The Geological Society of Australia

ABSTRACTS

Number
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PALAEO DOWN UNDER 2
ADELAIDE
11-15 July 2016

Edited by
John R. Laurie, Peter D. Kruse,
Diego C. García-Bellido & James D. Holmes

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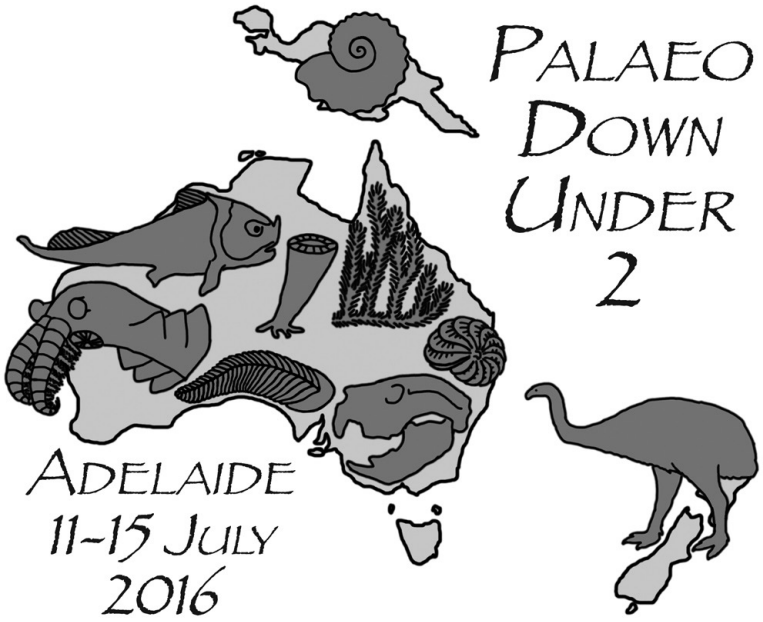

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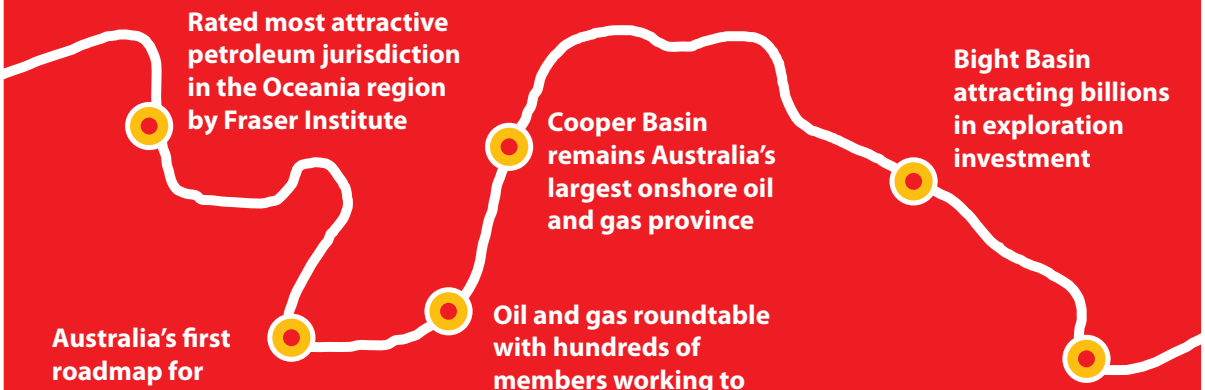
South Australia's door is open.



South Australia's trusted regulatory framework continues to meet community and industry expectations. It's already paved the way for global exploration companies to begin developing our vast gas reserves and invest billions of job-creating dollars. We are also the first state to create a comprehensive roadmap for unconventional gas projects - developed by hundreds of stakeholders. And deep water exploration in the Bight Basin is happening now, all within a robust regulatory environment.
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SOUTH AUSTRALIA

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Foreword

On behalf of the organising and scientific committees, we welcome you to *Palaeo Down Under 2* (PDU2) in Adelaide. This conference is being held on the main campus of the University of Adelaide, the third oldest university in Australia, but the first to grant degrees in science. The University of Adelaide was the first university in Australia and only the second in the world to admit women to academic courses. Indeed, the university's first science graduate was also its first woman graduate.

It has been 16 years since the original *Palaeo Down Under* was held at Kinross-Walaroi School in Orange, New South Wales and attracted over 120 delegates. *PDU2* has attracted over 160 delegates from 13 countries, and we thank all of you for your contribution to the success of the conference, and your willingness to share the results of your latest research in both oral presentations and posters. A very full programme will span the five days of the conference, with concurrent sessions every afternoon. There are also dedicated symposia on the Ediacaran and Cambrian systems, under the auspices of their respective International Subcommissions. Other themes include Palaeontology promotion, New Zealand palaeontology, Dinosaurs and their world, Palaeozoic, Mesozoic, Cenozoic, New techniques in palaeontology, Palaeontology into the 21st century and Cave palaeontology. Altogether, there are over 120 oral presentations and 40 posters. In addition to these, there are several meetings including the Annual General Meeting of *Australasian Palaeontologists*, and business meetings of the International Subcommission on Cambrian Stratigraphy and the International Subcommission on Ediacaran Stratigraphy. There is also a workshop on *Computed tomography at the Australian Synchrotron*, a pre-conference excursion to the Cambrian of Kangaroo Island and the Ediacaran and Cambrian of the Flinders Ranges, a mid-conference excursion to Hallett Cove, one of Australia's foremost geological and archaeological sites, and a post-conference excursion to Cenozoic sites in the Lake Eyre Basin and Burra. In addition to the science, there is the Icebreaker reception on Sunday evening, and the Conference Dinner on Thursday evening. We hope you are stimulated by the content of the programme and that you enjoy all available opportunities to mix with colleagues both old and new. We also trust that you will take the time to enjoy the sights and ambience of Adelaide during your stay.

We acknowledge with enormous gratitude the contribution from our sponsors, partners and supporters.

Pierre Kruse & John Laurie

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ABOUT ADELAIDE

Adelaide is the capital city of South Australia and is the fifth largest city in Australia, with a population of about 1.3 million. The city was established in 1836 as a planned capital for a free-settler colony, and Colonel William Light designed the city with a grid of wide boulevards and public squares. The square-mile city centre is surrounded by heritage-listed parklands. To the east are rolling hills, while the beaches are to the west. Adelaide is often referred to as 'the twenty minute city', as it only takes you twenty minutes to get to where you want to go. It is also known as the festival city and was the first Australian capital city to introduce a festival of arts. There is also the Adelaide Fringe Festival, the Adelaide Cabaret Festival and WOMAdelaide, the annual world music and dance festival. Adelaide has been recognised as one of the world's top ten liveable cities for the past few years.

The Adelaide region also boasts three of the best wine regions in Australia: the Barossa Valley, about 60 km to the northeast of Adelaide, the Clare Valley, another 60 km further north, and McLaren Vale, 35 km to the south of the city. Adelaide has a diverse cultural mix that guarantees that the food is sensational. Rundle Street in Adelaide's east end includes a mix of historic pubs and family-run cafes and restaurants. Five minutes away, Norwood Parade is famously European in its influence while Gouger Street, which is close to Chinatown and the Adelaide Central Market, is crammed with Asian restaurants. Leigh and Peel streets are replete with quirky bars and eateries, and boutique breweries.

From the metropolitan beaches to the stunning Botanic Gardens and numerous parks, there's plenty of space for kids to run around and burn off some energy. If your little ones have a keen interest in animals, you can take them to Adelaide Zoo. There they can meet Wang Wang and Fu Ni – the South Hemisphere's only breeding pair of Giant Pandas. If the kids have an inquisitive mind, you can take them to the South Australian Museum where they are encouraged to get hands-on and learn about the world around us in an interactive way. If you are into art, there is the Art Gallery of South Australia, with 38,000 pieces in its collection, or the Jam Factory Contemporary Craft and Design Studio, or you can take the Art Galley Walking Trail, which takes you around many of the inner city galleries.

It's winter so you will be in Adelaide during the height of the Australian Football League season, so be prepared to be inundated with talk of form/performance by the two South Australia-based teams, the Adelaide Crows and Port Power, who over the years have developed an intense rivalry.

VENUES

INGKARNI WARDLI

This building is the home to the Faculty of Engineering, Computer and Mathematical Sciences. The Kaurna name means ‘place of learning or enquiry’ and recognises the original custodians of the land on which the university is situated. It is the first educational building in Australia to be awarded a green six-star rating when it opened in 2010.

THE BRAGGS BUILDING

This building is the headquarters for the Institute of Photonics and Advanced Sensing. It is named after two of the university’s greatest alumni, Sir William Henry Bragg and his son Sir William Lawrence Bragg, who jointly won the Nobel Prize in Physics in 1915 for their services to the analysis of crystal structure using x-rays. They were notified of the award shortly after Lawrence Bragg’s younger brother, Robert, was killed during the Gallipoli campaign in World War 1.

MAWSON BUILDING

This building was named after Sir Douglas Mawson, the geologist and Antarctic explorer, who became a lecturer in petrology and mineralogy at the University of Adelaide in 1905. He joined Shackleton’s Nimrod expedition to Antarctica in 1907-1909, and with Edgeworth David and Mackay was the first to climb Mt Erebus and to reach the South Magnetic Pole. He later (1911-1914) led the Australasian Antarctic Expedition to King George V Land and Adelie Land. After serving in the British Ministry of Munitions during World War 1, Mawson led the British Australian and New Zealand Antarctic Research Expedition (BANZARE) in 1929-1931, which led to the formation of the Australian Antarctic Territory in 1936.

SOUTH AUSTRALIAN MUSEUM

The concept for the South Australian Museum originated in London with the foundation of the South Australian Literary Association on 29 August 1834. The object of the society was to support intellectual pursuits in literature, art, history and natural science.

In June 1856, 20 years after Governor Hindmarsh proclaimed South Australia a province, an Act to provide for an institution that would incorporate a public library and museum was approved. Frederick George Waterhouse helped to establish the museum with the donation of his own valuable entomological and ornithological collection and, in 1860, he became curator of the South Australian Institute Museum, which opened in 1862. Many years later, legislation giving the South Australian Museum autonomy from the Art Gallery and Library was passed. This Act became operational in 1940.

The role of the South Australian Museum is to increase understanding of natural and cultural heritage and to serve the community by acquiring, preserving, interpreting and presenting material evidence concerning people and nature; and to provide opportunities for study, education and enjoyment.

SOCIAL EVENTS

ICEBREAKER RECEPTION

The Icebreaker reception will be held in the foyer of the South Australian Museum (on North Terrace, about 10 minutes from the main PDU2 venues) from 5:30 to 7:30 pm on the evening of Sunday 10 July 2016. The Icebreaker reception is included in all the various full-week conference registration fees but is not included in the single-day registration fee. All registered full-week delegates, and those accompanying persons and single-day delegates who have purchased an Icebreaker Reception voucher, are entitled to attend this function and enjoy a variety of canapés and beverages including a selection of Australian wines. This is an opportunity to socialise with fellow participants in the ambience of the Museum.

CONFERENCE DINNER

The conference dinner will be held at the Crowne Plaza (16 Hindmarsh Square, Adelaide) on the evening of Thursday 14 July. Pre-dinner drinks and canapés will be offered from 7:00 pm, prior to commencement of dining service at 7:30 pm. Participants will enjoy a meal comprising three courses with associated drinks. The evening will feature the inaugural award of AAP's Robert Etheridge Jr Medal for lifetime contribution to Australasian palaeontology, and Mary Wade Prize for best paper on Australasian palaeontology by an early career researcher in an AAP publication.

MID-CONFERENCE EXCURSION

HALLETT COVE

This excursion to the classic Hallett Cove geological heritage site will be held on the afternoon of Wednesday 13 July. It is open to all full-week delegates and their accompanying persons, and to those single-day delegates who select this day as (one of) their nominated attendance day(s) and their accompanying persons. Participants will be able to inspect Ediacaran strata subjected to Delamerian folding, Permian glacial deposits plus associated glaciation features, and Cenozoic deposits, while enjoying the boardwalk and coastal scenery. Leaders: Jim Jago, Jim Gehling.

Map of University of Adelaide campus

PDU2
ADELAIDE, 2016

CONFERENCE PROGRAMME

Time	SUNDAY 10 JULY
12.00-17.00	CONFERENCE CHECK-IN — INGKARNI WARDLI
17.30-19.30	ICEBREAKER RECEPTION — SOUTH AUSTRALIAN MUSEUM

KEY	VENUES
EDIACARAN	THE BRAGGS
CAMBRIAN	INGKARNI WARDLI
PALAEOZOIC	MAWSON LECTURE THEATRE
MESOZOIC	SOUTH AUSTRALIAN MUSEUM
CENOZOIC	CROWNE PLAZA HOTEL
GENERAL	

Names of oral presenters and poster defenders are in **bold**

PDU2 Sessions & Codes

Venues: The Braggs Lecture Theatre, Ingkarni Wardli & Mawson Lecture Theatre
Session 1: 9.00-10.30; **Session 2**: 11.00-12.30; **Session 3**: 14.00-15.30; **Session 4**: 16.00–17.30

Monday, July 11
- Mo-1: Opening Ceremony + Ediacaran Keynote
- Mo-2: Ediacaran Symposium
- Mo-3: Ediacaran Symposium
- Mo-4A: Ediacaran Symposium
- Mo-4B: Palaeontology Promotion

Tuesday, July 12
- Tu-1: Cambrian Symposium
- Tu-2: Cambrian Symposium
- Tu-3A: Cambrian Symposium
- Tu-3B: Dinosaurs and their world
- Tu-4A: Cambrian Symposium
- Tu-4B: Cenozoic session

Wednesday, July 13
- We-1: Palaeozoic Session
- We-2A: Palaeozoic Session
- We-2B: Palaeobotany

Thursday, July 14
- Th-1: Mesozoic Session
- Th-2: New Techniques in Palaeontology
- Th-3A: Cambrian Symposium
- Th-3B: Palaeontology into the 21st century
- Th-4A: Cambrian Symposium
- Th-4B: Synchrotron Workshop

Friday, July 15
- Fr-1: Cenozoic session
- Fr-2: Palaeozoic session
- Fr-3A: Cambrian Symposium
- Fr-3B: New Zealand and Cave Palaeontology
- Fr-4: Cambrian Symposium

