, the usefulness of these historical collections has been limited by poorly documented fossil provenance data and a general lack of chronological and stratigraphic data. Current research is focused on the late Pleistocene and Holocene fauna of Cathedral Cave, where a new excavation is investigating faunal turnover alongside other climatic and chronological proxies. Excavations in Cathedral Cave are currently at 4.2 m depth, making it one of the deepest palaeontological digs in Australia. The excavation has uncovered a complex stratigraphy composed of 14 individual layers. Layers encountered include a heavily indurated floor over 1 m thick, processing of which is challenging but rewarding and yielding remains of megafauna species not previously recorded from Cathedral Cave. A rich and interesting assemblage of mammals, birds, reptiles and frogs is emerging from the Cathedral Cave sample.

Key words: palaeontology, palaeoecology, Wellington Caves, Pleistocene, Holocene, cave stratigraphy, marsupial fossils

BEYOND ZIRCON: ONE BILLION YEARS OF TECTONIC HISTORY RESOLVED BY APATITE DOUBLE DATING OF THE WESTERN SIBERIAN MARGIN

J. Gillespie[1], S. Glorie[1], G. Jepson[1], A. Khudoley[2], N. Priyatkina[2,3], A. S. Collins[1]

[1]Tectonics, Resources and Exploration (TRaX), Department of Earth Science, School of Physical Science, University of Adelaide, SA 5005, Australia

[2]Institute for the Earth Sciences, St. Petersburg State University, 7/9 University Nab., 199034, Russia

[3]New South Wales Institute for Frontiers Geoscience, University of Newcastle, Newcastle, NSW 2308, Australia

Email address: jack.gillespie@adelaide.edu.au

The Yenisey Ridge fold and thrust belt is a contentious and poorly understood region on the western margin of the Siberian Craton. This region records a geological history that is key to understanding the paleogeography of Siberia during the Neoproterozoic, with implications for the configuration of the Rodinian supercontinent. Competing hypotheses locate the Yenisey Ridge at either the centre of a Grenvillian age collision along the Siberian margin, or at a distance of up to 1000 km from the Siberian Craton during the early Neoproterozoic. Here we present a case study, integrating published zircon U-Pb data with new apatite U-Pb analyses, illustrating the power of complementary multi-mineral U-Pb analysis to resolve tectonic questions. Samples from throughout the stratigraphy of the region were analysed with these methods in an attempt to improve our understanding of the age and source of the units. We combine apatite U-Pb and fission track analysis with a characterisation of the trace and REE elements in individually dated grains to chart the thermotectonic evolution of the western Siberian margin over the last billion years.

The apatite U-Pb results presented here revise our understanding of the age and tectonic setting of key units in the Yenisey Ridge, refining our models for the tectonic evolution of the region. Additionally, low-temperature fission track thermochronology records a thermal event significantly posting-dating the deposition of the units. The data suggests that the region experienced cooling concurrent with the eruption of the Siberian Traps and the initiation of rifting in the West Siberian Basin at ~250 Ma. These improved constraints on the age of critical stratigraphic units will help develop a more complete model for the thermotectonic evolution of the Yenisey Ridge and clarify its position in Neoproterozoic plate tectonic reconstructions.

Key words: geochronology, thermochronology, tectonics, Asia

TWO BILLION YEARS OF THERMAL EVOLUTION IN THE NORTHERN GAWLER CRATON, SOUTH AUSTRALIA

James W. Hall[1], S. Glorie[1], Alan S. Collins[1], Anthony J. Reid[1,2],

[1]Tectonics, Resources and Exploration (TRaX), Department of Earth Sciences, University of Adelaide, SA 5005, Australia

[2]Geological Survey of South Australia, Department of State Development, GPO Box 1264, Adelaide, SA 5001, Australia

Email address: james.hall@adelaide.edu.au

The Gawler Craton, South Australia preserves a complex thermal evolution, from deep crustal levels to shallow crustal levels, over its ~2.5 Ga history. This includes numerous orogenic and magmatic events, along with the formation of world-class mineral deposits, such as Olympic Dam. Due to its complex and protracted tectonic history, the thermal evolution of the Gawler Craton is still poorly understood. In this study, we present new apatite U/Pb (550 – 350 °C) and apatite fission track (AFT; 120 – 60 °C) data, in conjunction with new and previously published $^{40}Ar/^{39}Ar$ and (U-Th-Sm)/He data, to unravel the thermal evolution of the northern Gawler Craton.

Apatite U/Pb data preserves five distinct deep to mid-crustal cooling periods from 2.3 Ga to 1.3 Ga. The Sleaford, Cornian, Kimban, and Kararan Orogenies and Hiltaba Event are all recorded, in addition to younger ~1.3 Ga compression relating to the collision of the West Australian Craton and the South Australian Craton. In the Neoproterozoic and Phanerozoic cooling is predominantly restricted to upper crustal levels and is separated into two regions; the central and northern Gawler Craton, and the Olympic Domain. Regional cooling within the central and northern Gawler Craton is recorded by AFT data at ~600 Ma. The main phase of cooling in the northern Gawler Craton is interpreted to be southward thrusting of the Karari Shear Zone resulting from the southward compression by the Alice Springs Orogeny to the north of the Gawler Craton during the Carboniferous. This timing matches the break in sedimentation between termination of the Officer Basin and deposition of the Arckaringa Basin. A younger Triassic thermal perturbation is recorded by AFT data within the central Gawler Craton. Comparatively, AFT data from the Olympic Domain records regional cooling at ~1 Ga and at ~400-300 Ma, with a late Jurassic thermal event recorded near Olympic Dam. Spatially, the Olympic Domain data produces a NNW-SSE trending corridor of younger ages that aligns with major mineral deposits within the region. Overall, mid crustal cooling within the northern Gawler Craton is predominately caused by the Hiltaba event and Kararan Orogeny while upper crustal cooling is predominately caused by the Alice Springs Orogeny.

Keywords: Apatite fission track, apatite U/Pb, Gawler Craton, thermochronology, tectonics, South Australia

ON THE UTILITY OF MAFIC GRANULITES TO ADDRESS THE CONTROVERSY OVER METAMORPHIC P–T–T EVOLUTION OF THE HIGHLAND COMPLEX, SRI LANKA

Xiao-Fang He[1,2], Martin Hand[2], David E. Kelsey[2], Laura J. Morrissey[2, 3], M. Santosh[1,2]

[1] School of Earth Sciences and Resources, China University of Geosciences Beijing, No. 29 Xueyuan Road, Haidian District, Beijing, 100083, China

[2] Department of Earth Sciences, School of Physical Sciences, University of Adelaide, Adelaide, SA 5005, Australia

[3] School of Natural and Built Environments, University of South Australia, Adelaide, Australia

Email address: xiaofang.he@adelaide.edu.au

Constraining the metamorphic pressure–temperature evolution of continental crust has typically been done using metasedimentary and felsic rocks, owing to thermodynamic models for minerals in mafic rocks being particularly challenging to develop. However, using recent advances in the thermodynamic framework for partially melted mafic granulites, we demonstrate the utility of mafic granulites for addressing the controversy surrounding metamorphic evolution of the Highland Complex in Sri Lanka. The Sri Lankan fragment of Gondwana records Neoproterozoic metamorphism associated with the assembly of the supercontinent. In previous studies the metamorphic *P–T* record of Gondwana amalgamation has been derived from the granulite to ultrahigh temperature (UHT) rocks of the Highland Complex using a variety of thermobarometric techniques. This disparate approach has led to confusion about the *P–T* conditions and *P–T* paths, and consequently disagreement about the tectonic evolution. To address this confusion, we constrain the time-integrated *P–T* conditions and evolution using garnet-bearing mafic granulites from the eastern and western sides of the Highland Complex using the same new thermodynamic modelling framework, and present new zircon U–Pb geochronology and garnet trace elements data indicating an equilibrium existence of garnet and zircon associated with a long-lived UHT metamorphism possibly more than 100 Myr (ca. 660–520 Ma). The western Highland Complex is characterised by a down-pressure-dominated retrograde *P–T* trajectory involving the consumption of garnet and development of extensive symplectite microstructures whereas the eastern Highland Complex is characterised by a cooling-dominated retrograde *P–T* trajectory involving much more subtle reaction microstructure development. The amount of melt produced during heating, and the effects of melt loss on the mineral assemblages and protolith compositions have been investigated by reintegrating melt as part of constraining the *P–T* evolution of the samples. The change in style of *P–T* path from east to west during the late Neoproterozoic provides insight into the nature of tectonic processes operating in this region during Gondwana amalgamation and highlights the importance of using a systematic approach in methodology and spatial coverage. Moreover, our results demonstrate the utility of mafic rocks for constraining the *P–T* histories of terranes that may have been poorly characterised due to a paucity of metasedimentary rocks.