Time	Authors	Title
		MONDAY 11 JULY
8.30-9.00	**CONFERENCE CHECK-IN — INGKARNI WARDLI**	
9.00-9.30	**OPENING CEREMONY — THE BRAGGS**	
	THE BRAGGS: "EDIACARAN SYMPOSIUM"	
9.30-10.15	KEYNOTE: Prof **DROSER**	Catching the second Ediacara wave: ecology and biology of the Ediacara Biota as recorded in South Australia
10.15	**GROUP PHOTO — OUTSIDE THE BRAGGS**	
10.30-11.00	MORNING TEA	
11.00	**Runnegar** & Droser	Celebrating Jim Gehling's contributions to the palaeobiology, stratigraphy and sedimentology of the Ediacaran Period of Earth history
11.15	**Fang** et al	Microbially induced sedimentary structures from the Mesoproterozoic Ruyang Group, western Henan Province
11.30	**Prokopenko**	Evolution of the nitrogen cycle in the context of changing redox conditions during the late Neoproterozoic: the Ediacaran nitrate revolution?
11.45	**Zhou** et al	The Ediacaran acanthomorphic acritarch biostratigraphy of South China
12.00	**Morton** & Grey	Ediacaran palynology of Munyarai 1: lithostratigraphic implications for the Munyarai Trough, Officer Basin, South Australia
12.15	**Hughes I** et al	Abundant fossil macroalgae in the Ediacara Member (Rawnsley Quartzite), South Australia
12.30-14.00	LUNCH	
14.00	**Mitchell** & Kenchington	Tiering and competition in Mistaken Point Ediacaran communities
14.15	**Bobrovskiy** et al	New data on the habitat of the Ediacara biota: evidence from the Zimnie Gory locality, White Sea region
14.30	**Sun W** & Sharma	Ediacaran body fossils and trace fossils from the Hotpet Sandstone of the Bhima Group in the Bhima Basin, southern India
14.45	**Chen L** & Yang F	New finds of embryo-like fossils in the Weng'an Biota
15.00	**Hoyal Cuthill**	Growth and development in the Ediacaran: new quantitative approaches
15.15	**Tarhan** et al	Taphonomic history of the Ediacara Member, Rawnsley Quartzite, South Australia
15.30-16.00	AFTERNOON TEA	
16.00	**Coutts** et al	Analysis of a highly resolvable and diverse Ediacaran community from north Ediacara Conservation Park, Flinders Ranges, South Australia
16.15	**Zhang XL**	Macroscopic fossils from the late Ediacaran Dongpo Shale of North China
16.30	**Evans** et al	Ontogeny of *Dickinsonia costata*
16.45	**Gehling** & Droser	The answer to Darwin's Dilemma: bilaterian-grade Ediacarans that left movement and feeding traces
17.00	**Chen Z** & Zhou	Screwlike trace fossils in the Ediacaran Dengying Formation, South China
17.15	**Allen** et al	Stromatolite biostratigraphy of the western Amadeus Basin supports Neoproterozoic–Cambrian stratigraphic revisions
17.30-19.30	***AAP* ANNUAL GENERAL MEETING — THE BRAGGS**	

INGKARNI WARDLI: "PALAEONTOLOGY PROMOTION" (CONCURRENT SESSION)

14.00	**Eriksson**	Reconstructing the past – when extinct organisms come to life
14.15	**Hocknull** et al	If you build it they will explore: palaeontology and digital technology creates a gateway for Science Technology Engineering and Mathematics (STEM)
14.30	**Luo**	Microtubular structures as the youngest ambient inclusion trails from the early Middle Triassic phosphatised bromalites of southwestern China: new insights
14.45	Wroe et al	Digitally reconstructed Neanderthals meet finite element analysis and computational fluid mechanics: so why the long face?
15.00	**Macken** et al	Fossil collection management at the Naracoorte Caves: 45 years in the making
15.15	**Pope** & Williams	Protecting fossils in South Australia – what works, what doesn't, and what can we do to improve?

Time	Authors	Title
		TUESDAY 12 JULY
		THE BRAGGS: "CAMBRIAN SYMPOSIUM"
9.00-9.45	KEYNOTE: Prof **ZHU**	From Snowball Earth to the Cambrian Explosion: recent research advances from China
9.45	**Holmes** et al	Assemblage relationships between Cambrian Lagerstätten and their palaeobiogeographic implications
10.00	**Parkhaev**	Origin and early evolution of Mollusca
10.15	**Jacquet** et al	Phosphate, facies and fossilisation of early Cambrian molluscs
10.30-11.00	MORNING TEA	
11.00	**Shu D** et al	The earliest-known vertebrates and the Cambrian Explosion
11.15	**Li G**	Subdivision of the Cambrian Terreneuvian Series: a biostratigraphic or a chemostratigraphic marker?
11.30	**Ahlberg** et al	Cambrian Series 2 biostratigraphy and chronostratigraphy of Scandinavia: a reappraisal
11.45	**Han J** et al	Dwarfed vendobionts from the Cambrian Kuanchuanpu Formation in South China
12.00	**Hughes N**	The Cambrian palaeontological record of the Indian subcontinent
12.15	**Paterson** et al	The early Cambrian Emu Bay Shale Konservat-Lagerstätte of South Australia: diversity, palaeoecology and preservation
12.30-14.00	LUNCH	
14.00	**Gaines** et al	Palaeoenvironmental and depositional setting of the Emu Bay Shale, a unique early Cambrian Lagerstätte
14.15	**Collins**	The community succession in the Burgess Shale Formation on Fossil Ridge, British Columbia
14.30	**Betts** et al	New integrated shelly fossil biostratigraphy, carbon isotope chemostratigraphy and geo- chronology of the lower Cambrian, S Australia
14.45	**Claybourn** et al	The small shelly fauna of the Shackleton Limestone Formation, Transantarctic Mountains
15.00	**Kruse** & Debrenne	Ajax Mine archaeocyaths: a preliminary biozonation for the upper Hawker Group
15.15	**Zhao Y** et al	Revised oryctocephalid trilobite zonation and intercontinental correlation through the Cambrian Series 2-Series 3 boundary interval at Balang, Guizhou, China
15.30-16.00	AFTERNOON TEA	

		INGKARNI WARDLI: "DINOSAURS AND THEIR WORLD" (CONCURRENT SESSIONS)
14.00	**Jannel** et al	Simulated range of motion and hindfoot posture of *Rhoetosaurus brownei* Longman 1926 (Sauropoda, Gravisauria)
14.15	**Gray S** et al	Palaeoenvironmental setting of non-avian dinosaur tracks in the Lower Cretaceous (Valanginian–Barremian) Broome Sandstone of Reddell Beach, Dampier Peninsula, Western Australia
14.30	**Hunter** & Kear	Opalised crinoid communities from the Bulldog Shale, Eromanga Basin, South Australia
14.45	**Smith** & Holland	Cretaceous time capsules: remarkable preservation of fish and crustaceans inside the bivalve *Inoceramus sutherlandi* M'Coy 1865 from the Allaru Mudstone (late Albian), Eromanga Basin, Queensland
15.00	**Syme** et al	Living by the Eromanga Sea: taphonomy of crocodyliform and osteichthyan fossils from the Early Cretaceous Winton Formation at Isisford, Queensland
15.15	**Salisbury** et al	3D digital analysis of non-avian dinosaur tracksites at Lark Quarry and Minyirr; implications for understanding Australia's Cretaceous dinosaurian faunas
15.30-16.00	AFTERNOON TEA	
		INGKARNI WARDLI: "CENOZOIC SESSION"
16.00	**Samiullah** et al	Evolution, systematics and biogeographic studies of new fossil remains of giraffids from the Lower Siwalik Hills of Punjab, Pakistan
16.15	**Khan M**	Tragulids (Artiodactyla, Ruminantia, Tragulidae) from the Siwaliks of Pakistan
16.30	**McGowran**	Mysterious Priabonian: geohistory and biohistory in the Palaeogene-Neogene biospheric transition
16.45	**Akhtar**	New remains of Bovidae from the Late Miocene-Early Pliocene of the Siwaliks, Pakistan
17.00	**Khan A** et al	Miocene Rhinocerotidae from the Siwaliks of Pakistan
17.15	**Cook J** et al	The bigger they are the harder they hop? Predicted stress during bipedal hopping in macropodoids
		MAWSON LECTURE THEATRE: "CAMBRIAN SYMPOSIUM"
16.00	**Yuan J** et al	Revision of the biostratigraphy of oryctocephalid trilobites during Cambrian Stage 4 and Stage 5 interval
16.15	Zhao Y, **Peng J** et al	Suitability of the Wuliu-Zengjiayan section, Guizhou, China, as a stratotype for Cambrian Stage 5
16.30	**Yin** et al	Remarkable change of microbiota around the trilobite *Oryctocephalus indicus* Zone
16.45	**Stouge** et al	The Cambrian HERB excursion (Furongian) from the Martin Point Formation of the Cow Head Group, Western Newfoundland, Canada
17.00	Peng S et al	Candidate section for the base of Cambrian Stage 10 at Wa'ergang, Hunan, China
17.15	**Miller** et al	Combining biostratigraphy, sequence stratigraphy and carbon-isotope geochemistry to define the base of stage 10, the highest stage of the Cambrian system
17.30-19.30	**INTERNATIONAL SUBCOMMISSION ON CAMBRIAN STRATIGRAPHY BUSINESS MEETING — MAWSON LECTURE THEATRE**	

Time	Authors	Title	WEDNESDAY 13 JULY
		THE BRAGGS: "PALAEOZOIC SESSION"	
9.00-9.45	KEYNOTE: Assoc Prof **CRAMPTON**	Extinction in Palaeozoic zooplankton: resolving revolution, respite and reversal	
9.45	**Zhen** & Percival	Conodont biozonation of the Australian Upper Ordovician – advancing towards a fine-scaled regional biostratigraphic correlation	
10.00	**Drage** et al	Freshly moulted nileid trilobites from the Fezouata Lagerstätte of Morocco	
10.15	**Kachovich** et al	Middle Ordovician (Darriwilian) radiolarians from Piccadilly, western Newfoundland	
10.30-11.00	MORNING TEA		
11.00	**Bradshaw M**	Devonian bivalves from the Mount Ida Formation, Victoria, Australia: a preliminary report	
11.15	**Long** & Cloutier	New advances in understanding the origin of tetrapods	
11.30	**Penrice** & Deeming	Morphometrics of feeding anatomy in stereospondyl amphibians	
11.45	**Laurie** et al	Timescale 'paradigm shift': CA-IDTIMS and Permian palynostratigraphy	
12.00	**Hunter** & McNamara	Prolonged coexistence of 'archaic' and 'modern' Palaeozoic ophiuroids – evidence from the Early Permian, southern Carnarvon Basin, Western Australia	
12.15	**Lee S** et al	True or not: end-Guadalupian mass extinction in the Boreal Realm	
12.30-13.30	LUNCH		
13.30-18.00	**MID-CONFERENCE EXCURSION to HALLETT COVE**		
18.00-19.30	**INTERNATIONAL SUBCOMMISSION ON EDIACARAN STRATIGRAPHY MEETING — THE BRAGGS**		

INGKARNI WARDLI: "PALAEOBOTANY" (CONCURRENT SESSION)

11.00	**Mays** et al	Gondwanan ginkgoes: heralds of Cretaceous biogeographic and climatic change
11.15	**Hill R**	The Cenozoic Araucariaceae macrofossils of southern Australia
11.30	**Tarran** et al	Oldest record of *Metrosideros* (Myrtaceae): fossil flowers, fruits and leaves from Australia
11.45	**Kerr** et al	Phylogeny, fossil history and biogeography of Ripogonaceae
12.00	**McInerney** et al	Reconstructing canopy closure in Cenozoic forests of Australia using carbon isotope ratios of fossil cuticle
12.15	**Hill K** & Hill R	Determining the distinction between sun and shade leaves for palaeoclimate inference

Time	Authors	Title
		THURSDAY 14 JULY
		THE BRAGGS: "MESOZOIC SESSION"
9.00-9.45	KEYNOTE: Dr **HOCKNULL**	From dig to digital dinosaurs
9.45	**Bean** & Long	Has anything changed for the Mesozoic fish of Eastern Australia? A revision of Talbragar and Koonwarra fauna may shed some light
10.00	**Caswell** & Frid	Palaeoecology of ocean deoxygenation: Jurassic marine ecosystem change
10.15	**Wild** et al	Fossils of the East Indiaman Ridge: first palaeontological assemblages from the western Perth Abyssal Plain, eastern Indian Ocean
10.30-11.00		MORNING TEA
		THE BRAGGS: "NEW TECHNIQUES IN PALAEONTOLOGY"
11.00	**Maksimenko** et al	Applications of synchrotron computed tomography in palaeontology
11.15	**Asatryan** et al	A new approach to the study of Ordovician radiolarians from the Malongulli Formation, New South Wales using 3D X-ray micro-CT imaging
11.30	**Long** & Trinajstic	Advanced methods of imaging and 3D printing applied to problems in early vertebrate evolution
11.45	**Bevitt** et al	Neutron micro-computed tomography as a non-destructive tool for palaeontology in Australia
12.00	**Milroy** et al	Visualising extinction and evolution using synchrotron radiation
12.15	**Hocknull** et al	Size doesn't matter: integrating and accessing massive 3D datasets with no compromise on model fidelity
12.30-14.00		LUNCH
		THE BRAGGS: "CAMBRIAN SYMPOSIUM" (CONTINUED)
14.00	**Yun H** et al	Small shelly fossils from the lowest Cambrian bioclastic limestones on the southwestern margin of North China: composition and biostratigraphy
14.15	**Muscente** et al	Investigating the possible common ancestry and cnidarian affinities of sphenothallids, byroniids and hyolithelminthids
14.30	**Li L** et al	The complex of hierarchical microstructures in a Cambrian micromollusk: *Pelagiella madianensis*
14.45	**Fu D** et al	A new locality of Burgess Shale-type fauna from the lower Cambrian Shuijingtuo Formation in Changyang, Hubei, South China
15.00	**Holmer** et al	The attachment strategies of Cambrian kutorginate brachiopods – the curious case of two pedicle openings and their phylogenetic significance
15.15	**Liu W** & Zhang X	Microbially induced sedimentary structures from the Fortunian strata of South China
15.30-16.00		AFTERNOON TEA
16.00	**Zhai D** & Hou X	Reconstruction of the body plan of *Kunmingella* (Bradoriida) and discussion on its relationship with Ostracoda
16.15	**Caron** & Aria	Cambrian suspension-feeding lobopodians and the early radiation of panarthropods
16.30	**Zhang Z** & Holmer	The diversity and morphology of Cambrian lophotrochozoans: a perspective from the Chengjiang Lagerstätte of China
16.45	**Ortega-Hernández** et al	Evolution of the panarthropod ventral nerve cord: a palaeobiological perspective
17.00	**Cong** et al	Soft-bodied fossils from the background mudstone of the Chengjiang Biota - an ignored preservational window
17.15	**Ma**	A can of cycloneuralian worms
19.00-21.30		**CONFERENCE DINNER — CROWNE PLAZA HOTEL**

		MAWSON LECTURE THEATRE: "PALAEONTOLOGY INTO THE 21ST CENTURY" (CONCURRENT SESSIONS)
14.00	**Topper** et al	Reduced relief: elucidating the Sirius Passet biota with lasers
14.15	**Eriksson**	Virtual dissection of Cambrian 'Orsten' fossils
14.30	**Ziegler** & Van Huet	A novel quantitative methodology for assessing taphonomic abrasion on fossil bone
14.45	**Clement** & Long	New insights into the origins of Gondwanan tetrapodomorph fishes
15.00	**King** et al	Bayesian analysis and the origin of the jawed vertebrate body plan
15.15	**Lloyd**	A novel metatree approach to generating large phylogenetic hypotheses of extinct taxa
15.30-16.00		AFTERNOON TEA
		INGKARNI WARDLI: "SYNCHROTRON WORKSHOP"
16.00-17.30	**Maksimenko** (Australian Synchrotron) **& Milroy** (Central Queensland University)	COMPUTED TOMOGRAPHY AT THE AUSTRALIAN SYNCHROTRON: A PALAEONTOLOGICAL USER'S PERSPECTIVE An interactive workshop detailing what is beam time, how it is useful in palaeontology, how to apply for access to synchrotron radiation, what to expect, hardware and software considerations for CT scans, visualising techniques

Time	Authors	Title
		THE BRAGGS: "CENOZOIC SESSION" (CONTINUED)
9.00-9.45	KEYNOTE: Prof **ARCHER**	Gains, gaps and gags: Riversleigh's growing contributions to unravelling the past, present and future of Australia
9.45	**Lee W** & Brandt	Priority effects over macroevolutionary time scales
10.00	**Van Huet** et al	A relative chronology and preliminary palaeoenvironmental interpretation of recent marsupial fossil finds from the Nepean Peninsula, Victoria
10.15	**Treloar** et al	A pre-European mammal assemblage of the northwestern Flinders Ranges, South Australia from subfossil deposits
10.30-11.00		MORNING TEA
		THE BRAGGS: "PALAEOZOIC SESSION" (CONTINUED)
11.00	**Gubanov** & Ebbestad	Evolution of early molluscs: the case study from the Late Ordovician Boda Limestone (Sweden) and the early Silurian of Severnaya Zemlya Archipelago (Arctic Siberia)
11.15	**Percival** & Strusz	Silurian (Wenlock-Ludlow) brachiopods from Quidong, New South Wales, Australia
11.30	**Choo** et al	A new osteichthyan fish and the earliest gnathostome-dominated vertebrate fauna, from the late Silurian of Yunnan, China
11.45	**Camilleri** et al	Mid-Palaeozoic Ostracoda of central Victoria, southeast Australia
12.00	**Bradshaw** & Bradshaw	Trace fossils of the Devonian Taylor Group, Antarctica, and the Tumblagooda Sandstone of Western Australia: a comparison
12.15	**Dowding** & Ebach	The Early Devonian palaeobiogeography of eastern Australasia
12.30-14.00		LUNCH
		THE BRAGGS: "CAMBRIAN SYMPOSIUM" (CONTINUED)
14.00	**Zhang Z** & Zhang Z	Morphology and ontogeny of the earliest acrotretid brachiopod *Eohadrotreta* and its implications for brachiopod phylogeny
14.15	**Daley** et al	*Myoscolex* from the Emu Bay Shale: morphology and affinity
14.30	**Schroeder** et al	An enigmatic new 'petalloid' organism from the Emu Bay Shale (Cambrian Stage 4), Kangaroo Island, South Australia
14.45	Zhao Y, **Yang X** et al	Exceptionally preserved fossils from the Jianhe Biota in the "Tsinghsutung Formation", Balang, Guizhou, China
15.00	**Young** & Vinther	The onychophoran-like myoanatomy of the Cambrian gilled lobopodian *Pambdelurion whittingtoni*: implications for the early evolution of arthropod skeletomusculature
15.15	**Sun H** et al	Orthothecide hyoliths from the Mantou Formation (Cambrian Stage 5) of Hebei Province, North China
15.30-16.00		AFTERNOON TEA
16.00	**Laibl** & Esteve	Giant early postembryonic stages of trilobites reveals evolution of lecithotrophic development in Cambrian
16.15	**Babcock** et al	Exceptionally preserved Cambrian trilobite in a concretion from Utah, USA
16.30	**Lerosey-Aubril** et al	The Weeks Formation Lagerstätte (Utah, USA): a unique window on the evolution of animal life during the late Cambrian
16.45	**Zhu X** & Peng S	Late Cambrian Guole biota from South China
17.00	**Yang A** et al	Carbon isotope composition of upper Furongian to Lower Ordovician carbonates in North China and global correlation implications
17.15	**Hayman**	Charles Darwin's illness: a proposed Precambrian origin
17.30		***PDU2* CLOSING REMARKS AND FAREWELL — THE BRAGGS**
17.45		**POST-CONFERENCE EXCURSION BRIEFING — THE BRAGGS**

INGKARNI WARDLI: "NEW ZEALAND PALAEONTOLOGY and CAVE PALAEONTOLOGY" (CONCURRENT SESSION)

14.00	**Conran** et al	Eocene floral diversity in New Zealand: a warm life in the South Seas?
14.15	**Waycott** et al	New insights from New Zealand and Italian Eocene fossils that inform marine angiosperm evolution
14.30	**Lee D** et al	Biodiversity and palaeoecology of Hindon and Foulden Maars: two early Miocene *Konservat-Lagerstätten* from New Zealand
14.45	**Geary** et al	Palaeoecology of Pliocene fossil plants and fungi from northern New Zealand
15.00	**Jones** et al	The importance of ancient cave deposits for understanding early Mesozoic lepidosaurian reptiles
15.15	**Reed** & Reardon	Fossil bats from Quaternary cave deposits at Naracoorte, South Australia

Authors	Title POSTERS — INGKARNI WARDLI ATRIUM
Ahn S & Zhu M	Calibrating the temporal relationships between the AHC acritarch assemblage and carbon isotope chemostratigraphy in the Yangtze Platform, South China
Andrae et al	Ecosystem change through the Neogene in Australia: documenting the rise of C4 vegetation
Berrell et al	Microvertebrate fish remains from the Early Cretaceous Toolebuc Formation (Albian) of Richmond, central-northern Queensland, Australia
Binnie	Application of benthic Foraminifera to infer Holocene sea-level changes in northern Spencer Gulf, South Australia
Brewster et al	Adaptive significance in the hind limbs of extant and extinct emus (*Dromaius* species)
Conran et al	A Palaeocene fossil bee hair from New Zealand: ancient evidence of small-flower pollination?
Drage et al	Trilobite moulting behaviour from the Emu Bay Shale, South Australia
Gozalo et al	Trilobites from an archaeocyath-bearing level of Cambrian Stage 4 in the Cantabrian Mountains (northern Spain)
Gray J et al	Agamid lizard fossils from South Australian caves and their implications for environmental change during the Quaternary
Gubanov & Ebbestad	A new primitive rostroconch mollusc from the latest Late Ordovician of the Boda Limestone, Sweden
Gubanov et al	New illustrated history of life time scale
Hall et al	Sizing up *Rugoconites*: a study of the ontogeny and ecology of an enigmatic Ediacaran genus
Hannah	Climate controlled marine palynomorph distribution over the last 210 ka from offshore West Coast, New Zealand
He et al	Morphology of Family Leanchoiliidae (Megacheira, Euarthropoda) from the Chengjiang Biota and its significance
Hou et al	The artiopod arthropod *Acanthomeridion* from the lower Cambrian Chengjiang Lagerstätte, China, and the phylogenetic significance of the genus
Howard et al	Taphonomy of leaf wax *n*-alkanes in soils: field transect and experimental degradation experiment
Kenny	Bringing a Cambrian trilobite to life: reconstructing *Redlichia*
Lee S et al	Three-dimensional morphometric investigation on the variation of sulcal development in some neospiriferine brachiopods
Lerosey-Aubril et al	New exceptionally-preserved arthropods from the middle Cambrian of Utah and Nevada, USA
Lerosey-Aubril et al	Late Cambrian (Furongian) exceptional fossils from the McKay Group of British Columbia, Canada
Liñán et al	A new lower Cambrian trilobite from the Pusa Formation of Spain: biostratigraphic and evolutionary consequences for the older opisthoparian trilobites
Lundberg et al	Integrated Cambrian stratigraphy of the Tomten-1 drill core, southern Sweden
Parkhaev	The Cambrian molluscs of Australia – overview of taxonomy, stratigraphy and palaeogeography
Peng J et al	The trilobite *Bathynotus kueichouensis* (Cambrian Series 2) and its implications for stratigraphy
Percival & Kruse	Middle to late Cambrian (Stage 4 – Jiangshanian) linguliform brachiopods from Australasia and their biogeographic affinities
Pledge & Thurmer	Another enigmatic tooth from the Leaf Locality, Miocene, Lake Ngapakaldi, South Australia
Qing et al	Rapid diversification of Ediacaran acanthomorphic acritarchs after Marinoan glaciation: fossil record from Ediacaran Doushantuo Formation in South China
Reid et al	An Ediacaran pioneer community: possible evidence of primary succession in a juvenile-dominated assemblage from the Flinders Ranges, South Australia
Rich & Vickers-Rich	Southeastern Australia's Cretaceous polar tetrapods in a Greenhouse World
Richards & Paterson	Reanalysis of Ediacara-type fossils from the lower Cambrian (Fortunian) Uratanna Formation of South Australia
Rodriguez & Van Huet	A stratigraphic and geochronological analysis of the *Simosthenurus occidentalis* site, Gunnamatta Beach, Nepean Peninsula, Victoria
Thomsen et al	Determining the incidence of oral necrobacillosis ('lumpy jaw') in an extinct Pleistocene macropod (kangaroo) *Macropus giganteus titan* Owen 1838
Valent & Fatka	Exceptional 3D preservation of hyoliths from the mid-Cambrian sediments of the Buchava Formation (Skryje-Týřovice Basin, Barrandian area, Czech Republic)
Wang H et al	New observations on the most mineralised brachiopod *Diandongia* from the Chengjiang Lagerstätte (Cambrian, Stage 3) of eastern Yunnan, China
Wang Z et al	Ordovician conodont biozonation and biostratigraphy of North China
Willink et al	Carbon isotopes: putting some spice into Middle Cambrian stratigraphy of the southern Georgina Basin in central Australia
Yang X et al	A preliminary study of microscopic skeletal fossils from the Cambrian Jiumenchong Formation at Guizhou, China
Zhao F	Spatial variation in diversity and composition of Cambrian Burgess Shale-type faunas in South China
Zhen et al	Youngest Ordovician conodont fauna known from Australia and associated tabulate corals from the Angullong Formation of central New South Wales

KEYNOTE ABSTRACTS

Gains, gaps and gags: Riversleigh's growing contributions to unravelling the past, present and future of Australia

Archer, Mike

University of New South Wales, Sydney, Australia

Riversleigh's 24 my-long fossil record was World Heritage-listed, together with Naracoorte Caves, in 1994. Riversleigh research has involved more than 100 palaeontologists in 26 institutions in 11 countries, and has more than trebled previous knowledge about the palaeodiversity of Australia's pre-Quaternary vertebrates. Even many of our living families have acquired a prehistory here for the first time. The >250 Late Oligocene to Middle Miocene assemblages, which fall into five successive Faunal Zones spanning two rounds of climate change, are more diverse than any other Australian fossil or modern ecosystem. Tracking lineages over 24 my provides new information to assist conservation of living species—the growing field of palaeoconservation. As an example, we now have an innovative program underway to save the endangered Mountain Pygmy-possum based on the 24 my fossil record of this unique lineage of marsupials. A sequence of U-Pb dates now provides the basis for an improved continental biochronological framework for Australia. Extraordinary, currently inexplicable preservation is also coming to light including 17 my-old sperm cells containing nuclei and other organelles. Most recently, discovery of even more extensive but previously unknown fossil deposits southwest of the World Heritage Area, now called 'New Riversleigh', has revealed richly fossiliferous, datable deposits of Late Miocene age. Yet many challenges remain. These include the need to process more limestone from new sites, research isotopic profiles, radiometrically date parts of the record (e.g. Late Oligocene), find the first pre-Quaternary fossil records for recalcitrant mammal families (e.g. so far no fruit bats or numbats), discover how subcellular fossilisation of soft tissues has occurred, and determine the biomechanics and ecosystem roles of creatures without living descendants. Finally, as the arena where many of the palaeontologists of Oz began their careers, a legacy of embarrassing moments (including mine) will be noted!

Extinction in Palaeozoic zooplankton: resolving revolution, respite and reversal

Crampton, James S.[1,2]; Cooper, Roger A.[1,2]; Sadler, Peter M.[3] & Foote, Michael[4]

[1] GNS Science, Lower Hutt, New Zealand; [2] Victoria University, Wellington, New Zealand; [3] University of California, Riverside, USA; [4] University of Chicago, Chicago, USA

Over long time spans, is survivorship controlled primarily by biotic, species-species interactions or by external environmental factors, and how do these fundamental drivers vary through time? We tackle this problem using new methods and a global compilation of the major Ordovician-Silurian zooplankton group, the graptolites, which occupied the largest biome on the planet. Our dataset has unprecedented temporal resolution of 37,000 years between observations, on average, through the entire 74 my lifespan of the clade.

Extinction rate in the graptolites was apparently controlled substantially by global climate change and may have been paced at Milankovitch-like periodicities. Through most of the Ordovician, extinction rates were low and newly evolved species were most at risk of extinction. In contrast, during the latest Ordovician and Silurian, the extinction regime changed, and repeated severe spikes in extinction rate affected short- and long-lived species equally, a pattern that matches the 'field of bullets' model. During the most severe Late Ordovician Mass Extinction episode, extinction selectively targeted the oldest species. Although these patterns of selectivity suggest some qualitative difference between 'background' and 'major/mass' extinction, in terms of magnitude, there is apparently a continuum between the end-member, lowest and highest extinction rates.

These results to date suggest that major features of graptolite species extinction history were controlled primarily by abiotic factors and that extinction selectivity varied or even reversed on very short timescales (<<1 million years). A simple biotic/abiotic control dichotomy, however, is overly simplistic and the data require more nuanced interrogation. In this presentation we will explore the drivers, rates, pacing and impacts of extinction in this major group across the full spectrum of extinction intensities.

Catching the second Ediacara wave: ecology and biology of the Ediacara Biota as recorded in South Australia

Droser, Mary L.

University of California, Riverside, USA

Since their discovery by Reg Sprigg, soft-bodied fossils of the Ediacara Member not only represent an important part of Australia's fossil heritage, but they are critical to the understanding and interpretation of the unfolding of animal life on this planet. In particular, both the record of diversity and ecological innovation are exceptionally well preserved in these rocks. Excavation of fossil beds at the National Heritage Site of Nilpena, west of the Flinders Ranges, has exposed over 300 m^2 of fossiliferous surface, providing an opportunity for thorough study of the record in situ.

Fossils occur abundantly in four lithofacies of the Ediacara Member. While *Dickinsonia* and *Charniodiscus* occur in all lithofacies, most fossils are lithofacies dependent. Organisms with a tubular construction were the most abundant in these Ediacaran seas, in particular, the genus *Funisia* covers entire beds. *Funisia* also has the distinction of providing evidence for sexual reproduction through densely packed cohorts. Size distributions of other taxa recorded from individual beds also provide ecological and biological insight including variability between taxa. For example, *Tribrachidium* exhibits strong cohort population structure, whereas the form genus *Aspidella* occurs consistently in right-skewed body size distributions, presumably reflecting the size distribution of the associated frond.

Ediacara Member fossils also display a greater morphological diversity than older assemblages. For example *Coronacollina*, described only from the Ediacara Member, has long biomineralised spicules extending from a thimble-shaped body. This represents the oldest multielement macroscopic body fossil. Ediacara Member fossils also demonstrate several feeding modes not apparent among older assemblages.

From Dig to Digital Dinosaurs!

Hocknull, Scott A.

Queensland Museum, Brisbane, Australia and Griffith University, Brisbane, Australia

Having spent over 15 years digging for dinosaurs in Australia: what's been found and where will it all go from here? We have discovered, dug and prepared more dinosaur fossils than ever before thanks to a wave of dedicated citizen scientists who have helped build new and enormous collections of dinosaur fossils. These collections have further promoted the need for regionally based museums to be the custodians of their collections in context. The journey has not been an easy one but it now provides opportunities for better (and in context) research, new educational experiences, palaeotourism and regional employment. Ten years ago this was all simply a pipe dream. Now these opportunities are par for the course and continue to grow.