Key words: U–Pb zircon geochronology; calculated pseudosections; ultrahigh temperature (UHT); phase equilibria; melt reintegration

DISTRIBUTION OF GOLD AND THE RELATIONSHIP TO PYRITE TRACE ELEMENT GEOCHEMISTRY AT THE ERNEST HENRY DEPOST, QUEENSLAND

James B. Hewett[1], Richard Lilly[1]
[1]Department of Earth Science, University of Adelaide, North Terrace, SA 5005, Australia.
Email address: james.hewett@student.adelaide.edu.au

The Ernest Henry deposit is situated within the Eastern Fold Belt of the Mount Isa Inlier, NW Queensland, and is the largest Iron Oxide Copper Gold (IOCG) deposit in the Proterozoic Cloncurry district. The hydrothermal deposit is hosted in brecciated meta-intermediate volcanic and metasedimentary rocks with a chalcopyrite-pyrite-carbonate-quartz-magnetite-gold ore assemblage.

This study investigates the mineralogical, textural and geochemical association between gold and pyrite with samples collected from three drill holes (EH768, EH859 and EH864) at ~700 m vertical depth within the ore body.

This study has found that ~ 98 % of the Au at Ernest Henry is in the form of native gold grains. Free gold grains are commonly observed associated with chalcopyrite and are located on the surfaces of pyrite grains. The gold-associated pyrite crystals formed during an earlier paragenetic stage and are commonly enriched in As. This data is consistent with the interpretation that the majority of Au has entered the Ernest Henry system during the same hydrothermal fluid event as the main chalcopyrite mineralisation, and that the pre-existing As-rich pyrite surfaces have acted as a catalyst for gold deposition. It is discussed that the electrochemical reduction of Au onto pre-existing pyrite surfaces is the mechanism in which most of the gold is precipitated at Ernest Henry.

Implications from this study have assisted in methods of improving gold recovery at Ernest Henry, and a better understanding of the timing of the ‘C’ and ‘G’ in ‘IOCG’ deposits in the local Cloncurry District.

Key words: Arsenian pyrite, electrochemical reduction, free gold, pyrite geochemistry, semiconducting properties, trace elements

120 MYR OF EPISODIC MID-CRUSTAL METAMORPHISM AND FLUID-ROCK INTERACTION DURING THE ALICE SPRINGS OROGENY; THE STRANGWAYS RANGE, CENTRAL AUSTRALIA

D. Howlett[1], M. Hand[1], T. Raimondo[2], L. Morrissey[1]
1. School of Physical Sciences, University of Adelaide, Australia
2. School of Natural and Built Environments, University of South Australia, Australia
Email address: daniel.howlett@adelaide.edu.au

In the Strangways Range, central Australia, kilometre-scale amphibolite facies shear zones transect *c.* 1700 Ma granulite facies gneisses and represent extensive zones of mid-crustal rehydration. Garnet Sm–Nd and monazite U–Pb ages, along with elemental zoning profiles of garnets, are obtained from rock samples collected from the shear zones and indicate periods of prograde metamorphism occurred at *c.* 450 Ma, *c.* 380 Ma and *c.* 330 Ma during the *c.* 450–300 Ma Alice Springs Orogeny (ASO). The rehydrated shear zone rocks are typically coarse grained garnet–staurolite–biotite–muscovite–quartz–plagioclase ± kyanite ± sillimanite ± hornblende assemblages. Calculated *P–T* pseudosections from the geographically widespread shear zone samples indicate *P–T* conditions of 6.3–7.4 kbar and 580–680 °C. These modelled *P–T* conditions suggest geothermal gradients of between 84–97 °C/kbar across the 5000 km^2 Strangways Range region. Along with the range of ages obtained from the shear zone samples, and a lack of conclusive petrographic evidence for polymetamorphism, it suggests that a regionally elevated geothermal gradient persisted throughout the majority of the ASO in the Strangways Range region. In such a scenario, prograde amphibolite facies metamorphism may have resulted from significant rehydration of the *c.* 1700 Ma granulite terrain with fluid infiltration directed by pre-existing crustal scale faults. These rehydrated crustal structures represent zones of lithospheric weakness which may have enabled the accommodation of far-field plate stresses during the ASO resulting in crustal thickening.

Key words: Strangways, geochronology, garnet, REE, pseudosection, amphibolite, fluid, mid-crust.

DECIPHERING CENTRAL ASIAN MOUNTAIN BUILDING; A THERMOCHRONOLOGY APPROACH

Gilby Jepson[1], Stijn Glorie[1], Dmitry Konopelko[2, 3], Martin Danišík[4], Yunus Mamadjanov[5], Alan S. Collins[1]

[1]Centre for Tectonics, Resources, and Exploration (TRaX, Department of Earth Sciences, The University of Adelaide, 5005, Australia.
[2]Saint Petersburg State University, 7/9 University Embankment, SPb 199034, Russia.
[3]Novosibirsk State University, 2 Pirogova St., Novosibirsk, 630090, Russia.
[4]John de Laeter Centre, Applied Geology, TIGeR, Curtin University, Perth, 6846, Australia.
[5]Institute of Geology, Earthquake Engineering and Seismology of the Academy Science of the Republic of Tajikistan, Dushanbe 734063, Tajikistan
Email address: gilby.jepson@adelaide.edu.au

The classical view of the plate tectonic paradigm implies that the majority of mountain building occurs at the margins of tectonic plates. Major ranges such as the Andes, the Himalaya, and the Rockies all form along the boundaries between major tectonic plates. However, the existence of major mountain ranges far from any modern plate boundary, such as the Tian Shan in Central Asia, forces us to consider how these intracontinental systems fit within the earth system. These areas represent a unique challenge due to the complex nature of the tectonics, featuring multiple phases of deformation in response to far-field stress propagated from the plate margins into the continental interior. The Tian Shan is a vast mountain belt stretching thousands of kilometres through Central Asia that developed throughout the Meso-Cenozoic as a response to tectonic forces at the distant Eurasian continental margins. Thus, the Tian Shan represents an ideal natural laboratory for testing our theories on the development of an intracontinental model.

The aim of this project is to determine the thermal history of the region, and to understand the timing of major fault reactivation and mountain building in the Tian Shan. By employing medium to low temperature thermochronology (apatite U-Pb, zircon (U-Th-Sm)/He, zircon fission track, apatite fission track, and apatite (U-Th-Sm)/He) in conjunction with published zircon U-Pb work in the region, it is possible to produce a detailed tectonic history of the rock, tracking it from formation all the way through to its place on the surface at present day. When these techniques are focused along fault zones in mountain ranges it is possible to decipher the major tectonic influences that caused the growth of one of the world's largest mountain ranges.

The Tian Shan is a major controlling factor on the climate of Asia, and hosts numerous petroleum plays, in addition to a variety of mineral deposits including orogenic and volcanic ore deposits. By using thermochronology we can develop a model for the tectonic evolution of the Tian Shan that provides a framework for further research in these fields.

Key words: tectonics, mountain-building, thermochronology, Central Asia

IMPROVING NEXT-GENERATION HYDROGEOLOGICAL MODELS WITH NUCLEAR MAGNETIC RESONANCE AND ELECTROMAGNETICS

Chris Li[1,2], Rebecca Doble[1], Graham Heinson[2], Mike Hatch[2], Kevin Cahill[3], Aaron Davis[3]
[1]CSIRO Land and Water, SA 5064, Australia
[2]Department of Earth Sciences, The University of Adelaide, SA 5000, Australia
[3]CSIRO Mineral Resources, WA 6151, Australia
Email address: chris.li@csiro.au

Groundwater is important for water supply and industries such as agriculture and mining. It is vital to manage groundwater resources properly. Numerical models can be useful for groundwater management but their effectiveness is hampered by large uncertainty. This is partly due to an incomplete understanding of the subsurface, as traditional hydrogeological approaches such as aquifer tests can only provide point-scale information.

This limitation may be improved by incorporating geophysics, which can provide spatially continuous data. In hydrogeology, one commonly used geophysical technique is airborne-electromagnetics (EM) due to its large spatial coverage. It has been used for a wide range of applications, including groundwater exploration, surface water-groundwater interactions and seawater intrusion.