So where to from here? The growth of new 3D digital scanning and capturing technologies along with advanced digital visualisation and manufacture (e.g. virtual reality and 3D printing) has now opened up a Pandora's box of opportunity for ways to research and communicate our palaeontological story worldwide. Sharing our heritage digitally and in full 3D is an imperative if we are to remain relevant in the data age. New home-grown digital technology is allowing us to do this. We will go for a virtual tour of 'Dr. Scott's 3-D palaeo-emporium' that I have built up over the last five years; explore museum collections and visit new areas of research and discovery – all from the comfort of an Xbox controller. The future will be a combination of real and virtual… but how we end up using all this data I cannot say. Other than it will be *awesome*!

From Snowball Earth to the Cambrian Explosion: recent research advances from China

ZHU, Mao-Yan

Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, China

The Cryogenian–Cambrian time interval (720–520 Ma) is a critical transition in the evolutionary history of the Earth–Life system, which is marked by an extreme climatic event, the 'Snowball Earth', at the beginning, and a remarkable life evolutionary event, the 'Cambrian Explosion', at the end. Successive and well exposed late Neoproterozoic–early Cambrian strata from South China, which yield a number of extraordinarily well preserved fossil Lagerstätten, provide invaluable information to unravel the evolutionary process of the Earth–Life system during this critical interval.

Cryogenian strata of South China are characterised by two glacigenic intervals. New high-resolution zircon U-Pb dates confirm the synchroneity and duration of the Sturtian glaciation, which initiated rapidly at 716 Ma and ended at 660 Ma. The new data will permit the development of a more highly resolved age model for the Cryogenian. In addition, macroscopic eukaryotes have been recently reported within the terminal Cryogenian Nantuo Formation (*ca* 636 Ma). All these new data provide a test for Cryogenian climatic models.

Numerous fossils with various preservation modes from the Ediacaran of South China are evidence of rapid evolution of multicellular organisms in the immediate aftermath of the termination of the Cryogenian ice age. These fossils include: (1) a high diversity of macroscopic carbonaceous compressions, some of which share distinct characteristics of the Ediacara fossils while some exhibit features similar to animals; (2) phosphatised microfossils from the Doushantuo phosphorite consisting of complex multicellular algae, various types of embryo fossils, larvae and juveniles of stem-group animals; (3) silicified microfossils from the Doushantuo Formation which is characterised by large acanthomorph acritarchs which exhibit two distinct assemblages, and thus can be used for global correlation of Ediacaran stratigraphy; and (4) a new Ediacara fossil assemblage from the 'Shibantan limestone' in the middle Dengying Formation exhibit a complex benthic mat ecosystem.

Increasing new data from the Ediacaran and early Cambrian of South China demonstrate that the interval from Snowball Earth to the Cambrian Explosion represents a time of transition from an earlier microbial world to the metazoan world we know today. But the transition can be viewed as an episodic process that shows a close causal link with atmospheric and oceanic changes, particularly the oxygenation of seawater.

GENERAL ABSTRACTS

Cambrian Series 2 biostratigraphy and chronostratigraphy of Scandinavia: a reappraisal

Ahlberg, Per[1]; Cederström, Peter[2] & Babcock, Loren E.[3]

[1] Lund University, Lund, Sweden; [2] Axelvoldsvägen, Eslöv, Sweden; [3] Ohio State University, Columbus, USA

Zonation and regional correlation of Terreneuvian and Cambrian Series 2 strata of Scandinavia have been commonly based on polymerid trilobites, acritarchs, trace fossils and small shelly fossils. The zones can be categorised as assemblage zones and are generally vaguely defined. Four Cambrian Series 2 trilobite zones are generally recognised above the upper Terreneuvian *Platysolenites antiquissimus* Zone. In ascending order they are the *Schmidtiellus mickwitzi*, *Holmia inusitata*, *H. kjerulfi* and *Ornamentaspis*? *linnarssoni* zones. Some recent authors have suggested abandoning use of the *H. inusitata* Zone, and also recommended subdividing the *O.*? *linnarssoni* Zone into a lower subzone characterised by *O.*? *linnarssoni* and an upper subzone characterised by *Comluella*? *scanica* and *Ellipsocephalus lunatus*.

Recent work reveals important new information on the distribution and stratigraphic significance of trilobites in Cambrian Series 2 of Scandinavia, and it is evident that some zonal assemblages reflect biofacies more than temporal differences. For the purpose of simplicity and to minimise ambiguity of the biozonation, we propose a division of the succession into four interval-zones: the *S. mickwitzi*, *H. kjerulfi*, *Strenuaeva*? *spinosa* and *Chelediscus acifer* zones. Each zone is defined by the first appearance of the eponymous species and delimited at the top by the base of the succeeding zone. The species were selected because they are distinctive, easily recognisable and, except for *S. mickwitzi*, known to be widespread. The first appearance of *Strenuaeva primaeva*, a distinctive ellipsocephalid trilobite, nearly coincides with the first appearance of *H. kjerulfi* and can be used as a secondary marker for the base of the *H. kjerulfi* Zone. *Calodiscus lobatus* is a geographically widespread eodiscoid trilobite. Its FAD in Scandinavia nearly coincides with that of *S.*? *spinosa*. The eodiscoid *Chelediscus acifer* is known from England, southeastern Newfoundland and northernmost Sweden. Strata with *C. acifer* are inferred to be younger than those yielding eodiscoids of the *Serrodiscus bellimarginatus-Triangulaspis annio-Hebediscus attleborensis* assemblage, and older than strata of the *Morocconus notabilis* Zone of Newfoundland and Morocco.

New remains of Bovidae from the Late Miocene-Early Pliocene of the Siwaliks, Pakistan

Akhtar, Muhammad

University of the Punjab, Lahore, Pakistan

New Bovidae fossils have been collected from the Late Miocene-Early Pliocene outcrops of northern Pakistan. The bovids are described on the basis of abundant material from the Middle Siwalik Subgroup of Pakistan and the remains increase known taxonomic diversity. Quantitatively, boselaphines are predominant. Comparative morphometric features of the late Miocene-early Pliocene bovids of Pakistan are presented here. The recovered material comprises upper and lower molars and provides evidence of the various sizes of Siwalik bovids.

Stromatolite biostratigraphy of the western Amadeus Basin supports Neoproterozoic–Cambrian stratigraphic revisions

Allen, Heidi-Jane; Grey, Kathleen & Haines, Peter W.

Geological Survey of Western Australia, Perth, Australia

Although well known from the central Amadeus Basin (Northern Territory, Australia), until recently, Neoproterozoic stromatolites were recorded from only a few localities in the Western Australian portion of the basin. Occurrences were restricted to stratigraphic units previously assigned to the Bitter Springs and Boord Formations. A Geological Survey of Western Australia targeted mapping program has resulted in major stratigraphic revision and the discovery of numerous new stromatolite localities.

A previously established biostratigraphic framework for the Neoproterozoic Centralian Superbasin and Adelaide Rift Complex, based on palynostratigraphy and stromatolite biostratigraphy, was tested in the western Amadeus Basin. There are no drillholes suitable for palynology, but stromatolites are abundant. Taxa present not only conform to the biostratigraphy of other Neoproterozoic successions in Australia, but expand the correlations and infill parts of the scheme. Nearly all taxa from mid-Tonian assemblages (including *Tungussia erecta* and most taxa from the *Acaciella australica* Assemblage) are present, as is the late Tonian *Baicalia burra* Assemblage. The Cryogenian (interglacial) succession is

characterised by the *Atilanya fennensis* Assemblage. The mid-Ediacaran *Tungussia julia*, widespread across Australia, can now be shown to be associated with *Tesca stewartii* and other forms.

Stromatolite biostratigraphy demonstrates correlation between the western and central Amadeus Basin, Adelaide Rift Complex, northwestern Tasmania and the Officer, Louisa, Wolfe, Georgina and Murraba basins. An abundance of data indicates that stromatolites are reliable temporal and stratigraphic markers throughout Australian Neoproterozoic successions. Continent-wide Neoproterozoic stromatolite biostratigraphy is consistent with correlations based on lithostratigraphy, isotope chemostratigraphy, sequence stratigraphy, seismic data and palynostratigraphy.

A new approach to the study of Ordovician radiolarians from the Malongulli Formation, New South Wales using 3D X-ray micro-CT imaging

Asatryan, Gayane M.[1]; Aitchison, Jonathan C.[1] & Webby, Barry D.[2]

[1] University of Queensland, Brisbane, Australia; [2] University of Sydney, Sydney, Australia

The application of X-ray micro-CT imaging to radiolarian studies provides an opportunity to obtain data not previously available. Combined with use of the AVISO 3D program for image processing, this technique allows determination of structural detail including the exact number of pores, shell layers and otherwise indeterminable internal skeletal detail. These are important criteria in studies of radiolarian taxonomy and evolution.

Four samples were taken from clasts in limestone breccia of the graptolitic Ordovician Malongulli Formation on the Belubula River at its junction with Coppermine Creek and Sugarloaf Creek in New South Wales. These were studied using both SEM and micro-CT. The radiolarian assemblage is dominated by *Borisella subulata* (Webby & Blom), *Haplotaeniatum spongium* (Renz), *Inanigutta complanata* (Nazarov), *Kalimnasphaera maculosa* Webby & Blom and *Palaeoephippium octaramosum* Renz, and was previously assigned to the Katian stage based on co-occurring graptolite and conodont faunas.

The application of micro-CT imaging is important for the future of radiolarian studies. Having precise numerical data on their skeletal architecture will lead to a better understanding of their taxonomy and systematics, as well as the early evolution of this important group of organisms.

Exceptionally preserved Cambrian trilobite in a concretion from Utah, USA

Babcock, Loren E.[1,2]; Kastigar, Jessica M.[1]; Gunther, Val G.[3]; Cook, Ann E.[1] & Robison, Richard A.[4]

[1] Ohio State University, Columbus, USA; [2] Lund University, Lund, Sweden; [3] Brigham City, Utah, USA; [4] University of Kansas, Lawrence, USA

The stratigraphic record of the ‘Cambrian Explosion’ is remarkable both from an evolutionary perspective and from a taphonomic perspective. Conditions favouring exceptional preservation were manifested during a number of time intervals including those during which concretions developed. Here we illustrate how advanced imaging technology is helping to elucidate anatomical details preserved in concretions that previously went undetected.

Small flattened calcite concretions in the Wheeler and Marjum formations (Cambrian: Drumian Stage) of western Utah, USA, are renowned for the preservation of articulated trilobite exoskeletons. Concretions, usually with cone-in-cone calcite on the stratigraphically lower sides of arthropod exoskeletons, occur within a series of discrete stratigraphic intervals likely formed during late-transgressive or highstand sea-level events. The origin and configuration of the concretions are inferred to have resulted from early diagenesis within a microbial ‘decay halo’ that developed shortly after death or moulting.

Cone-in-cone concretions show varying degrees of exceptional preservation of non-biomineralising arthropod tissues. One remarkable specimen is a trilobite, *Hemirhodon amplipyge*, preserved in a broken concretion from the Marjum Formation. The incomplete concretion retains the intact cephalon and anterior thorax. The margin of the concretion is barely beyond the margin of the exoskeleton, apparently the original extent of a microbial halo that preceded carbonate precipitation. Compression of the glabella suggested the presence of a fossilised digestive tract beneath the axis, which was confirmed by x-ray computed tomography. Calcite filling of the alimentary tract can be discerned on the underside of the concretion. The crop is large and bulbous, mirroring the shape of the glabella. The alimentary tract continues posteriorly into a slender, simple, tubular midgut. A pair of simple antennae and four pairs of biramous appendages are attached on the ventral side of the cephalon, and additional biramous appendages attach in the thorax. The inner branches of the appendages are spinose.

Has anything changed for the Mesozoic fish of eastern Australia? A revision of Talbragar and Koonwarra fauna may shed some light

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There is no longer a representative of the widespread genus *Leptolepis* in Australia. *Leptolepis koonwarri* has been recently renamed as *Waldmanichthys koonwarri* by Sferco & Lopez-Arbarello (2015). In this paper they have erected the new family Luisiellidae as a distinctly Gondwanan clade of freshwater fish known from Argentina and Australia. The members are *Luisiella*, *Cavenderichthys* (formerly known as '*Leptolepis*' *talbragarensis*') and *Waldmanichthys*. Bean (2006) has reviewed both *Cavenderichthy*s and *Waldmanichthys* recently, and including updating previous work, we present new information on the updated data matrix and phylogenetic analysis. Three of the other fish genera from Talbragar; *Archaeomene*, *Aphnelepis* and *Aetheolepis* were first described by Woodward (1895) and Wade (1941). These are included in the Family Archaeomenidae, but they have not been restudied since then, so updated descriptions of these taxa will from a new study which will incorporate new specimens. There is also a member of this family in Koonwarra, *Wadeichthys oxyops* (Waldman 1971), and one in Antarctica, *Oreochima ellioti* (Schaeffer 1972). These taxa are to be redescribed in order to determine the phylogenetic relationship of this family with respect to the Order Pholidophoriformes. Arratia (2013) published a revision of this clade and her data matrix will be used as a basis for a re-evaluation of the phylogeny of the Archaeomenidae by recoding new characters from the descriptions and adding more taxa to the data matrix to generate new phylogenetic hypotheses on the relationships of these fishes using PAUP 4.10. There are several other described fish found at Talbragar and Koonwarra, but in 2006 two specimens of a large fish were found at the Talbragar site that have not yet been described. There is a third specimen of the same fish in the Australian Museum in Sydney, and so this new material will form the focus of another detailed investigation. These studies will enable a better understanding of the biogeographic patterns and phylogenetic relationships of the earliest teleost fishes on the Australian mainland.

New integrated shelly fossil biostratigraphy, carbon isotope chemostratigraphy and geochronology of the lower Cambrian, South Australia

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Integrated multi-proxy data is a requirement of the International Subcommission on Stratigraphic Classification (ISSC) for development and ratification of chronostratigraphic boundaries, particularly the integration of biostratigraphic and chemostratigraphic data. Global correlation of lower Cambrian strata has been notoriously difficult, mainly due to diachronism and endemism of key fauna. Until now, the stratigraphic distribution of early Cambrian taxa from Australia has been poorly resolved, preventing effective correlation and largely isolating the South Australian successions from a global chronostratigraphic synthesis.

Three new shelly fossil zones are defined based on temporal range data compiled from 22 measured stratigraphic sections and drill cores across the Arrowie and Stansbury basins. Instructive taxa include selected tommotiids, organophosphatic brachiopods, molluscs and bradoriid arthropods. Stratigraphic ranges of key shelly fauna are predictable and repeatable enabling robust correlation with coeval strata in neighbouring basins. Additionally, while cosmopolitan genera facilitate rudimentary global correlation, high-resolution species-level correlation is often possible. $\delta^{13}C$ curves from nine stratigraphic sections and drill cores are closely comparable to the global curve for the Cambrian. These multi-proxy data when combined with high-resolution CA-IDTIMS radiometric dates facilitate, for the first time, robust correlation of lower Cambrian successions in South Australia with strata in Antarctica, Avalonia, Laurentia, Siberia and especially China, embedding the lower Cambrian of South Australia in a global chronostratigraphic context.