However, there are limitations in the hydrogeological applications of EM. Firstly, geophysical interpretation may be ambiguous. For instance, a high electrical conductivity signal may indicate the presence of saline groundwater or clay. Secondly, geophysical inversion often involves smoothing which may inadequately represent the hydrogeological system under study. Thirdly, although electrical conductivity can be related to hydraulic conductivity via a petrophysical relationship, this relationship contains large uncertainty as it is highly site-specific and spatially variable.

This study aims to overcome these limitations by incorporating nuclear magnetic resonance (NMR). NMR is a geophysical technique that exploits the magnetic properties of the subsurface water protons with oscillating magnetic fields. It can estimate the subsurface water content (both freely mobile and clay-bound), porosity and hydraulic conductivity. This information can be used as direct inputs for groundwater models as well as to improve the aforementioned EM limitations.

The overall expected outcome of this study is developing a methodology that uses EM and NMR to improve groundwater modelling. More specifically, this study will (i) examine how EM-derived hydrogeological data can be improved by NMR, (ii) evaluate different ways of incorporating geophysical data into groundwater models, and (iii) demonstrate the value of geophysics, especially NMR, in groundwater modelling.

Key words: Nuclear magnetic resonance, electromagnetics, groundwater modelling, hydrogeology

A NEW ~230,000 YEAR AUSTRALIAN RECORD: FERN GULLY WETLAND, NORTH STRADBROKE ISLAND

C. Kemp[1,2], J. Tibby[1,2], C. Barr[1,2] and L. Arnold[2,3]

[1] Department of Geography, Environment and Population, University of Adelaide, SA 5005, Australia

[2] Sprigg Geobiology Centre, University of Adelaide, SA 5005, Australia

[3] Department of Earth Sciences, University of Adelaide, SA 5005, Australia

Email address: christopher.kemp@adelaide.edu.au

Records of Australian climate beyond the Holocene are rare, records which cover the period from 100 to 300 ka are very few. The new record recovered from the Fern Gully Wetland on North Stradbroke Island reaches back ~230 ka albeit in a discontinuous manner. The record covers the last interglacial and penultimate interglacial (Marine Isotope Stage 5 and Marine Isotope Stage 7), with some parts of late Marine Isotope Stage 6 also recorded. A multiproxy study of the site has the capacity to add greatly to the understanding of Australia's past climate and to help with predictions of future climate changes.

The sediment was predominantly deposited during the interglacial warm periods of MIS5 and MIS7. The sediment shows the changing conditions during MIS5 period as it quickly became wet during the peak in global sea level as well as a large section of MIS7, allowing for a highly detailed study of that period. The multiproxy results indicate several patterns. There is a highly variable fire history (indicated by macro-charcoal record) especially in MIS7, where it links with rapid changes in plant types seen in the pollen record. The dust record, detailed using sediment inorganic content and then elementary analysis, shows variable wet and dry patterns in MIS5, but is largely constant conditions in MIS7, contrary to the variable pollen and charcoal records. This changing pattern could indicate that the Australian MIS7 was more stable and possibly wetter than MIS5 for most of the continent, while the central eastern coast experienced a more unstable climate.

Key words: palaeoclimate, multiproxy, MIS5, MIS7, ITRAX

PRECIPITATION IN AUSTRALIA DURING MIS3: AN ANALYSIS OF PUBLISHED PALAEOCLIMATE DATASETS

C. Kemp[1,2], J. Tibby[1,2], C. Barr[1,2] and L. Arnold[2,3]

[1] Department of Geography, Environment and Population, University of Adelaide, SA 5005, Australia
[2] Sprigg Geobiology Centre, University of Adelaide, SA 5005, Australia
[3] Department of Earth Sciences, University of Adelaide, SA 5005, Australia
Email address: christopher.kemp@adelaide.edu.au

The climate and the major drivers of that climate during Marine Isotope Stage 3 (29 to 59 ka BP) in Australia are not well understood. Substantial debate surrounds the role of climate in the extinction of megafauna and the extent to which millennial scale climate variability (which are canonical features of MIS3 ice core records), was experienced in Australia. Addressing these issues is hampered by the paucity of well-dated palaeoenvironmental records and the lack of multi-site studies that synthesise continental scale climate change back to 59 ka BP.

In this study, we present a synthesis of 35 Australian palaeoclimate records. Qualitative assessments of precipitation at each site through MIS3 are plotted using a method similar to Harrison and Digerfeldt [1]; detailing dry and wet phases, as well as periods of increasing or decreasing precipitation for each of the sites. We find evidence for a distinct pattern of changing climate, with a period of greater than mean precipitation from 44 to 48 ka BP, before extensive drying of the continent around 35 ka BP. There is some spatial variation in the distribution of precipitation, with many south-eastern sites dry during peak continental precipitation. The continental precipitation record is positively correlated with summer insolation at 30 degrees south.

Key words: Palaeoclimate, synthesis, MIS3, precipitation

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FLIGHTLESS RAILS (AVES: RALLIDAE) FROM THE EARLY MIOCENE ST BATHANS FAUNA, OTAGO, NEW ZEALAND

Ellen K. Mather[1], Alan J. D. Tennyson[2], R. Paul Scofield[3], Vanesa L. De Pietri[3], Suzanne J. Hand[4], Michael Archer[4], Warren D. Handley[1], Trevor H. Worthy[1]

[1]College of Science and Engineering, Biological Sciences, Flinders University, Adelaide, South Australia, Australia.

[2] Museum of New Zealand Te Papa Tongarewa, PO Box 467, Wellington 6140, New Zealand.

[3] Canterbury Museum, Rolleston Avenue, Christchurch 8013, New Zealand.

[4] PANGEA Research Centre, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia.

Email address: math0083@flinders.edu .au

The Bannockburn Formation, Otago, New Zealand, is an extremely valuable source of terrestrial vertebrate fossils between Cretaceous and Pleistocene age. These fossils, which are found in the lower 30 m of the formation, have been dated to the early Miocene (19–16 Ma) and are referred to as the St Bathans Fauna [1]. The fauna have been found across 35 sites along or near the Manuherikia River, all of which were covered by a large palaeo-lake at the time of deposition. Consequently, fossil specimens are dominated by fish and water fowl. The Rallidae, a family of birds that are commonly found in wetland environments, are the second-most common birds represented in the St Bathans Fauna after the ducks. However, their fossils have not been closely studied or described, despite being represented by hundreds of specimens. We used qualitative osteological features and analysed measurements from wing and leg bones to determine two new rail species in monospecific genera were represented. One species was extremely common, and a second distinctly larger one was uncommon. The common taxon exhibited a significant degree of sexual dimorphism and was tiny, well under 100 g in mass. Both species exhibited skeletal proportions and osteological features that indicated they had reduced wings and were flightless, a condition that has evolved repeatedly in island endemic rails [2]. Therefore, flightless rallid species have been present in New Zealand for at least two points in time over the past 20 million years, which suggests that the environmental conditions that allowed the recent Holocene New Zealand avifauna to be predominated by flightless birds were also present in Miocene New Zealand.

Key words: Palaeontology, palaeoenvironments, Bannockburn Formation, fossil record

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THE TECTONIC DEVELOPMENT OF THE PAEO-MESOPROTEROZOIC BAROSSA COMPLEX, GAWLER CRATON, SOUTH AUSTRALIA

Kieran Meaney[1], Martin Hand[1], Justin Payne[2]
[1]Continental Evolution Research Group (CERG), Department of Earth Sciences, The University of Adelaide, SA 5005, Australia
[2]School of Natural and Built Environments, University of South Australia, GPO Box 2471 Adelaide
Email address: kieran.meaney@adelaide.edu.au

The Barossa Complex marks the south eastern most exposure of the Gawler Craton in South Australia. Its position adjacent the Tasman Line makes it one of the best places to assess the now obscured eastern continental margin during the Paleo- to Mesoproterozoic, and as such makes it a potentially valuable point for evaluating Australia's position within Proterozoic superconinents.

Deposition of the metasedimentary protoliths to the Barossa Complex occurred between 1730 Ma and 1650 Ma, synchronous to the onset of the Kimban Orogeny in the Gawler Craton and the deposition of the Willyama Supergroup to the northeast. U-Pb and Hf isotopic analyses from detrital zircon indicates detritus was largely derived from the Gawler Craton with minor input from the North Australian Craton. Syn-depositional granite intrusions are identified in the northern extent of the Barossa Complex, which preserve crystallisation ages of c. 1717 Ma.