Neutron micro-computed tomography as a non-destructive tool for palaeontology in Australia

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The physical extraction of fossilised remains from rocks enables quantitative physiological investigation of bone dimensions, volume and porosity, but leads to the destruction of valuable contextual information found within the matrix surrounding the fossils. Soft-tissue remains and other subtle aspects of anatomy not visible to the naked eye may also be removed during this process. It can also be time consuming and requiring rare expertise and special facilities. Conventional and synchrotron-based X-ray computed tomography (XCT) have been used for many years as critical tools for revealing valuable 3D internal and surface renderings of scientifically important fossils. However, in many cases, poor contrast and poor sample penetration with conventional X-rays restrict useful results. Neutrons offer an alternative means of recovering the internal details of specimens as their absorption coefficient is different from that of X-rays and not closely related to atomic number and density. The Australian Nuclear Science and Technology Organisation (ANSTO) has recently completed the commissioning of DINGO, Australia's first and only neutron micro-computed tomography (nCT) instrument, at the OPAL nuclear research reactor (Sydney, NSW). This presentation will use specific examples from recent work to outline the physical capabilities of DINGO, the limitations, accessibility, and directions for future research. It will be clear that DINGO has already been able to obtain unpreceded contrast and detailed reconstructions of anatomical details from extraordinary fossilised remains still embedded within their host matrices. To date, successful scanned specimens have come from a range of sites within Australia, Antarctica, New Zealand, China, USA and Mongolia. Examples, include the fossilised cranial soft-tissue remains of a Jurassic stem mammal, fossilised stomach of a Cretaceous dinosaur, and the unusual tooth structure of an ancient herbivorous reptile. In many cases, high resolution XCT scans of these same specimens were found to be uninformative in contrast to the results provided by neutron scanning.

New data on the habitat of the Ediacara biota: evidence from the Zimnie Gory locality, White Sea region

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The Ediacara biota represents the first communities of macroscopic organisms preserved in the palaeontological record. The White Sea Assemblage found in the Zimnie Gory, one of the richest localities of the Ediacara biota in the world, has been previously assumed to inhabit estuarine, prodelta and shelf-mud environments. However, new observations reveal numerous sedimentary features which do not fit this model and suggest that the fossil-bearing beds were formed on a tidal flat.

Deposits containing impressions of the Ediacaran organisms in the Zimnie Gory record evidence for bidirectionality of palaeoflow (bimodal-bipolar direction of cross beds, herringbone cross bedding and reactivation surfaces), alternating high- and low-energy conditions (lenticular, wavy and flaser bedding, high content of clay pellets, flat pebbles and chips, numerous clay drapes within sandstones) and subaerial exposure (rill marks, mini-ripples and flat-topped ripples, polygonal pattern of mat-like surfaces and possible desiccation cracks). Channel forms are often filled with flaser-bedded sandstones with layers of flat clay pebbles and chips. The fossil-bearing intervals are made up of fining-upward cycles, reflecting progradation of a tidal flat.

Evidence of *in situ* preservation of many Ediacaran organisms in the Zimnie Gory indicate that they were not just buried, but also lived on a tidal flat. This broadens our knowledge of the habitat of the Ediacara biota and has important ecological and biological implications for these organisms.

Devonian bivalves from the Mount Ida Formation, Victoria, Australia: a preliminary report

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The Mount Ida Formation, near Heathcote, is the youngest unit of a conformable succession of Silurian to Early Devonian sediments deposited along the western edge of the Melbourne sedimentary basin. The formation is arenaceous, 2100 m thick where it is exposed in the core and eastern limb of the Mount Ida Syncline. It has been subdivided into the Cornella, Dealba and Stoddart Members. The best bivalve faunas are derived from the Stoddart Member, where they are accompanied by a prolific brachiopod, trilobite, gastropod, hyolith, crinoid, receptaculitalean, ostracod and

tabulate coral fauna. The fossils occur as internal and external moulds in well cemented quartz sandstone, and beds represent shell layers accumulating in a nearshore, current-swept environment. Mud blebs among the shells are common, indicating the erosion of mud layers offshore. The majority of shells are disarticulated, and some are bound or coated by bryozoan growths, or provided a substrate for the coral *Pleurodictyum megastoma*. The growth of the latter suggests quiet conditions following turbulent deposition. The most common bivalves are the epibyssate pteroids *Cornellites* (3 species) and *Leptodesma* (1 species). Both of these genera are inequivalve, but only the more inflated left valves are preserved in the fauna, suggesting selective sorting and transport based on convexity. These genera are accompanied by large and rarer *Lyriopecten* (1 species). Endobyssate bivalves include *Modiomorpha* (3 species), *Goniophora* (1 species) and '*Goniophorina*' (1 species). Infaunal deposit feeding palaeotaxodonts include *Notonucula* (3 species), also *Phestia* (2 species), *Nuculites* (3 species) and *Praectenodonta* (2 species). Burrowing suspension feeding bivalves include *Glossites* (1 species), *Palaeoneilo* (1 species), *Paracyclas* (1 species) and *Eoschizodus* (1 species). The bivalve fauna includes taxa that possessed very different lifestyles and their incorporation into shell beds may reflect turbulent erosive conditions in several different environments, sorting and final accumulation in a different setting.

Trace fossils of the Devonian Taylor Group, Antarctica, and the ?Silurian-Devonian Tumblagooda Sandstone of Western Australia: a comparison

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The Taylor Group (1200 m) forms the lower part of the Beacon Supergroup and rests unconformably on Ross Orogen rocks. The Group is older and thickest in the McMurdo region, where an arenaceous succession with minor siltstone has been subdivided into at least four sedimentary sequences involving seven formations. The succession is entirely Devonian in age based on microfossils in the Terra Cotta Siltstone near the base (?Emsian) and a rich fauna of fish fossils in the highest unit (Aztec Siltstone) that together give late Middle to early Late Devonian ages. Trace fossils are common at certain levels. The burrow *Heimdallia* forms dense populations in the lower two formations, with *Diplichnites* trackways on foresets. Small arthropod traces (*Cruziana*, *Rusophycus*) occur in the intervening siltstone. A major sequence boundary in the north coincides with a dramatic change in ichnofauna to one dominated by *Skolithos* and U-shaped burrows. The highest sandstone formations contain the first appearance of *Beaconites* (*B. antarcticus, B. barretti*), with the latter ichnospecies persisting up into the Aztec Siltstone. Large trackways are also present. A range of sedimentary facies representing marginal marine conditions are typical of the bulk of the succession, with a rapid change to sandy floodplain deposits in the uppermost unit. In Western Australia near Kalbarri, the Tumblagooda Sandstone comprises a similar thickness of sandstone of Silurian or Early Devonian age, that contains *Heimdallia*, *Diplichnites* and *Skolithos*. The Murchison River Gorge is the only occurrence of *Heimdallia* outside Antarctica. While some specimens of this ichnogenus are very similar to those of Antarctica, others show behavioural differences that may justify a separate ichnospecies. Above a prominent pebble horizon, which may mark a sequence boundary, the higher part of the succession contains a trace fossil assemblage that indicates shallow marine conditions, with *Daedalus*, *Skolithos*, *Diplocraterion* and *Monocraterion.*

Mid-Palaeozoic Ostracoda of central Victoria, southeast Australia

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The Humevale Siltstone (late Silurian to Early Devonian, Gorstian to Pragian), Woori Yallock Formation (Early Devonian, Emsian) and Norton Gully Sandstone (Early Devonian, Emsian) of central Victoria, Australia contain rich invertebrate fossil faunas including fossil Ostracoda. Most fossil material in these formations occur as natural moulds. Eight taxa of ostracods have been so far recognised from these formations: *Velibeyrichia wooriyallockensis* (Chapman), *Velibeyrichia* (*s.l.*) *australiae* (Chapman), *Velibeyrichia* sp. 1, *Velibeyrichia* sp. 2, *Beyrichia*? *ligatura* (Chapman) *Ulrichia* sp., *Euglyphella* sp. and *Strepulites* sp. Ostracod assemblages are mainly shallow marine and include moderate- to low-energy biocoenoses, pseudo–biocoenosis (gravity flow accumulations) and thanatocoenoses. In addition, reviews of the Australian type species of *Bungonibeyrichia* Copeland and the North American type species of *Velibeyrichia* Henningsmoen, are being undertaken to provide greater clarity in the differential diagnosis for these closely related genera. Future research includes the study of fossil fauna from the Early Devonian Fairy Formation of eastern Victoria, which may include the oldest truly athalassic ('freshwater') ostracod species known on Earth.

Cambrian suspension-feeding lobopodians and the early radiation of panarthropods

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The early evolution of Arthropoda, Tardigrada and Onychophora has its origin in lobopodians, a paraphyletic group of disparate Palaeozoic vermiform animals with soft legs. Though the morphological diversity that this group encompasses likely illustrates the importance of niche diversification in the radiation of lobopodians, the ecology of these animals remains poorly characterised. Here we describe a new luolishaniid taxon from the middle Cambrian Burgess Shale (Walcott Quarry) in British Columbia, Canada, whose specialised morphology epitomises the suspension-feeding ecology of this clade, and is convergent with that of some modern marine animals, such as caprellid crustaceans. This species possesses two long pairs and four shorter pairs of elongate spinose lobopods at the front, each bearing a slender bifid claw, and three pairs of stout lobopods bearing single, strong, hooklike, anterior-facing claws at the back. The trunk is remarkably bare, widening rearwards, and extends beyond the first pair of lobopods into a small 'head' bearing a pair of visual organs and a short proboscis with numerous teeth. Based on a critical reappraisal of character coding in lobopodians, our phylogeny retrieves most 'long-legged' lobopodians, hallucigeniids and luolishaniids as a basalmost grade within Panarthropoda. This result suggests that panarthropods initially radiated from cycloneuralian ancestors probably adapted to suspension feeding.

Palaeoecology of ocean deoxygenation: Jurassic marine ecosystem change

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Investigating the palaeoecological changes that occurred during past ocean deoxygenation can help us understand how the biosphere will be impacted over the next millennia. Changes in seafloor ecosystems were explored and compared during two periods of ocean deoxygenation. The first was an oceanic anoxic event (OAE) in the early Toarcian (Early Jurassic) that has similarities with the climate changes occurring in the present-day. The second, a period of prolonged regional deoxygenation was associated with changing Late Jurassic (~150 Ma) circulation. Palaeoecological changes in body and trace fossils were investigated using high temporal resolution data (100s–1000s of years).

Large shifts in biodiversity, population size, body size and life history of the dominant benthic taxa occurred in response to the Toarcian OAE. Ecological change spanned multiple trophic levels and changes in the macrobenthos impacted their pelagic predators resulting in biogeographic range shifts. Palaeoecological changes during regional Late Jurassic deoxygenation were less severe, no extinctions occurred, and the seafloor was recolonised multiple times. Using quantitative analytical approaches (developed for contemporary ecology) we document changes in the biological traits of fossil taxa which revealed new information on the changes that occurred during the two events. Changes in the biological traits of fossil taxa showed that the cessation, or shallowing, of bioturbation was the most significant impact of deoxygenation. These changes would have impacted core ecological processes such as the regeneration of nutrients, food web dynamics, and benthic-pelagic coupling.

Quantification of the relationships between palaeoecological change and proxies for palaeoenvironmental change showed that both hypoxia and primary productivity were important drivers. The patterns of Jurassic ecosystem change share many similarities with present-day deoxygenated systems. Critically, the recovery from global anoxia in the Toarcian was very slow and connectivity, with other potential sources of new recruits, would have been an important contributor to ecosystem recovery.

New finds of embryo-like fossils in the Weng'an Biota

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The Ediacaran Doushantuo Formation at Weng'an in South China provides a critical taphonomic window into the early evolution of complex multicellular eukaryotes, including algae and possible animals. Among the most controversial and potentially most important Doushantuo fossils are the spheroidal microfossils with a palintomic cell cleavage pattern. These fossils have been variously interpreted as sulphur-oxidising bacteria, unicellular protists, mesomycetozoean-like holozoans, green algae akin to *Volvox*, and blastula embryos of early metazoans or bilaterian animals. However, their complete life cycle is unknown and it is uncertain whether they had a cellularly differentiated ontogenetic stage, making

it difficult to test their various phylogenetic interpretations.

We will here describe new spheroidal fossils from black phosphorites of the Doushantuo Formation that have been overlooked in previous studies. These fossils represent later developmental stages of previously published blastula-like fossils, and they show evidence for cell differentiation, germ-soma separation, and programmed cell death. Their complex multicellularity is inconsistent with a phylogenetic affinity with bacteria, unicellular protists, or mesomycetozoean-like holozoans.

Available evidence also indicates that the Doushantuo fossils are unlikely animals or volvocine green algae. We conclude that they are multicellular eukaryotes in affinity, and further interpreted as probable multicellular algae that maybe related to the fossil algae in the Weng'an Biota. If so, the complete life cycle of these embryo-like fossils could be reconstructed: the embryo-like fossils as the sporophyte generation, the algal fossils *Wengania*, *Thallophyca* and *Paramecia* as the gametophyte generation.

Screwlike trace fossils in the Ediacaran Dengying Formation, South China

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Screwlike trace fossils, characterised by distinct inclined ridges, were discovered in the Ediacaran Dengying Formation in the Yangtze Gorges area, South China. Most of them are preserved as positive hyporelief and negative epirelief on the bedding surface of limestone. The geometrical features, including width, inclined angle, and ostensible distance between adjacent ridges, indicate that the appearance of the trace fossil is consistence with double spirals. We propose that the screwlike burrows were produced by animals with flattened bodies, possibly an acoelomate animal such as a flatworm. The tracemaker twisted its body when moving forward, and as a microbial mat miner it produced horizontal burrows just beneath microbial mats where sediment was still rich in oxygen. Simulation indicates that animals using basic behavior of rotation can make such complex spiral traces. The flexible body allows them to split a microbial mat by rotation torque. The trace fossil indicates a different burrow technique of a soft acoelomate animal. The successive variation of such traces through time should represent both the morphological and the behavioral evolution of the tracemakers.

A new osteichthyan fish and the earliest gnathostome-dominated vertebrate fauna, from the late Silurian of Yunnan, China

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Ongoing fossil discoveries from the late Silurian (Ludlow) Kuanti Formation of Qujing, Yunnan, offer a priceless glimpse into early gnathostome evolution with a hitherto unsuspected diversity of pre-Devonian bony fishes. These fossils offer insights in the origins and early divergence of the bony fishes and have greatly reduced the morphological gaps between the major osteichthyan lineages (actinopterygians and sarcopterygians).

Recently prepared material, comprising a partially articulated postcranium and isolated mandibles, from the Kuanti Formation represents a novel taxon of early osteichthyan. The main specimen displays a combination of scale and dermal surface features that ally it with the contemporaneous *Guiyu oneiros* and the slightly younger *Psarolepis*, taxa that are resolved in different analyses as either stem-osteichthyans or very primitive sarcopterygians. These early osteichthyans possess large spine-bearing pectoral girdles and dorsal plates, combined with a placoderm-like dermal pelvic girdle, the only instance of these archaic structures within the crown-group Gnathostomata. The new fish has coarse enamel ridges covering all dermal surfaces, with large surface pore openings present on the dermal bones and ridge scutes, but absent from the scales. The rhombic scales combine the the ridged ornament of *Guiyu* with a prominent neck separating the crown and base, as seen in *Psarolepis.* The anterior flank scales of the new fish are striking, being exceptionally tall and displaying, in addition to the typical early osteicthyan peg-and-socket articulation, a separate dermal interlocking system.

The abundance and diversity of fossil gnathostomes from the late Silurian of Yunnan alludes to a high degree of trophic specialisation in these animals well before the advent of the Devonian 'Age of Fishes'. The South China block may well have been one of the earliest centres of diversification for the jawed vertebrates.

The small shelly fauna of the Shackleton Limestone Formation, Transantarctic Mountains

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The lower Cambrian Shackleton Limestone Formation in Antarctica has not previously been systematically sampled for small shelly fossils. Presented here is the first description of the faunas, their biostratigraphy, ecology, taphonomy and regional correlation, from stratigraphic sections measured through an autochthonous fault-repeated carbonate succession in the Holyoake Range. The fauna shows a moderate diversity and abundance, including archaeocyaths, brachiopods, bradoriids, chancelloriids, helcionelloid molluscs, hyoliths, sponge spicules and trilobites. The state of preservation is predominantly phosphatised steinkerns, including external and internal moulds of the original organisms. Tubular structures are also present within, which appear to be composed of framboidal pyrite, indicating bacterial mediation in their construction. The ecology of the limestone assemblage reflects previously reported facies descriptions for the then continental shelf of East Gondwana. Biostratigraphy indicates a faunal connection to both Australia and China, and potentially the Himalayas, dating the formation to Cambrian Series 2, Stages 3-4.

New insights into the origins of Gondwanan tetrapodomorph fishes

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The evolution from water to land represents one of the greatest vertebrate evolutionary transitions, and as such, the tetrapodomorph fishes (Osteichthyes: Sarcopterygii) have fascinated scientists for hundreds of years. Robust debate continues around the timing of this momentous evolutionary step, and also whether the group first emerged in the Northern or Southern Hemisphere. With the aid of synchrotron tomography, we present new data on key Gondwanan taxa, such as *Koharalepis* from the Middle Devonian Aztec Siltstone of Antarctica, and the emblematic *Gogonasus* from the Late Devonian Gogo Formation of Western Australia. Our exceptional 3D-preserved specimens contribute significant data to the abovementioned debates, as well as elucidating new information regarding the evolution of air breathing and tetrapodomorph braincase evolution.

The community succession in the Burgess Shale Formation on Fossil Ridge, British Columbia

Collins, Des

Toronto, Canada

The community succession in the Burgess Shale on the west-facing slope of Fossil Ridge is much richer and more diverse than Walcott imagined. Five metres of very fossiliferous Burgess Shale layers below Walcott's Quarry were excavated by ROM field parties between 1994 and 2000. Together with the Phyllopod Bed, they make up the 7.8 m-thick Greater Phyllopod Bed (GPB). Approximately 134 fossil-bearing layers were collected by the ROM field parties. Twenty-eight of these layers yielded fossils in sufficient numbers to provide a clear representation of the animals buried at these levels.

Three communities in the Phyllopod Bed were described by Walcott in 1912. To these we can add 14 similar to Walcott's 'Great *Marrella splendens*' community; five communities dominated by the sponges, *Hazelia* and *Waptia*, and inhabited by small ptychoparid trilobites; one dominated by the polychaete, *Stephenoscolex*; two by the mollusc, *Odontogriphus*; one by the crustacean, *Canadaspis* and the mollusc *Wiwaxia*; one by the nektaspid, *Naraoia*; and the last by Walcott's 'Great *Eldonia*' community in the Phyllopod Bed. The radiodontan, *Peytoia nathorsti* also characterises the GPB.

About 20 m above Walcott's Quarry, the second major set of communities occurs in the four metre thick Raymond Quarry Beds. These yielded distinct, less diverse communities of larger animals characterised by the priapulid, *Ottoia*, the arthropods, *Leanchoilia* and *Sidneyia*, and by the large anomalocaridid, *Anomalocaris canadensis*.

The third major set of communities occurs in the Collins Quarry at two levels, 50 m and 55 m above the Walcott Quarry. The Collins Quarry was discovered by David Rudkin in 1984, and excavated in 1988 and 1990. Both communities are characterised by the trilobite, *Ehmaniella burgessensis*, a small arthropod with pincers, the cephalopod, *Nectocaris*, the vetulicolian, *Banffia*, and the third radiodontan, *Hurdia*. Each major set of communities is characterised by a different radiodontan.

Soft-bodied fossils from the background mudstone of the Chengjiang Biota – an ignored preservational window

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The celebrated Chengjiang biota is hosted by the Yu'anshan Member (Cambrian Series 2, Stage 3), Chiungchussu Formation, a clastic lithostratigraphic unit of the lower Cambrian of eastern Yunnan, China. The Yu'anshan Member is dominated by extremely fine-grained mudstone interbedded with layers of siltstone, of which the mudstone is subdivided into two types. One is the event grey mudstone layer (yellowish after weathering), lacking algal fragments, but rich in fossils. The other is the background dark grey mudstone layer (dark yellow to brown after weathering), normally containing abundant black algal remains. The typical exceptionally preserved Chengjiang fossils are predominantly from the event mudstone, while the specimens from the background mudstone have been ignored for a long time, primarily due to the rarity and poor quality of the soft-bodied fossils within this slowly deposited sediment. However, recent discoveries reveal that morphological and anatomical features of soft tissues can also be exquisitely preserved in the background mudstone, such as the circulation system of *Fuxianhuia protensa* and the brain of *Lyrarapax unquispinus*, a newly described anomalocaridid. Element-mapping analyses on specimens of *Lyrarapax* from both types of mudstone show that the soft tissues preserved in the event mudstone have been largely replaced by pyrites, while remains from the background mudstone are preserved as a thin carbon film.

This new discovery of exceptionally preserved soft tissues from the background mudstone will increasingly add new data on the morphological and anatomical features of early Cambrian animals, thus enhancing the understanding of the real evolutionary innovations that occurred during the Cambrian Explosion. More importantly, the carbon remains of the background fossils are more similar to the typical Burgess Shale-Type (BST) fossils; comparative studies on the preservation of soft-body fossils in both types of mudstone will shed light on the taphonomy of the BST fossils worldwide.

Eocene floral diversity in New Zealand: a warm life in the South Seas?

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Although southern Australian mid–late Eocene vegetation is known to have been meso- to megathermal (tropical to subtropical) and comprising highly diverse (200+ species) Lauraceae-dominated rainforests, the vegetation of New Zealand at the same time is largely unknown. A study of the macrofloras and palynology of a series of sites of Eocene age across New Zealand shows that the vegetation there also contained diverse rainforests (140+ taxa; ~70% identified to family) dominated by Lauraceae and Myrtaceae, but also with *Nothofagus*, particularly subgenus *Brassospora*, ferns and uncommon but diverse Proteaceae. Floristic elements now represented in Australia, New Guinea and New Caledonia were common in the Eocene of New Zealand, apparently going extinct at various times during the land reduction and subsequent cooling phases of the late Palaeogene and Neogene, respectively. Conifer diversity seems to have been relatively low at most sites examined, based on both micro- and macrofossils, but Araucariaceae were common in late Eocene Waikato sediments, possibly indicating a warmer phase or other edaphic shift. Overall the vegetation between 42–27 Ma appears to have been mesothermal and there is some supporting evidence for ~subtropical conditions and year-round high moisture availability based on CLAMP analyses and epiphyllous fungal diversity.

The bigger they are the harder they hop? Predicted stress during bipedal hopping in macropodoids

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The Sthenurinae, or short-faced kangaroos, are an extinct subfamily of kangaroo that includes the largest vertebrate species for which routine saltation (hopping) has been proposed. However, for some sthenurines, particularly the larger species, it has been argued that hopping may not have been viable and that stresses generated by hopping would have considerably exceeded safety factors sustained by the long bones of the hind limbs. To test this argument we collected femoral data from 14 species of extant bipedal macropodoids and nine extinct sthenurines, including *Procoptodon* sp., and

predicted stresses in the femur over a range of duty factors during one hopping cycle. Duty factor was calculated as the ratio between time where both hind limbs are in contact with the ground (contact time) and total time of stride (time on the ground and time in the air). Previous work has shown that among quadrupedal mammals, duty factor tends to increase with body mass, although why this is so has remained unclear. In the present study, duty factors for 11 extant species were used to determine whether duty factor was related to body size for macropodoids. We found that, as with quadrupeds, duty factor appears to increase with body mass. Furthermore, we found that at higher duty factors, larger bipedal hoppers produce stress comparable to that of their smaller counterparts. These findings do not conclusively demonstrate that gigantic sthenurines routinely hopped, but do highlight a mechanism, i.e., increasing duty factor, whereby even the largest of macropod species may have been able to circumvent limitations imposed by increasing body mass. Our findings may also help to explain why larger quadrupedal mammals tend to increase duty factor with increasing body mass.

Analysis of a highly resolvable and diverse Ediacaran community from the northern Ediacara Conservation Park, Flinders Ranges, South Australia

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A fossil bed (NECP Bed-1) recently excavated from north Ediacara Conservation Park in the Flinders Ranges, South Australia, preserves a diverse community of Ediacaran body fossil impressions, trace fossils, and a texturally complex microbial mat. The first sample, of less than 2 m², was preserved by fine sand grains (0.2–0.5 mm) moulding a benthic Ediacaran community in higher resolution than has previously been observed in the fossiliferous Ediacara Member of the Rawnsley Quartzite. This has enabled the observation of organisms smaller than 2 mm in size, making them some of the smallest resolvable Ediacaran fossils recorded in the Flinders Ranges. Ten other non-contiguous samples of the same bed, were characterised by similar textured organic surfaces (TOS) and sedimentary structures as NECP Bed-1, and shared a similar taxonomic diversity.

Most of the commonly described Ediacaran genera are represented on the bed, and include *Parvancorina minchami*, *Spriggina floundersi*, *Rugoconites enigmaticus*, *Dickinsonia costata*, *Charniodiscus arboreus*, *Kimberella quadrata*, *Tribrachidium heraldicum*, *Yorgia waggoneri*, and two new genera (Form 1 and Form 2). Two *Charniodiscus* fronds aligned with current ripples preserved on the top of the bed provide a palaeocurrent direction for the burial event. Spatially aggregated specimens of juvenile *Parvancorina* are abundant on this surface (n>100). The population displays bimodal orientations of their medial ridges with the prevailing current, a trend that suggests either active alignment with the burial current, or with a prevailing bimodal ambient current, that may have played a significant role in their lifestyle. *Dickinsonia* and *Kimberella* feeding trace fossils are relatively abundant. Several body fossils of *Spriggina* and *Parvancorina* overlap *Dickinsonia* 'footprints', indicative of the dynamics of these primordial organisms. The combination of a high diversity, complex TOS and trace fossils demonstrate that NECP Bed-1 was relatively mature, and an active and complex substrate on which these organisms flourished.

Myoscolex from the Emu Bay Shale: morphology and affinity

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The Cambrian 'muscle worm' *Myoscolex ateles* is an enigmatic animal characterised by well preserved musculature, known only from the Emu Bay Shale of South Australia (Cambrian Series 2, Stage 4). It has an elongate body with over 20 segments defined by bundles of muscle fibres and rodlike structures, a tapering posterior, and unclear anterior features. *Myoscolex* has been compared to annelids, arthropods, *Opabinia* and chordates. Excavations at Buck Quarry have yielded hundreds of new specimens, which have been examined and described. Both longitudinal and dorsal-ventral muscle bands are visible in the specimens, with the latter arranged in opposing pairs. Muscle fibres measured under the SEM are about 2 µm in width, well within the range of arthropod and annelid muscle fibres. Each body segment has one pair of high-relief, mineralised rodlike structures bearing setae that are arranged in a crosshatch pattern. The new material reveals, for the first time, the presence of smooth external cuticle adorned with triangular plates, in addition to the internal layers of body musculature. The cephalic region in several specimens has at least one rounded sclerite with a raised rim, although rare specimens show three or even five rounded sclerites, and tiny, paired structures that may represent

minute head appendages. Although no evidence of *Opabinia*-like flaps or a proboscis was seen, some characteristics of *Myoscolex* suggest a stem-lineage euarthropod affinity, including the cephalic sclerite(s), smooth external cuticle, and presence of longitudinal and dorsal ventral muscles. The arrangement of musculature in *Myoscolex* is also comparable to that of the opheliid polychaetes, while the triangular plates resemble either the elytra of polynoid polychaetes, or the tergites or sternites seen in some euarthropods. The rodlike structures could be interpreted as euarthropod setae or polychaete aciculae. Determination of the affinity of *Myoscolex* requires further examination of growth dynamics and fossil preservation.

The Early Devonian palaeobiogeography of eastern Australasia

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Biogeographical analyses of Devonian Australasia (Australia and New Zealand) often utilise a narrative approach to the interrelationships of biotic provinces. In an attempt to apply a rigorous methodology, temporally and spatially limited areas of endemicity (biochorema) were identified and subsequently hierarchically analysed. Bichorema were proposed using geo-spatial computer software and analysed through phylogenetic programs, resulting in the formalisation of 20 biochorologic sub-provinces such as *Humevale*, *Boola*, *Walhalla-Kilgower*, and *Wurutwun* which are attributed to the Melbourne terrane. These sub-provinces, when compared to the relationships of eastern Australasian tectonostratigraphic terranes, provided crucial insight into the geological and biotic history of the region. The relationship between these units show a significant holdover of Silurian species, the interactions between convergent terranes and the continental margin, the distinct history of the Lachlan Fold Belt terranes, and offers biotic support for the existence of the Tasmanian microcontinent Vandieland.

The distributional patterns of taxa are a useful tool for palaeogeographic reconstructions, providing supplementary information to geological hypotheses. Biogeographic analyses and data, when rigorously applied can be used to corroborate palaeogeographic hypotheses.

Freshly moulted nileid trilobites from the Fezouata Lagerstätte of Morocco

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Arthropods, including trilobites, must moult their protective exoskeleton for growth, development and repair. The process of moulting involves the separation of the exoskeletal cuticle from the epidermis, secretion of new cuticle and transferral of structures (muscle attachment, sensory and circulatory systems), then splitting and shedding of the old cuticle (exuviation). Post-moulting, the new larger exoskeleton is soft and must be expanded before it stiffens, and is fully mineralised in some groups.

At this 'soft-shell', freshly moulted stage, prior to expansion and hardening, the individual remains extremely vulnerable to predation, and thus the stage tends to be very short-lived. The brevity of this stage in the arthropod moult process is reflected in the rarity of preserved soft-shelled specimens. However, freshly moulted individuals likely also have a lower preservation potential owing to their incomplete exoskeletal mineralisation. Very few trilobite specimens to date have been described as preserved immediately post-moulting in their soft-shell stage. These are distinguished based on clear wrinkling and flattening of the exoskeleton. However, deformation may also produce this appearance, and thus possible freshly moulted specimens must be considered in the context of preservation. We describe a rare example of preservation of this short-lived period in the arthropod life cycle.

Ten specimens of a nileid trilobite species were collected from the Burgess shale-type Lower Ordovician Fezouata biota of Morocco. These illustrate the moulting sequence, including two probable moulted exoskeletons, several fully mineralised and hardened carcasses, and others showing variable degrees of soft-shell exoskeletons. The latter show differing amounts of characteristic longitudinal wrinkling, and flattening. Preservational bias is excluded, as other arthropods from the same locality do not show wrinkling or deformation, and nor do the putative nileid moults. The co-occurrence of moults, typical carcasses and soft-shelled carcasses (also seen on a wider scale from the locality) represents one of the only existing examples of a preserved in-the-act mass moult assemblage.

Reconstructing the past – when extinct organisms come to life

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In many ways art is the antithesis to science. It is fueled by emotion, does not have to be reproducible and there rests no burden of evidence upon its architect. There are, however, instances when art and science join in perfect alliance, such as when artists help us palaeontologists bring our extinct organisms to life.