Long lived metamorphism initiated in the Barossa Complex very soon after deposition at c. 1630 Ma, with the development of a low angle metamorphic fabric. Peak granulite conditions occurred at c. 1590 Ma. The northern Barossa Complex preserves lower grade metamorphic features and c. 1590 Ma zircon with hydrothermal REE signatures, which are potentially linked to the wider Hiltaba event ongoing in the Gawler Craton at this time. Post peak and retrograde metamorphism continued until c. 1550 Ma and is associated with retrograde shear zones with extensional kinematics in the southern Barossa Complex.

The Barossa Complex shares a depositional and metamorphic history with the Willyama Supergroup and Mt. Isa inlier basin sequences, and was likely part of a transcontinental plate margin system during the Late Paleo- Early Mesoproterozoic. East dipping subduction was the likely driver for extensive rift basin development across the eastern margin of Proterozoic Australia before the Isan-Olarian orogeny inverted these basins. The Barossa Complex is the southernmost exposure of this system.

Key words: Barossa Complex, Gawler Craton, Zircon U-Pb, REE distribution

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RECONSTRUCTION OF LATE PLEISTOCENE TO HOLOCENE PALAEOENVIRONMENTAL CHANGE AT BASIN LAKE, FRASER ISLAND

C. Murphy, F. McInerney, J. Tyler, J. Tibby, P. Gadd, A. Williams
E-mail address: claire.murphy@student.adelaide.edu.au

Fraser Island lake sediments may record valuable information about past environmental changes, which in turn may provide key insights into the mechanisms driving this variability. This information is vital if we are to determine how the Fraser Island environment has reacted to climate changes in the past, and by extension, how it may react to similar conditions in the future. In this study, the geochemical composition of sediments from Basin Lake, Fraser Island, were characterised using a combination of organic and moisture content analyses, micro-XRF analysis, traditional XRF analysis, X-ray diffraction, particle size analysis and radiocarbon dating. The Basin Lake sediments contain a mixture of locally derived sand and far travelled dust, in proportions that have varied through time. Changing environmental conditions resulted in the deposition of four distinct sediment units within the lake. The new data presented here indicates that regional scale aridity was a dominant influence on sediment deposition on Fraser Island at or before 49 thousand years before present, resulting in a high percentage of distally sourced sediment in Basin Lake. During the Last Glacial Maximum, extreme local aridity resulted in increased contribution from locally-derived sediment before a return to wetter conditions during the early Holocene. The Late Holocene sediments preserve evidence for greater climate variability, alternating between arid and wet environments.

Key words: Dust, palaeoenvironments, lake sediments, scanning XRF, grain size analysis

USING NEW GEOPHYSICAL DATA TO CONSTRAIN THE LITHOSPHERIC RELATIONSHIP BETWEEN THE GAWLER CRATON AND MUSGRAVE PROVINCE

Alicia Pollett[1], Stephan Thiel[2], Betina Bendall[3], Tom Raimondo[1], Martin Hand[4]
[1]School of Natural & Built Environments, University of South Australia, GPO Box 2471, Adelaide SA 5005, Australia
[2]Geological Survey of South Australia, Department of Premier and Cabinet, GPO Box 1264, Adelaide 5000, South Australia
[3]South Australian Department of Premier and Cabinet, GPO Box 1264, Adelaide 5000, South Australia
[4]Geology and Geophysics, School of Physical Sciences, University of Adelaide, Adelaide 5000, South Australia
Email address: alicia.pollett@unisa.edu.au

The location of the boundary between the Gawler Craton and Musgrave Province is currently inferred from magnetic and gravity anomalies, yet the nature of this boundary is poorly understood. Thick overlying Arckaringa and Officer Basin sediments restrict outcropping basement, and the number of basement-intersecting drill holes across the northern Gawler is limited. This region is critical to identifying the lithospheric relationship between the adjacent terranes, providing insights into the mechanism of Australian Proterozoic assembly. We present 14 new heat flow estimates located within the Nawa Domain of the Gawler Craton, along with the first heat flow value calculated from within the Musgrave Province, with the aim of improving our understanding of northern Gawler lithosphere. We present these heat flow estimates in conjunction with magnetotelluric (MT) data that transects the study area. The new datasets show that a transition exists from above average heat flows (68–89 mWm^{-2}) exhibited in the northern Gawler Craton and Musgrave Province, through to higher heat flow values (93–112 mWm^{-2}) observed in the Archean Gawler core. This transition corresponds to a highly resistive region located between two conductive bodies observed in the MT data; seismic interpretations from the GOMA seismic line indicate that this transition most likely corresponds to a structural feature located between the Sarda Bluff Fault and Big Swamp Bore Fault within the Nawa Domain. This transition zone may indicate a shift from underlying Gawler basement in the south of the study area to Musgrave basement in the north. The collection of more densely-spaced heat flow and/or MT data throughout the region from will further reveal the nature and location of the boundary between the Gawler Craton and Musgrave Province.

Keywords: Gawler Craton, Musgrave Province, Heat Flow, Magnetotellurics, Seismics

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CHARACTERISTICS OF A JUVENILE POPULATION OF *DICKINSONIA COSTATA* FROM THE FLINDERS RANGES

Lily. M. Reid[1,2], Diego. C. García-Bellido[2,3], Bruce. Runnegar[4], and Jim. G. Gehling[2,3]
[1]School of Natural and Built Environments, University of South Australia, SA 5095, Australia
[2]South Australian Museum, North Terrace, SA 5005, Australia
[3]School of Biological Sciences, University of Adelaide, North Terrace, SA 5005, Australia
[4]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA, United States
Email address: lily.reid@mymail.unisa.edu.au

Dickinsonia is one of South Australia's most abundant and emblematic Ediacaran taxa, with fossils found preserved in a range of Ediacaran palaeoenvironments. Specimens span a range of sizes and a wide variety of intriguing morphological characteristics. A semi-contiguous surface from the Crisp Gorge fossil locality in the central Flinders Ranges presents a large juvenile population of *D. costata*. This surface now forms the framed rock wall in the South Australia Museum's First Life: Ediacara Biota Gallery. This population comprises 180 individuals, with an average length of just 13.3mm, well below the average size for this taxon, which can reach up to 200mm in length. Individuals present three notable characteristics including a previously described 'shrinkage rim', a raised lip that partially surrounds the body and a deep-relief protuberance which broadly deforms one end of the upper surface of the body. A positive correlation ($r = 0.22$, p-value = 0.01) exists between the shrinkage rim, interpreted as a taphonomic feature in response to burial, and the raised lip. We suggest the raised lip feature may also be taphonomic, and together these characteristics may have been the result of a physical contraction in response to the burial process. The deep-relief protuberance, recorded in 15% of the population, is also noted in limited specimens within the South Australian Museum collections and appears to be present only in juvenile *D. costata*. It is not related to the underlying substrate. The function of this feature remains uncertain, however, it's exclusive presence in juvenile-sized specimens suggests it may be a feature associated with juvenile growth and development in this taxon.

Key words: Flinders Ranges, Ediacara, Dickinsonia, palaeontology, palaeoecology

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BRITTLE VS DUCTILE DEOFRMATION IN SALT DETACHMENTS: AN EXAMPLE FROM THE SALT RANGE, PAKISTAN

L. Richards[1], R.C.King[1], A.S. Collins[1], M.Sayab[2], M.A.Khan[3], M. Haneef[4], C.K. Morley[5], J. Warren[6]

[1] Centre for Tectonics Resources and Exploration (TRaX), Department of Earth Sciences, University of Adelaide, Adelaide 5005, South Australia, Australia
[2] Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland
[3] Karakoram International University, University Road, Gilgit, Gilgit-Baltistan
[4] Department of Geology, University of Peshawar, Jamrud Road, Khyber Pakhtunkhwa, Pakistan
[5] PTTEP, 27th Floor, ENCO Building, Soi 11, Vibhavadi-Rangsit Road, Chatuchak, Bangkok, Thailand, 10900
[6] Chevron PTTEP International Master Program in Petroleum Geosciences, Room # 239a, Department of Geology, Faculty of Science, Chulalongkorn University, 254 Phyathai Rd., Patumwan, Bangkok 10300 Thailand
Email address: lachlan.richards@adelaide.edu.au

The Salt Range, Pakistan is the surface expression of an evaporite detachment over which the Potwar Plateau fold-thrust belt has moved. Whilst previous publications regarding this region have focused on the petroleum prospectivity, deformation, and large-scale processes, this work characterises the Salt Range detachment at the meso-(10 cm to 10s of metres) and micro-scale (cm to lm) and examines correlations to the macro-scale (10s of metres to kms). Two detailed scaled cross sections are analysed alongside structural measurements to characterise the detachment at the meso-scale with optical analysis of microstructures that formed during deformation characterising the micro-scale. Both ductile and brittle features observed in cross section indicate composite deformation processes acting simultaneously; this contrasts with models of salt detachments behaving homogeneously. Microstructural analysis indicates processes of grain boundary migration and crystal lattice distortions. The microstructurally revealed competition between intra-crystalline deformation and recrystallization at shallow depths and low temperatures links passes up-scale to mesoscale evaporite mylonites and progressively in the weaker units, whereas more brittle processes operate in the stronger lithologies in this near-unique outcrop of a the emergent toe of a major salt-bearing detachment fault.