We are all painfully aware of the sometimes daunting task of reconstructing and grasping how an organism actually looked when it was still alive because the incompleteness of the fossil record. Even if we may be successful in getting our message across to the relatively small inner circle of research colleagues, it may pose a significantly greater challenge to spread the message in an interesting and pedagogical manner to those who are not specialists in our field. To put it briefly, how do we reach out to the general public and promote our science of palaeontology?

One way is to 'breathe life' into our extinct and petrified creatures simply by making our fossils into works of art; sculptures that can be readily viewed in museums and which provide an immediate impression of what these once-living organisms looked like. But to do this effectively requires consummate skill; fortunately some artists have dedicated their lives to create highly detailed, precise, three-dimensional replicas of extinct biotas, and one such person is Esben Horn of 10 tons studios on the outskirts of Copenhagen, Denmark.

In this talk, I will present some examples of our fruitful collaboration and discuss some ongoing projects on Cambrian organisms. Based on personal experience, I will discuss how such collaborations can be mutually beneficial for scientists and artists alike. Moreover, I will address how the outcome can be used for outreach and teaching purposes, and also become important tools in research.

Virtual dissection of Cambrian 'Orsten' fossils

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The 'Orsten' Lagerstätte of Sweden contains remarkably well preserved minute fossils from Cambrian bituminous limestones ('Orsten') of the Alum Shale Formation. Since the discovery of these fossils, a sequence of investigations has followed disclosing, among other things, morphological details of utmost interest for the evolution of, and relationships among, early arthropods and their allies. The 'Orsten' fossils are typically dominated by arthropods in the size range of 2 mm or less. The external morphology, including cuticle-bearing extremities, of many 'Orsten' metazoans has been thoroughly described. However, their internal organs and tissues (such as intestines, muscles, etc.) have rarely been addressed and the lack of knowledge of internal anatomy limits the extent to which palaeobiological conclusions can be drawn. In this presentation, I will discuss how the state-of-the-art Synchrotron Radiation X-ray Tomographic Microscopy (SRXTM) analytical technique provides a chance to overcome that problem and offers novel ways to explore these fossils. Sample treatments, analytical set-up as well as some data acquired over the last few years will be presented. All analyses have been performed at the TOMCAT beamline station at the Swiss Light Source (SLS) facility, Paul Scherrer Institute, Switzerland, which provides optimal resources for speedy and precise sample and data processing. The SRXTM technique offers the ability to three-dimensionally reconstruct the morphology in sub-micron resolution, construct virtual serial sections and study concealed anatomical structures. The resulting data allow new structures to be revealed for previously known taxa and for new taxa yet to be identified, with the added benefit of not destroying the unique specimens in the process. The 3D-rendered data of 'Orsten' fossils, revealing their internal anatomical structures, form powerful tools for interpreting functional morphology and mode of life, and allow direct comparisons with the internal anatomy of closely related extant organisms.

Ontogeny of *Dickinsonia costata*

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Dickinsonia costata, an iconic member of the Ediacara biota from South Australia, is one of the most abundant fossils found at the Nilpena field site, west of the Flinders Ranges. Despite receiving much attention since these fossils were discovered, little quantitative data is available about how this organism grows. We present a detailed morphological

investigation of over 900 specimens of *Dickinsonia costata* from the South Australian Museum and Nilpena site. Our data demonstrate expansion is isometric with respect to total length and width, but allometric with respect to height. The organism grows by both the addition and the expansion of modules. Modules are generally added at a decreasing rate through ontogeny and the number of modules is variable based on size. Despite this overall trend, module number is not tightly constrained by size; specimens with same module number can differ in total length by as much as four times. *Dickinsonia costata* modules are generally equal in length at the midline, and increase at the outer margins moving from the posterior to the anterior of the specimen. Module width shows two phases of growth, with modules at the posterior end of the specimen increasing more rapidly than at the anterior end. Variations in expansion rates of modules all contribute to the maintenance of an elliptical shape and total length to width ratio for *Dickinsonia costata.* Our data highlights the importance of increasing surface area via the length to width ratio as the major constraint on growth. These results suggest complex growth patterns for module addition and expansion in *Dickinsonia costata*.

Microbially induced sedimentary structures from the Mesoproterozoic Ruyang Group, western Henan Province

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Microbially induced sedimentary structures (MISS) result from the interaction between benthic microorganisms and sediments. The Mesoproterozoic Ruyang Group in the southern North China Platform is dominated by peritidal siliciclastic rocks and contains abundant MISS, including mat chips, polygonal sand cracks, wormlike structures, mat-smoothed ripple marks and wrinkle structures. Facies analysis suggests that the MISS-hosting sediments were deposited in a supratidal to intertidal setting. MISS from different facies have distinctive morphology resulting from changes in depositional environments. The upper subtidal to lower intertidal zone lacks *in situ* MISS but contains redeposited mat chips. The upper intertidal zone is distinguished by mat-smoothed ripple marks. The lower supratidal zone is rich in various MISS, especially the large and morphologically complex polygonal sand cracks indicative of growth of thick mats in microenvironments with relatively low hydrodynamics that were frequently exposed. The upper supratidal zone developed small sand cracks formed by thin microbial mats. Microanalysis of thin micritic laminae, oriented mica grains and pyrite-concentrated laminae are interpreted as being biogenetic, with the direct involvement of microbes. Polygonal sand cracks and wormlike structures are interpreted to have resulted from dehydration of microbial organic substances. Morphological associations and micro features of MISS from the Ruyang Group are similar to those found in modern siliciclastic coastal environments. Thus, complex MISS in the Ruyang Group may indicate active and diversified microbial communities in Mesoproterozoic coastal settings.

A new locality of Burgess Shale-type fauna from the lower Cambrian Shuijingtuo Formation in Changyang, Hubei, South China

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Lower Cambrian Burgess Shale-type fossil Lagerstätten have been reported from various localities in southern China during the last few decades. Such fossil assemblages have long served as fossil treasure houses to explore the Cambrian Explosion. Recently, a new locality of the Shuijingtuo Formation in Changyang, Hubei has been found, representing the northern part of the Yangze Platform in China. The stratigraphical horizon of the Shuijingtuo assemblage is coeval with the Chengjiang fauna and thus indicative of a Cambrian Stage 3 age.

The fossils are excellently preserved, revealing the anatomy of soft parts and containing valuable phylogenetic information. The present investigations of the new fauna revealed the presence of arthropods, annelids, priapulids, cnidarians, brachiopods, sponges and algae, and some problematic taxa. The fossiliferous strata consist of stacked couplets of thin event and background mudstone layers; the best soft-bodied fossils are preserved in distinct event (light in colour) mudstone layers. The new locality indicates a much wider distribution of Burgess Shale-type fauna during the lower Cambrian.

Palaeoenvironmental and depositional setting of the Emu Bay Shale, a unique early Cambrian Lagerstätte

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The early Cambrian (Cambrian Series 2, Stage 4) Emu Bay Shale (EBS) is an outlier among Cambrian Lagerstätten. Overwhelmingly, soft-bodied Cambrian biotas were preserved in distal shelf and slope environments via the Burgess Shale-type pathway. The EBS biota is noteworthy not only for its unique style of preservation, but also for its more proximal depositional setting. Previous interpretations of water depth and environmental setting of the EBS biota have varied significantly, due to the cryptic nature of the fine-grained sediments that host the Lagerstätte. In order to better constrain the palaeoenvironmental setting of the EBS biota, we conducted an intensive study of the EBS and adjoining strata. The EBS may be divided into three units, a basal mudstone (8 m), a heterolithic middle unit (45.5 m) comprising regularly interbedded mudstone, fine sandstone and minor polymict conglomerate, and a top unit (22 m) of thin-bedded fine sand with diminutive bedforms. The soft-bodied biota occurs in mudstones of the lower member and the lowermost middle member. Several features exclude a shelf setting for the EBS: 1) excellent sorting with only rare grading, and strong separation of sand and mud into discrete depositional beds; 2) pervasive soft-sediment deformation, including wet-sediment loading and gravitationally induced slump structures; and 3) the occurrence of paraconglomerates at multiple horizons, bearing cobbles of diverse lithology. These attributes suggest that the EBS was deposited in a tectonically active nearshore basin in a fan delta setting. The lithological succession and the transition into the overlying tidally influenced Boxing Bay Formation indicate that the EBS represents accumulation across a range of depth and energy conditions in a prograding fan delta complex. The inferred prodelta setting of the EBS biota is unique among Cambrian exceptional biotas, and may have been influenced by freshwater and nutrient delivery from terrigenous runoff.

Palaeoecology of Pliocene fossil plants and fungi from northern New Zealand

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Assemblages of well preserved plant and fungal fossils of probable Pliocene age have been found at several sites around Auckland, New Zealand, including Beachlands and Weymouth. The fossils include numerous fruits, wood, amber, leaves and rarely preserved bracket fungus basidiocarps. Most fossils show organic preservation and many retain three-dimensional structure, allowing for detailed investigation of macro and micro structural features.

These macrofossil assemblages are taxonomically rich, with about 50 fruit or seed morphotypes currently recognised from Beachlands and Weymouth. Affinities are currently known for only a few, including Menispermaceae endocarps (3 taxa), *Elaeocarpus* endocarps (2 taxa), *Terminalia* fruits (~3 taxa) and Casuarinaceae cones. Of these, only *Elaeocarpus* is extant in modern New Zealand. Other fossil types include wood of Nothofagaceae (southern beech), tree ferns and possible Araucariaceae, leaves of Lauraceae, Myrtaceae, possible *Brassospora*-type southern beech, Podocarpaceae, a fern, and numerous basidiocarps of the bracket fungus family Ganodermataceae. The microfossil flora of Beachlands is also diverse, with dominant components including spores from tree ferns (*Cyathea*), polypodiaceous ferns and ferns that produce smooth monolete spores, and pollen of five species of *Nothofagidites*, predominantly *N. cranwelliae*, a *Brassospora*-type southern beech.

Auckland apparently had a warm temperate to subtropical palaeoclimate at this time, as inferred from *Bombacacidites* (Malvaceae) and *Cupanieidites* (Sapindaceae) pollen and Menispermaceae and Combretaceae fruits. The sediments yielding the fossils reflect varied depositional environments, ranging from fluvial to muddy river or possibly estuarine at Beachlands and possibly estuarine to near-shore at Weymouth. Preliminary interpretation of the palaeoecology of Beachlands suggests that diverse plant and bracket fungus communities grew locally, within and around palaeovalleys, and that nearby (possibly further inland) stood forests of mixed beech.

The answer to Darwin's Dilemma: bilaterian-grade Ediacarans that left movement and feeding traces

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Among the diverse body plans of the soft-bodied Ediacara biota from late Ediacaran of White Sea assemblages, undoubted synapomorphies with extant animal phyla are generally absent. However, assessment of bedding assemblages of diverse taxa does suggest the existence of animals with bilaterian affinities. These include trace fossils, where the makers were too small to be resolved, as well as taxa with metameric body plans associated with serial body imprints and feeding traces.

The Australian and East European Platform record of late Ediacaran *Helminthoidichites* groove and levee traces, *Epibaion* serial resting traces of *Dickinsonia* and *Yorgia*, and fanned sets of *Kimberichnus* paired excavation traces attributed to *Kimberella*, represent clear evidence of the existence of motile benthic metazoans in shallow marine siliciclastic environments. Recent analysis of more than 250 specimens of *Spriggina* and two related, unnamed taxa from the western Flinders Ranges in South Australia, suggests that animals of euarthropod grade appeared in the late Ediacaran record that is arguably younger than 555 Ma. *Helminthoidichites* traces show evidence of scavenging organic matter trapped below thin, discontinuous sand layers. This behaviour may have been a prelude to penetrative burrowing that restricted the body fossil record of soft-bodied organisms in earliest Cambrian siliciclastic sediments worldwide.

Palaeoenvironmental setting of non-avian dinosaur tracks in the Lower Cretaceous (Valanginian–Barremian) Broome Sandstone of Reddell Beach, Dampier Peninsula, Western Australia

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The Lower Cretaceous (Valanginian–Barremian) Broome Sandstone of the Dampier Peninsula, Western Australia, is known to host abundant non-avian dinosaur tracksites that are preserved discontinuously across more than 80 km of coastline. Knowledge of the palaeoenvironment in which the tracks were formed is integral to understanding the relationships between these sites, yet site specific palaeoenvironmental studies are lacking. While the occurrence of dinosaurian tracksites near Broome has been known to science for over half a century, factors such as the remoteness of site locations and their occurrence within the intertidal zone have hindered investigations. We addressed these challenges by focusing our research on some of the most accessible track-bearing intertidal exposures, specifically those located at Reddell Beach near the township of Broome. A combination of traditional field data collection, thin section analyses and aerial-based photogrammetry (using an Unmanned Aerial Vehicle (UAV) and manned aircraft) were used to document the site.

The mineralogical composition of the sandstone was found to be highly uniform throughout the site, therefore lithofacies associations (LFAs) were defined based on the presence of structural features. Microscopic and field observations revealed three distinct lithofacies deposited in conditions that are best described by an arid tidal flat palaeoenvironment that, in several respects, exhibits strong parallels with the extant tidal flats of the Colorado Delta, Mexico. The presence of dinosaurian tracks within these facies indicate that their trackmakers travelled across the tidal flats, and may have utilised the flat, open palaeolandscape as a means of unimpeded passage through the area.

Evolution of early molluscs: case study from the Late Ordovician Boda Limestone (Sweden) and the early Silurian of Severnaya Zemlya Archipelago (Arctic Siberia)

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Larval form is a conservative archetype and its study contributes to our understanding of developmental biology and the evolutionary pathways in earlier molluscs. Although early ontogenetic development (embryonic and larval shell) is very important for the classification and systematics of molluscan high taxa, well preserved protoconchs are very rare in the geological record. The oldest finds of embryonic shell are known as isolated protoconchs, thus their taxonomic affinity is unclear.

Recently discovered, numerous, exceptionally preserved molluscan protoconchs of various affinities as well as adult

shells from the Late Ordovician-early Silurian of the Boda Limestone succession in Dalarna (Sweden) and the early Silurian of Severnaya Zemlya Archipelago, Arctic Russia enable the unravelling of the taxonomic affinity and evolutionary pathway of these molluscs.

Dwarfed vendobionts from the Cambrian Kuanchuanpu Formation in South China

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Ediacaran vendobionts are worldwide and diverse, and most of them, particularly frondlike forms, have long remained problematic in affinity and feeding behavior. Here we report five microscopic specimens of vendobionts from the early Cambrian Kuanchuanpu Formation in south China (535 Ma). The exceptional Orsten-type preservation reveals isomeres exhibit left-right asymmetry along the middle rachis, resembling that of *Yorgia*, and the ventral side of these fossils has two alternative rows of canal openings different from both cnidarians and ctenophores. The canal may be responsible for feeding on microbials. The specimens exhibit a two-layered body wall enclosing a single undifferentiated body cavity. The dwarfism of the descendants of Ediacaran organisms are ascribed to the competition of bilaterians or environmental changes at the Ediacaran-Cambrian transition interval.