Key Words: Salt Range, Pakistan, Evaporite Detachment; Microstructures, Fold-Thrust Belt

CALCIUM AND STRONTIUM ISOTOPE CYCLING IN COASTAL LAGOON-ESTUARINE ENVIRONMENTS, SOUTH AUSTRALIA: IMPLICATIONS FOR WATER MIXING, CARBONATE FLUXES AND FISH MIGRATION

Y. Shao[1], J. Farkaš[1,2], C. Holmden[3], L. Mosley[4], I. Kell-Duivestein[1,5], C. Izzo[4], P. Reis-Santos[4,6], J. Tyler[1], P. Toerber[2,1], J. Frýda[2], H. Taylor[7], D. Haynes[1], J. Tibby[8], and B. M. Gillanders[4]

[1]Department of Earth Sciences and Sprigg Geobiology Centre, School of Physical Sciences, University of Adelaide, Australia

[2]Department of Environmental Geosciences, Czech University of Life Sciences, Prague, Czech Republic

[3]Department of Earth Sciences, University of Saskatchewan, Saskatoon, Canada

[4]Department of Ecology and Environmental Science and Sprigg Geobiology Centre, School of Biological Sciences, University of Adelaide, Australia

[5]Institute of Applied Geosciences, Graz University of Technology, Austria

[6]MARE - Marine and Environmental Sciences Centre, Faculty of Sciences, University of Lisbon, Portugal

[7]School of Earth and Environmental Sciences, University of Wollongong, NSW, Australia

[8]Department of Geography, Environment and Population, School of Social Sciences, University of Adelaide, Australia

Email address: yuexiao.shao@adelaide.edu.au

To better understand the water sources and their mixing, as well as carbonate fluxes in the Coorong, the terminal estuary of Australia's largest river system (i.e. Murray-Darling), we established water mixing models using Sr and Ca isotopes (i.e. measuring $^{87}Sr/^{86}Sr$ and $\delta^{44/40}Ca$ signatures), coupled with PHREEQC simulations of mineral saturation states in local waters. Based on these, we were able to investigate the sensitivity of these isotope proxies to salinity changes along the lagoon (ranging from fresh to hypersaline, i.e., 0 to ~120 PSU). Additionally, the $^{87}Sr/^{86}Sr$ values for otoliths of the fish, the smallmouth hardyhead (*Atherinosoma microstoma*) were used as intergrated values of local water signatures. The geochemistry of waters in the Coorong were considered as a result of brackish/fresh water and marine water mixing, with a strong effect of evaporation, which caused hypersalinity in the South Lagoon). The water mixing models indicate that the North Lagoon is strongly controlled by seawater input from the Southern Ocean except when temporary groundwater input events and/or barrage outflow from the River Murray brought freshwater in to the Coorong. The South Lagoon is mostly hypersaline, as a result of marine water and freshwater (i.e., groundwater and/or drainage water from the Upper South East Drainage Scheme (USEDS)) mixing and much stronger evaporation. Sr isotope signatures in waters and otoliths suggested inputs from both seawater and freshwater were significant. The effect of water evaporation, which leads to oversaturation and precipitation of $CaCO_3$ (calcite and aragonite) in lagoon waters, had an effect on the Ca isotope composition of local waters, as these yielded systematically heavy $\delta^{44/40}Ca$ signatures due to removal of light Ca isotopes into $CaCO_3$. Our modelling of Ca isotope data suggests that about 35 to 44% of Ca in the South Lagoon waters has been removed as $CaCO_3$, which has implications for understanding local carbon cycling in the lagoon. The results of this study provide a basis for future applications of Sr and Ca isotopes that aim to reconstruct ancient environmental conditions and paleo-salinity changes in the Coorong based on sediment cores and/or fossil archives.

Key words: Hypersaline, Mineral Saturation, Precipitation, Water Sources, Calcium Removal, Otoliths, PHREEQC

RAMIFICATIONS FOR STRUCTURAL PERMEABILITY WITHIN THE PERTH BASIN: ANALYSIS OF CALCITE TWIN DATA & IN-SITU STRESSES

Alastair B. Stark[1], Rosalind C. King[1], Khalid Amrouch[2], Rowan Hansberry[1]
[1]Centre for Tectonics Resources and Exploration, Department of Earth Sciences, University of Adelaide, Adelaide, South Australia, Australia
[2]The Australian School of Petroleum, University of Adelaide, Adelaide, South Australia, Australia
Email address: alastair.stark@student.adelaide.edu.au

Understanding the orientation, stress conditions, and fluid-flow history of natural fracture networks can provide tighter constraints on the fracture genesis and tectonic evolution of the Perth Basin, Western Australia. Combined data from previous works indicate a present-day transpressional stress regime, and a maximum horizontal stress orientation of 076°E. However, palaeostress and the timing of fracture generation is poorly constrained. A comparison and analysis of present-day stress, and palaeostress orientations and magnitudes, is integrated with natural fracture network orientations, using data from wellbore image logs, well tests (leak off tests) and sample analysis across eight petroleum drill holes in the Perth Basin. Stress indicators in wellbore image logs are analysed to further constrain present-day stress, and Etchecopar's (1984) computerised Calcite Stress Inversion Technique is used to constrain the palaeostress conditions in the basin. This data can be used to establish a 4D understanding of the tectonic history of the Perth Basin, and the potential structural permeability of its tectonic features. From analysis of stress indicators, the mean regional maximum horizontal stress orientation in the study area is 089.9°N. Through fracture analysis, orientations comply with past studies, as defined by two clear sets (157°-337°) NNE-SSW, reflecting palaeo-basinal stresses and present-day in-situ stresses. Magnitudes highlighted in the Perth Basin closely match previous works defining the basin as transpressional ($\sigma_{Hmax} > \sigma_v \approx \sigma_{Hmin}$) stress regime. This includes vertical stress profile established in seven wells at 22 MPa km-1. The minimum horizontal stress was measured using two leak off tests and formation integrity tests at 14 MPa km-1. The maximum horizontal stress magnitude was measured using frictional limits at 30 MPa km-1. With palaeostress tensors calculated, indicating that of polyphase deformation has been recorded in the Perth Basin. These tensors include; NNW-SSE compressional event attributed to Early to Middle Triassic north-south compression, Late Triassic to Earliest Jurassic east-west extensional phase a NW-SE extensional regime in the Jurassic concluding with Post-Neocomian, north-south compression.

Key words: Present-day stress, Perth Basin, stress magnitudes, structural permeability, subsurface fluid flow

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METAMORPHIC CONDITIONS OF BLUESCHIST FROM MUD VOLCANOES IN THE MARIANA TRENCH

Renée Tamblyn[1], Martin Hand[1], Thomas Zack[2], David Kelsey[1], Laura Morrissey[1]
[1]Department of Earth Sciences, The University of Adelaide, SA 5005, Australia
[2]Department of Earth Sciences, University of Gothenberg, 405 30 Göteborg, Sweden
Email address: renee.tamblyn@adelaide.edu.au

From ca. 48 Ma to present, the western Pacific plate has been subducting under the Philippine Sea plate, forming the oceanic Ibu-Bonin-Mariana (IBM) subduction system [1]. It is the only known location where subduction zone products are actively transported to the surface by serpentinite-mud volcanoes [2]. In the southern Mariana segment, volcanoes sample the slab surface at a depth of ~27 km [2], allowing a unique window into the processes operating at these depths. A large volcano forms the South Chamorro Seamount, 85 km to the west of the trench, and was drilled by ODP during leg 195. This returned serpentinite muds as well as small (1mm – 1cm) clasts of serpentinized peridotite and blueschist. One blueschist chip contains abundant amphibole and chlorite, as well as epidote, clinozoisite, rutile, titanite, clinopyroxene and pumpellyite, and relic magmatic ilmenite and allanite. Phase equilibria modelling suggests that the blueschist reached conditions of ~13.7 kbar and ~580 °C, well exceeding those expected at the base of the Chamorro seamount. We interpret that this high-pressure assemblage formed at a depth of ~ 50 km within the subduction channel and was exhumed to shallower depths below the seamount prior to eruption. This provides a modern example of forced return flow of material from depth within a subduction channel, a mechanism predicted in numerical models and suggested for exhumation of high-pressure rocks from palaeosubduction zones. The material erupted from the South Chamarro Seamount is sampling a far greater depth than previously anticipated, meaning that chemical and isotopic studies on the chips must take this into account. Furthermore, the thermal gradient calculated (~423 °C/GPa or 11.4 °C/km) is slightly warmer than those predicted by numerical models and other blueschists worldwide [3]. A possible explanation is that the blueschist chip reached peak metamorphic conditions during an earlier phase of warm subduction, possibly caused by shallowing of the slab dip.

Key words: Blueschist, subduction, pseudosection, return flow, high-pressure

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ASSESSING THE USE OF TEMPERATURE TIME SERIES TO QUANTIFY GROUND WATER RECHARGE

Kelsey L. Tarabini[1], Dylan J. Irvine[1], Adrian Werner[1], Tariq Laattoe[1]
[1]National Centre for Groundwater Research and Training, Flinders University, SA 5042, Australia
Email address: tara0030@flinders.edu.au

Heat penetrates through the earth's surface into the ground via the natural heat transportation processes of conduction and convection. Stallman (1965) devised an analytical solution that uses the heat signal to calculate vertical water fluxes referred to as groundwater recharge. Whilst Stallman's method has had a strong presence in calculating daily groundwater-surface water exchange rates [1][2], to accurately estimate groundwater recharge, the analytical solution assumes a sinusoidal temperature wave at the boundary surface; homogenous material; one-directional flow and steady state recharge. These assumptions are easily violated in the real world and therefore, it is important to assess the limitations of these assumptions when they are violated. The interest lies with analysing whether the Stallman method is able to quantify an annual recharge rate; and investigating the degree to which low recharge values, sensor resolution, variations in rainfall, multi-directional flow and heterogeneous materials significantly impact the calculation of groundwater recharge. Synthetic data was setup in a finite element flow model (FEFLOW), where the violated assumptions were assessed and the calculated recharge values from the model compared to the synthetic data recharge values. The results of the investigation together with a case study from the Ovens Valley in Victoria, Australia will advise a method on quantifying annual recharge rates using the Stallman method.

Key words: groundwater, hydrology, recharge, temperature time series, heat processes

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WIND DRIVEN UPWELLING OFF THE GIPPSLAND COAST

N. Teder[1], J. Kaempf[1]
[1]College of Science and Engineering, Flinders University, SA 5042, Australia
Email address: tede0008@flinders.edu.au

The Gippsland coast which acts as an intermediate between the East Australian Current, and the Bass Strait is a site of interest as a wind driven upwelling site, due to the presence of cold water, and blue whales in the region [1, 2]. The region of interest was split up into two zones, one for the part of the Gippsland coast on the eastern side of Mallacoota, and on the southern side of Mallacoota; as both regions have different coastal orientations/conditions. For the amount of time looked at to determine a seasonality cycle, the ten year period between 2006-2015 was settled on, which also allows the effect of drought (seeing this time period intersects the millennium drought) and river discharge on the system to show. To determine if this region is undergoing a seasonal wind driven upwelling, as well as showing the impacts of rivers and droughts; wind data was obtained from Mallacoota weather station, and satellite data from NASA's Moderate Revolution Imaging Spectroadiometer (MODISA-A) to obtain chlorophyll-a, normalised fluorescence lineheight (for chlorophyll measurements) and sea surface temperature, river discharge data was from the Victorian Department of Environment, Land, Water and Planning. For the ten year period used for this study, there appears to be a dramatic chlorophyll response in February in particular to go with approximately one event a year that appears on the southern section of Mallacoota. The eastern section also shows a higher response of chlorophyll, but is less consistent than the south. River discharge was looked at for the southern study section due to the amount of major rivers outflowing to the sea in the region, and outside of a correlation around June in seasonal averages, it wasn't conclusive to say it is having an impact on the area. Comparing the impact of drought to non-drought periods, there seems to be a rather pronounced increase in chlorophyll-a readings in the non-drought period, however normalised fluorescence remains consistent between the two time periods, casting doubt if drought has any impact on upwelling in this area.

Keywords: Wind, Coastal, Upwelling, Gippsland, Victoria, Drought

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DATING AUSTRALIAN SKINK DIVERSIFICATION: FOSSIL *SPHENOMORPHUS* AND *EGERNIA* GROUP SKINKS FROM RIVERSLEIGH WORLD HERITAGE AREA (QUEENSLAND, AUSTRALIA)

Kailah M. Thorn[1], Catherine I. Nielsen[1], Michael Archer[2], Mark N. Hutchinson[3], Michael S.Y. Lee[1,3]

[1]College of Science and Engineering, Flinders University, Adelaide SA 5000, Australia.
[2]PANGEA Research Centre, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney NSW 2052, Australia.
[3]South Australian Museum, North Terrace, Adelaide SA 5000, Australia.
Email address: kailah.thorn@flinders.edu.au

Post-mortem disarticulation and the size and fragile nature of squamate cranial material leaves this group of vertebrates vastly underrepresented in Australia's fossil record. The Riversleigh World Heritage Area of north-eastern Australia is highly significant and has so far yielded multiple fossil skinks; preliminary studies [1] resulted in one new species *Tiliqua pusilla* [2], along with other material from all three major skink lineages in Australia (*Egernia* group, *Sphenomorphus* group, and *Eugongylus* group). Our study focuses on the first two lineages.

A limited published record of osteological information in living species of *Sphenomorphus*-group skinks has hindered detailed descriptions and phylogenetic analyses of fossil taxa. Three of the most complete specimens of *Sphenomorphus*-group skinks from Riversleigh - all mandibles - were chosen for detailed morphological analyses. Combined parsimony and Bayesian analyses of morphological and molecular data, robustly places two of these fossils within the Australian crown radiation, relatively close to a mesic, east-coast clade (*Coggeria, Coeranoscincus, Ophioscincus)*. The remaining fossil is either outside the Australian crown radiation, or a rather basal member. The tip-dated Bayesian analyses incorporating these fossils (and no other calibrations) estimates the age of the Australian *Sphenomorphus* group between 33.45 and 31.62 Mya.

Articulated remains of a fossil *Egernia* group skink recently recovered from the mid-Miocene AL90 site (~15Ma) at Riversleigh represent Australia's most complete pre-Pleistocene fossil lizard. Combined parsimony and Bayesian analyses of morphological and molecular data places it within the living genus *Egernia*, while *Tiliqua pusilla* sits basal to the divergence of the clade inclusive of *Tiliqua* (blue-tongued lizards) and *Cyclodomorphus* (pink-tongued lizards); the age of the Australian *Egernia* group is estimated at 34.61 Mya.

The nested positions of these fossils within their respective Australian crown clades indicate that the diversification of both *Sphenomorphus* and *Egernia* groups was well underway by the mid-Miocene, and suggest that these groups colonised Australia during the Oligocene.

Key words: palaeontology, Scincidae, *Egernia*, *Sphenomorphus*, Riversleigh, Miocene

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BASELINES FROM SUBFOSSILS: WHAT SMALL MAMMALS ROAMED THE FLINDERS RANGES BEFORE EUROPEAN SETTLEMENT OF AUSTRALIA?

Jessie-Briar Treloar[1], Mark N. Hutchinson[2,3], Graham C. Medlin[3]

[1] Sprigg Geobiology Centre, Department of Earth Sciences, The University of Adelaide, SA 5005, Australia

[2] Department of Ecology and Environmental Science, The University of Adelaide, SA 5005, Australia

[3] Biological Sciences, South Australian Museum, SA 5000, Australia

Email address: jessie-briar.treloar@adelaide.edu.au

Reconstructing Australia's pre-European mammal communities is challenging as many species became extinct, or were severely impacted on, prior to intensive scientific interest. Critical baseline data as a result, is almost non-existent, and alternative sources of information must be used, such as from Holocene fossil deposits. Cave-roosting owls are well known contributors of small mammal remains to Holocene deposits. To determine the original small mammals of the north western Flinders Ranges in South Australia, we examined well-preserved subfossil Barn Owl pellets and disarticulated pellet remains from the rock pile and sediment floor of a small cave in Aroona Dam near Leigh Creek. The sheltered depositional environment of the cave provided a unique sample of intact pellets that acted as a time capsule for the original small mammals of the area and effectively sealed off from any modern additions. The pellets were radiocarbon dated to between 550 and 1480 yrs BP. A total of 24 mammal species were identified from the assemblage. Over 29% of these species are now completely extinct, with over 25% locally extinct from the surrounding area. When data from our study is compared with similar studies from South Australia it is evident there has been an overall drop in small mammal species diversity of over 50% since European settlement. Subfossil deposits in caves are useful indicators of the original mammal assemblages in Australia and provide critical data that is relevant to conservation of currently vulnerable species.

Key words: Palaeontology, Small mammals, Holocene, Subfossils, Flinders Ranges, Extinction

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PALAEOBIOLOGY OF *MADAKOALA DEVISI* (PHASCOLARCTIDAE) USING NOVEL SPECIMENS FROM LAKE PINPA, SOUTH AUSTRALIA

Amy Tschirn[1], Aaron B. Camens[1], Gavin Prideaux[1]
[1]College of Science and Engineering, Flinders University, SA 5042 Australia
Email address: amy.tschirn@flinders.edu.au

Koalas (Marsupalia; Phascolarctidae) are a temporally and spatially widespread family, represented by a single extant species, Australia's largest arboreal folivore (*Phascolarctos cinereus*). Currently monotypic, Phascolarctidae itself is speciose, with 17 species from 10 genera described. Palaeobiological interpretations have hitherto been derived from craniodental material only. Based on these limited data, it had been inferred that phascolarctids have occupied the sedentary, arboreal specialist niche throughout their evolutionary history. Here, we describe the first near-complete skeleton of an Oligo-Miocene (24 - 26 Ma) phascolarctid—*Madakoala devisi*—from the Namba Formation, Lake Frome Basin, South Australia. Our dental analysis indicates that diagnostic characters of *Madakoala wellsi* reflect ontogenetic, rather than taxonomic, differences from *M. devisi*, thus taxonomy is currently under review. To elucidate the functional capabilities of the taxon, we compare the skeletal morphology with extant marsupial species using convergent eco-morphological models. An analysis of post-cranial characters reveals that *M. devisi* was a highly mobile arboreal specialist with an elongate, possibly prehensile tail, similar in ecological niche and locomotory style to the extant possum, *Pseudocheirus peregrinus*. This novel interpretation differs markedly from previous inferences, and demonstrates that the evolutionary history of phascolarctids is more complex than has previously been thought.

Key words: palaeontology, Oligo-Miocene, koala, ecomorphology

A TRIPARTITE APPROACH TO UNEARTHING THE DURATION OF HIGH TEMPERATURE CONDITIONS VERSUS PEAK METAMORPHISM: AN EXAMPLE FROM THE BUNGER HILLS, EAST ANTARCTICA

Naomi M. Tucker[1], Martin Hand[1], David E. Kelsey[1, 2], Richard Taylor[3], Chris Clark[4] and Justin L. Payne[5, 1]

[1]Department of Earth Science, School of Physical Sciences, The University of Adelaide, Adelaide, SA 5005, Australia
[2]Adelaide Microscopy, The University of Adelaide, Adelaide, SA 5005, Australia
[3]Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, UK
[4]Department of Applied Geology, Curtin University, Perth, WA 6102, Australia
[5]School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA 5095, Australia
Email address: naomi.tucker@adelaide.edu.au

We adopt a three-way approach that integrates: (1) monazite and zircon geochronology, (2) the trace element compositions of garnet, zircon and monazite, and (3) calculated phase equilibria forward models to evaluate the duration and *P–T* conditions of peak metamorphism in the Bunger Hills, East Antarctica. Metasedimentary rocks in the Bunger Hills record evidence for a protracted metamorphic history during the Mesoproterozoic. Taken in isolation, zircon and monazite ages suggest an extremely long duration of high-temperature conditions (ca. 200 Myr). Calculated P–T models of garnet–cordierite ± sillimanite gneiss estimate that peak metamorphism attained high to ultrahigh temperatures (5.5–7.1 kbar, 800–960 °C), and that the P–T path likely tracked along a down-pressure to isobaric cooling trajectory. Integrating trace element data from zircon, monazite and garnet indicates that despite the spread in U–Pb ages, in reality, peak metamorphism occurred over a comparatively shorter interval (ca. 1220–1180 Ma; 40 Myr). This study more definitively extends the spatial footprint of Stage-2 of the Albany–Fraser Orogeny into East Antarctica. It seems likely that the long duration of high thermal gradients was facilitated by regional extension due to collapse of over-thickened crust and that the Bunger Hills reflect the more slowly-exhumed core of the Albany–Fraser Orogen. The results of this study are interpreted within the context of the now separate terranes of the Musgrave–Albany–Fraser Orogen. The three-way approach adopted in this study demonstrates that zircon and monazite may grow and modify through a number of processes at suprasolidus conditions and therefore an integrated petrochronologic approach is essential for investigations on high-grade terranes.

Keywords: Albany–Fraser; Bunger Hills; East Antarctica; P–T pseudosection; rare earth element chemistry; U–Pb geochronology

DIGITALLY RECONSTRUCTING THE SKULL OF THE EXTINCT MARSUPIAL *NOTOTHERIUM INERME* (DIPROTODONTIDAE) AND INFERRING DIET USING MULTIDISCIPLINARY ANALYSES

Jacob D. van Zoelen[1], Natalie M. Warburton[2], Samuel D. Arman[1], Alana C. Sharp[3], Grant A. Gully[1], Gavin J. Prideaux[1]

[1]College of Science and Engineering, Flinders University, Bedford Park SA 5042;
[2]Murdoch University, 90 South Street, Murdoch WA 6150;
[3]Division of Biosciences, University College London, Gower Street, London, WC1E6BT
Email address: vanz0020@flinders.edu.au

Australia was inhabited by a diverse array of large Pleistocene vertebrates including the last representatives of the family Diprotodontidae. The best-known members of this group of quadrupedal herbivores are the rhino-sized *Diprotodon optatum* and hippo-like *Zygomaturus trilobus*. By comparison, *Nototherium inerme*, although first described in 1845, is poorly known, and has been beset by a convoluted taxonomic history. Recent discovery of two cranial specimens, one with the lower jaw in articulation, provide an opportunity to better understand this taxon. We generated a composite reconstruction of the skull and jaw-adductor morphology using three-dimensional programs, and made dietary inferences using qualitative comparative osteology and quantitative geometric morphometric analysis. These inferences were then tested using analyses of enamel microwear and stable carbon and oxygen isotopes. Morphological analysis suggests that *N. inerme* was adapted for selective feeding on browse (leaves and twigs). This was supported by the dental microwear evidence, but not by the stable-isotopic data, which indicate that it fed primarily on C_4 plants, which mostly consist of grasses. We advance two alternative dietary hypotheses to explain these data: 1) *N. inerme* was a specialist consumer of C_4 browse vegetation, similar to the giant Pleistocene kangaroo *Procoptodon goliah*; and 2) *N. inerme* was adapted to feeding on tough C_4 grasses or sedges growing near water bodies, which may have left a browse-like microwear signature. Further investigation will be required to clarify which is the more likely diet for the magnificent 'southern beast'.

Keywords: Palaeontology, Palaeobiology, Stable isotopes, Dental microwear texture analysis, Megafauna, Pleistocene, Australia

THE ROLE OF FLUID–ROCK INTERACTION AND MELT PRODUCTION IN INTRAPLATE MOUNTAIN BUILDING: THE HARTS RANGE, CENTRAL AUSTRALIA

Jan Varga[1,2], Martin Hand[2], Tom Raimondo[1,2],David E. Kelsey[2]
[1]School of Natural and Built Environments, University of South Australia, GPO Box 2471, Adelaide SA 5001, Australia
[2]School of Physical Sciences, University of Adelaide, Adelaide SA 5005, Australia
Email address: jan.varga@unisa.edu.au

The Harts Range rift and basement complex located in the eastern Alice Springs Orogen, central Australia represents a natural laboratory for the study of fluid ingress in the deep crust and melt production over a protracted interval. For the period 450–320 Ma, this tectonic domain is characterised by large-scale deformation of the Harts Range Group rift sequence and pervasive reworking of its underlying basement. Fluid–rock interaction is evidenced by extensive pegmatite intrusion into, and retrogression of pre-existing anhydrous basement, whereby emplacement occurred episodically throughout this 130 Myr period, quasi-concurrent with prograde upper-amphibolite facies metamorphism. The orthogneiss-dominated Entia Gneiss Complex (EGC) represents basement structurally underlying the Harts Range Group, and has evidence for associated deformation and fluid ingress between 390–320 Ma. The EGC also contains metapelites at various structural levels of the mid- to lower-crust, providing a means to constrain the thermobarometric record during a period of significant rheological weakening. Despite existing studies, the source of fluid that contributed to pervasive deformation and metamorphism is unresolved. Additionally, the role of fluid in the episodic history of crustal melting, and ultimately the generation of large-scale tectonic reworking in the Harts Range Group, remains unclear. In this contribution, we integrate U–Pb monazite geochronology, geochemistry, petrography and phase equilibria forward modelling from various metapelitic rocks at different structural levels of the Entia Gneiss Complex. Preliminary data show that the timing of metamorphism coincides with pegmatite crystallisation ages. These constraints form the basis for understanding the conditions and timing at which fluid flow occurred, and the potential sources of the fluid will be constrained by stable isotope analyses (δ18O and δD). The combination of in situ geochronological data with petrographic observations linked to *P–T* models is vital in providing temporal constraints on the physical and thermal evolution of the reworking event.

Key words: Alice Springs Orogen; metamorphism; pseudosection modelling; U–Pb geochronology; monazite; intraplate orogenesis; melt production; crustal fertility

THE ELATINA FORMATION, PICHI RICHI: IMPLICATIONS FOR SNOWBALL EARTH

Georgina M. Virgo, Rosalind C. King[1], Jonathan J. Tyler, Mark Bunch[2], Alan S. Collins[1]
[1] Centre for Tectonics, Resources and Exploration (TRaX), Department of Earth Sciences, The University of Adelaide, SA 5005, Australia
[2] Australian School of Petroleum, The University of Adelaide, SA 5005, Australia
Email address: georgina.virgo@adelaide.edu.au

The Elatina Formation is exposed in outcrops throughout South Australia, and has previously been used as a benchmark study in the development of the Snowball Earth hypothesis [1], which occurred during the Marinoan Glaciation between ~655 Ma and ~635 Ma [2]. Distinct glaciogenic layers interbedded with non-glacial deposits [1] within the formation reflect changes in the depositional environment over time [3]. Pichi Richi Pass in the central Flinders Ranges is an excellent example of the Elatina Formation, and has therefore been chosen as the study area to determine whether the depositional environment reflects cyclic glacial conditions or is dominated by a long-term glaciation consistent with Snowball Earth. To achieve this, a detailed facies analysis and 3D model of the Elatina Formation at Pichi Richi Pass was constructed to show the variability and distribution of the depositional system. Eight facies are identified within one lithostratigraphic unit of the Elatina Formation. From descriptions and spatial distribution of the facies, four depositional environments are recognized: glaciofluvial, deltaic, tidal, and shallow marine. These environments are consistent with findings from previous research of the sedimentary facies and palaeoenvironments in Pichi Richi Pass [4]. The results infer that the depositional environment of the Elatina Formation is not consistent with prolonged glacial conditions like that of Snowball Earth, but rather cyclic glacial and non-glacial periods.

Key words: Elatina Formation, Snowball Earth hypothesis, Marinoan Glaciation, Pichi Richi Pass, Flinders Ranges, facies analysis, 3D model

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THORIUM DISTRIBUTION IN THE CRUST: OUTCROP AND GRAIN SCALE APPROACHES

M. A Williams[1], D. E. Kelsey[1], D. Rubatto[2], M. Hand[1], K. Bockmann[1]
[1] Department of Earth Sciences, School of Physical Sciences, University of Adelaide, Adelaide 5005, South Australia, Australia
[2]Institute of Geological Sciences, University of Bern, CH-3012, Switzerland
Email address: megan.williams@adelaide.edu.au

Monazite is one of the most widely used geochronometers for high temperature processes. Additionally, monazite is a major host of Thorium (Th) in Earth's crust. Monazite composition may change across metamorphic grades and rock types according to Pressure–Temperature, rock composition (P–T–X) and coexisting assemblage. Together with melt production and migration, these factors largely control the transport and distribution of Th in Earth's crust. Despite the vital importance of age data from monazite for understanding the rates and timing of tectonic processes, there has been only limited effort to systematically understand the growth behaviour and compositional changes of monazite and associated REE–Th–U minerals as a function of P–T–X in compositionally homogeneous suites of natural rocks. That is the focus of this study.

We present new data from two compositionally homogenous suites of progressively metamorphosed metasediments, Mount Stafford, central Australia and the Ivrea–Verbano Zone, Italy. We integrate in-field gamma ray spectrometry data on bulk Th and compare it to monazite compositional data to explore Th behaviour in the Crust. Typically, GRS data show that Th concentration is consistent between rocks that underwent partial melting and their lower grade counterparts, resulting in no loss heat production at higher grade. Similarly, monazites in high grade rocks have similar chemical characteristics to monazite in their lower grade counterparts, suggesting monazite in granulite facies rocks may be residual from growth along the prograde path. We argue that a mineral scale approach to understanding Th behaviour must be complemented by bulk field geochemistry in order to understand changes to heat production as a consequence of melting processes.

Keywords: Petrology, Mineral Chemistry, Heat Production, Mt Stafford, Ivrea–Verbano Zone, Metamorphism, Monazite, Gamma-Ray Spectrometry

SPATIAL AND TEMPORAL VARIATION IN DETRITAL ZIRCON AGE PROVENANCE OF THE HYDROCARBON-BEARING UPPER ROPER GROUP, BEETALOO SUB-BASIN, NORTHERN TERRITORY, AUSTRALIA

Bo Yang[1], Todd M. Smith[1], Alan S. Collins[1], Tim J. Munson[2], Brenton Schoemaker[3], De Nicholls[3], Grant Cox[1], Juraj Farkas[1], Stijn Glore[1].

[1]Centre for Tectonics, Resources and Exploration (TRaX), Department of Earth Sciences, The University of Adelaide, SA 5005, Australia

[2]NT Geological Survey, Department of Primary Industry and Resources, GPO Box 4550, Darwin NT 0801.

[3]SANTOS Ltd., 60 Flinders St, Adelaide, SA 5000.

Email address: bo.yang@adelaide.edu.au

The Beetaloo Sub-basin of the McArthur Basin, northern Australia, comprises a succession of shallow-water, clastic sedimentary rocks that formed in the main depocentre of the Mesoproterozoic Roper Group. LA-ICP-MS detrital zircon U–Pb age isotopic data presented here provide new age constraints on the upper Roper Group and reveal spatial and temporal provenance variations illustrating the evolution of the basin and its margins. The large dataset indicate that zircons from the upper Roper Group were derived from Palaeoproterozoic and earliest Mesoproterozoic rocks. These are consistent with derivation from the surrounding exposed basement. Detrital zircon age variations up-section suggest a systematic temporal change in provenance. The Bessie Creek Sandstone has a major source dated at ca. 1823 Ma. Rocks of this age are common in northern basement exposures. Samples from the overlying Velkerri Formation, show derivation from a ca. 1590 Ma source, consistent with rocks exposed in Queensland. The Moroak Sandstone and the Kyalla Formation show progressively more ca. 1740 Ma detritus, which is consistent with sources in the Arunta Region and western Mount Isa Province. This variation is recording exposure and denudation of western Queensland rocks at ca. 1400 Ma due to rifting between Laurentia and the Northern Australian Craton. From then until at least ca. 1320 Ma, the increased ca. 1740 Ma detritus suggests continued uplift in Queensland and possible widening of the source region to include the Eastern-Fold-Belt of Mount Isa. In addition, the Arunta Province is likely to have been exposed and denuded. The Jamison sandstone and overlying Hayfield mudstone represent a marked change in provenance and were deposited after the Musgrave Orogeny, representing a newly-recognised siliciclastic basin.

Keywords: Beetaloo Sub-basin, Mesoproterozoic, Roper Group, detrital zircons, provenance analysis