Charles Darwin's illness: a proposed Precambrian origin

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Charles Darwin endured incapacitating, relapsing illness for most of his adult life with many, very varied symptoms. He suffered from attacks of eczema, lethargy, palpitations and chest pain; on HMS Beagle he experienced unremittent seasickness and when ashore he had at least one episode of severe headache as well as other illnesses. After the voyage he suffered from episodes of nausea, retching, vomiting, abdominal pain, much flatulence and visual disturbances. He also had giddiness, episodes of unwarranted fear and hysterical crying, together with heat and cold intolerance.

More than 40 very different diagnoses have been proposed for this illness; most may be dismissed as they are for complaints that are no longer recognised or are for disorders acquired during or after the voyage. The first symptoms of Darwin's illness were present long before the voyage. A maternally inherited, pathological mtDNA mutation explains not only the full spectrum of Charles Darwin's illness but also that of his older brother Erasmus, their mother and her siblings, and in turn their mother, Charles' grandmother, Sarah Wedgwood. Detailed family history shows illness spanning six generations of the Wedgwood-Darwin families.

Darwin's illness with its numerous symptoms and his family history of illness are characteristic of a mitochondrial disorder. Mitochondria were unknown in Darwin's time but he would have been intrigued to learn of them and of their endosymbiotic origin following the association of a primitive proteobacterium with a prokaryotic cell some 2 billion years ago. The organelles retain some of their original DNA, mtDNA, and mutations in this DNA are relatively common; pathological mutations result in impaired mitochondrial function causing numerous symptoms.

Darwin's illness restricted his activities, but as will be discussed, may not have had only negative effects.

Determining the distinction between sun and shade leaves for palaeoclimate inference

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We will present progress in the use of leaf cuticular features to determine the difference between sun and shade leaves. The advantage of creating a model for this purpose is that we can then use only fossilised sun leaves as proxies for past climates. Epidermal cell area (μm^2) is the strongest informer of whether a leaf is a sun or shade morphotype; small epidermal cells are indicative of sun leaves. Further to this, epidermal cell density (epidermal cells per mm^2) is negatively correlated with minimum temperature of the coldest month (°C). Therefore, We present minimum temperature estimates for several Tasmanian sites where *Nothofagus cunninghamii* leaf fossils have been collected and cuticular features measured. These predicted temperatures are colder than those previously estimated.

The Cenozoic Araucariaceae macrofossils of southern Australia

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The conifer family Araucariaceae has an especially interesting macrofossil record. It had a strong, worldwide distribution for a long period of time, but more recently it has been lost from the Northern Hemisphere and has been concentrated in a typical Gondwanic distribution. The macrofossil record is dominated by wood, foliage, male cones and female cones or isolated cone scales. Araucarian pollen is also common, but is not considered here. Wood and reproductive structures are relatively common, but in southern Australia, foliage dominates.

Four genera are of particular interest: the extant *Agathis, Araucaria* and *Wollemia*, and the fossil *Araucarioides*. *Agathis* leaves are relatively common fossils in southern Australia and also in New Zealand. There has been a recent convincing record of *Agathis* from South America and some old published records of *Araucaria* may still prove to belong to this genus. Setting species limits on fossil *Agathis* leaves is challenging and it may be that some described fossil *Agathis* species actually belong to *Araucarioides*.

Fossil *Araucaria* leaves are common in southern Australia, South America, New Zealand and Antarctica. The literature on these fossils is confusing, in part because of different forms of preservation (some have cuticular preservation, some do not). There appears to be a major issue with the application of species names to fossil *Araucaria* leaves, with very slight differences warranting separate specific identity. Southern Australia is one of the highly diverse regions for *Araucaria* fossils. The fossil record of *Wollemia* is highly contentious, and no unequivocal records of this genus exist.

Finally, the history of the extinct genus *Araucarioides* is gradually being reconstructed, and so far it appears to be restricted to the late Cretaceous-Palaeogene of southeastern Australia and New Zealand.

If you build it they will explore: palaeontology and digital technology create a gateway for Science Technology Engineering and Mathematics (STEM) audiences

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Play is a key behaviour of learning and taps into our need to explore and discover the real world. This is particularly true for STEM disciplines where exploration, observation and experimentation are powerful tools for research and education. The physical confines and sedentary nature of the classroom along with the restrictive mechanisms of the schooling environment make real world exploration limited (costly), impractical (time) or impossible (both). Museums (and like organisations) provide a key role in bridging this gap by providing authentic snapshots of the real world for en masse (and safe) consumption.

Traditional museum displays are analogue versions of a virtual or augmented-reality world experience. Museums sample the real world and make collections, extract or abstract them, and present these as authentic snapshots frozen in time, usually behind glass, and representing a mere fraction of the total collection itself. By extension this is a tiny fraction of the real world. The restrictions of exhibition space, specimen location, fragility, rarity, size, perceived 'sexiness' and budget all factor into decisions as to what part of this small sample gets to be displayed and interpreted.

Digital technology allows museums to break through this barrier and sample a much greater proportion of the real world to be included within their collections. Armed with a digital collection of specimens, sites and sounds there is a multitude of ways that these snapshots in time can be reanimated to augment real material, create entirely new ways of interacting with collections both real and virtual, and deliver experiences to a wider audience including people with sensory disabilities.

We will showcase examples of where we have integrated these museum digital collections with software platforms designed for the commercial, gaming and geospatial industries to create a variety of unique and engaging STEM experiences.

Size doesn't matter: integrating and accessing massive 3D datasets with no compromise on model fidelity

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Three-dimensional (3D) datasets are increasingly used in palaeontology across a diverse range of studies. The aim of capturing a 3D dataset is to digitally reproduce the object of interest in the highest fidelity possible with currently available technology. The level of detail is dependent on the applicability of the technology for the object's size and accessibility. For example, scanning a fossil site with a Synchrotron is probably not possible, while photogrammetry cannot yet capture internal structures of an object. However, integrating these separate 3D datasets and securely sharing them with the research and broader community has vast potential and will open up new areas for research and STEM education. Realising this potential encounters a major compromise common for those familiar with 3D modelling – *detail for computing power*. To adequately visualise a single 3D model you either need to invest in greater computing power to retain high fidelity detail or sacrifice large amounts of detail for a poor representation. This inevitably leads to an initial reduction in data collection in the first place. Why collect it if you can't use it? For datasets that can only be collected once before removal (e.g. site excavation layers, salvage sites, etc.) this compromise is a difficult pill to swallow.

Software developed in Brisbane, Australia, removes this major compromise with a platform that can visualise unlimited numbers of 3D models at any level of detail in a single scene. These data can be visualised directly from an external hard drive to online. The software allows us to compose scenes using 3D models created from a range of different techniques and captured at the current highest level possible. We will demonstrate this new technology with examples from research undertaken at the Queensland Museum by us, including a wide range of vertebrate fossils, dinosaur trackways, megafauna sites and caves.

The attachment strategies of Cambrian kutorginate brachiopods – the curious case of two pedicle openings and their phylogenetic significance

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The kutorginates are commonly the most abundant rhynchonelliform brachiopod found in the early Cambrian and they are also some of the oldest known rhynchonelliforms, first appearing in the unnamed Series 2 (Atdabanian) and becoming extinct by the unnamed Series 3 (Amgaian). Kutorginates are also the first known member of the extant rhynchonelliforms for which we have a detailed knowledge of their soft-part anatomy, including the lophophore, digestive tract and pedicle – all exceptionally preserved in *Kutorgina chengjiangensis*. The stout and annulated pedicle in the original report was described as protruding between the valves; however, newly collected better-preserved material now clearly shows that the pedicle actually protrudes from the apical perforation of *Kutorgina chengjiangensis.* This type of apical pedicle has also been described from other early Cambrian rhynchonelliforms, including the problematic chileate *Longtancunella chengjiangensis*. Exceptionally preserved similar pedicles are also known to emerge apically from Silurian chileate dictyonellids as well as from the recently described Silurian chileate *Trifissura*. However, it is clear that the only other exceptionally preserved kutorginate, a silicified *Nisusia,* was provided with an adult pedicle emerging between the valves from a posterior gap – thus *Nisusia* has two pedicle openings, but the apical foramen may represent the earliest attachment of the larvae, which subsequently became non-functional through ontogeny. It is suggested that both types of attachment strategies may have appeared early in the stem lineage of the Rhynchonelliformea.

Assemblage relationships between Cambrian Lagerstätten and their palaeobiogeographic implications

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Exceptional fossil deposits exhibiting preservation of soft parts (Konservat-Lagerstätten) are more prevalent in the Cambrian than at other times, and offer great insight into the evolution of animals following the Cambrian Explosion. It is well known that many of these deposits share common faunal elements, many of which have seemingly cosmopolitan distributions. These taxa are characteristic of what have been termed Burgess Shale-type (BST) biotas, named after the eponymous site in the Canadian Rocky Mountains, and which constitute the assemblages present in the majority of Cambrian lagerstätten. The similarities evident between these assemblages have been noted by a number of authors, although quantitative comparison has not been undertaken in a broad sense.

In order to examine the relationships between BST biotas based on assemblage we have compiled a database of over 600 genera present/absent at 12 Cambrian Lagerstätten from East Gondwana, South China, Siberia and Laurentia, and ranging in age from Cambrian Series 2 through Series 3 (approximately 517–502 Ma). We analysed these data using multivariate analyses, in particular the ordination methods of Non-Metric Multidimensional Scaling (NMDS) and Detrended Correspondence Analysis (DCA), to examine the relationships between sites. We obtained relative geographical coordinates by plotting sites on several continental reconstructions, and absolute age estimates by biostratigraphic correlation with the most recent Cambrian timescale, to test whether distance and/or age have a significant effect on taxon differences observed between assemblages. We also compared the distribution of diversity (number of genera per phylum) between sites.

Initial results suggest that both space and time have an important effect on Cambrian Lagerstätten assemblages, and that similarity between assemblages appears to increase from Series 2 to Series 3, possibly due to an increase in dispersal ability. Higher level taxonomic turnover is apparent through time.

Growth and development in the Ediacaran: new quantitative approaches

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The discovery of Neoproterozoic macrofossils stands as one of the most remarkable achievements in twentieth century palaeontology. However, ‘Ediacaran biota’ have proved difficult to place definitively among the extant taxa, and there remain many outstanding questions regarding their growth, development and functional morphology. This presentation will describe some new quantitative approaches to the analysis of growth, development and morphology in Ediacaran organisms, including fractal analysis of the Rangeomorpha. I will then discuss the implications for feeding modes and adaptive optimality in the Ediacaran, and explore whether quantitative growth analyses can provide new insights into these enigmatic fossils.

Abundant fossil macroalgae in the Ediacara Member, Rawnsley Quartzite, South Australia

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The Ediacara Biota contains fossil evidence of the first complex macroscopic organisms on the planet and comprises more than 50 unique and morphologically diverse genera. While the phylogenetic affinities of these fossils are debated, many are considered animals but macroalgae are typically not interpreted to be a common component. Excavation of 30 fossil beds with areas variously in the range 2-27 m^2 of the Ediacara Member (Rawnsley Quartzite) at the Nilpena Station National Heritage Site allows in situ examination of these taxa. Taxa of the Ediacara Member include iconic forms such as *Dickinsonia*, *Tribrachidium* and *Parvancorina* but a relatively common fossil found at Nilpena is a general form referred to as ‘Bundle of Filaments’ (BOF). There are three different morphologies of this form, the most common of which has a holdfast, stipe and a blade formed by a bundle of filaments. The second form lacks a stipe and is a band

form and the third has a long stipe and very small blades. Specimens are up to 50 cm long. BOF is unlike any other fossils found in the other classic Ediacara biota localities; however, it is comparable to fossils in the Doushantuo Formation black shales of South China. Although BOF is found on several of the 26 beds in South Australia, it typically occurs as isolated specimens. However, on one bed, around 7 m^2 in area, a dense assemblage with over 20 specimens per square metre occurs. Specimens show no evidence of transport (such as orientation or breakage) and are interpreted as being preserved *in situ*, revealing an algae-dominated community within the Ediacara Member. Minor taxa occurring with these specimens include some of the smallest specimens of *Dickinsonia* and sprigginamorphs.

The Cambrian palaeontological record of the Indian subcontinent

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The Indian subcontinent's biota is among the least well known of any Cambrian succession worldwide. Comprehensive revision of previously described type material and a substantial number of new finds reveal a typical Cambrian fauna. Regional biostratigraphic zonations for trilobites, brachiopods, small shelly fossils and trace fossils yield an integrated Cambrian biostratigraphic scheme that permits correlation along and across the lithotectonic zones of the Himalayan margin and southward onto cratonic India. These consist of 13 named biostratigraphic units for trilobites, seven for brachiopods, three for small shelly and organic-walled fossils, and one for trace fossils. The basal boundary of the Cambrian (~541 Ma) is biostratigraphically localised between Ediacaran carbonate-rich beds bearing the organic-walled tubular *Shaanxilithes ningqiangensis*, and dark, highly stratigraphically condensed beds bearing Fortunian (~535 Ma) and Cambrian Stage 2 age (~524 Ma) fossil assemblages. The oldest macrofossils presently known are Cambrian Stage 4 in age and some are widely represented in siliciclastic rocks across and along the Himalaya. Stage 5 fauna are the most diverse and best biostratigraphically characterised, with much of it relatively well preserved in limestone. Rates of sediment accumulation were notably high. The *indicus* Zone has recently been localised, a short distance below the *prachina* Zone. Furongian (late Cambrian, ~493 Ma) fossils are known in the Bhutanese Himalaya and the Cambrian succession is capped by an unconformity throughout the Himalaya. The regional Cambrian can be correlated globally with reasonable precision, and all parts of the Himalayan margin south of the Yarlung-Tsangpo suture have a core equatorial Gondwanan biota, most similar to those of North China and particularly, South China. Links with Australia are suggested but Indian biotas share less in common with Australia than with China. Knowledge of the Himalayan Cambrian biostratigraphy serves a critical role in constraining the Cenozoic uplift and erosional history of the orogen.

Opalised crinoid communities from the Bulldog Shale, Eromanga Basin, South Australia

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Opalised fossils occur frequently within predominantly Aptian horizons of the Bulldog Shale at Coober Pedy and Andamooka in the southern Eromanga Basin of South Australia. The skeletal remains of amniotes are especially famous; however, taxonomically rich assemblages of benthic macroinvertebrates are far more prolific. During the Early Cretaceous, the Eromanga Basin was inundated by an epicontinental seaway characterised by endemic cool water communities, yet little is known about the structure of these ecosystems, how they were formed, or their potential links with amniote fall material which likely served as both benthic island substrates and a nutrient source. Mesozoic amniote fall macroinvertebrate communities have been previously reported from Cretaceous strata, such as in Hokkaido, Japan. Therefore, similar assemblages in the Eromanga Basin are in critical need of attention, particularly relative to their exceptional opalisation and occasional soft tissue preservation. In this study, we conduct a preliminary survey of the diverse invertebrates in the collections of the South Australian Museum including exceptionally preserved opalised crinoids, which are not only a new genus but also show strong affinities to coeval communities in Antarctica. Additional crinoid material, discovered outside of the opal sediments, is associated with driftwood, and so far, one plesiosaur skeleton has been encountered with associated macroinvertebrates. We discuss the crinoid data in relation to these benthic island habitats to try to better understand their community structure.

Prolonged coexistence of 'archaic' and 'modern' Palaeozoic ophiuroids – evidence from the Early Permian, southern Carnarvon Basin, Western Australia

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The discovery of a very large ophiuroid in the Early Permian (Kungurian) Cundlego Formation in the southern Carnarvon Basin in Western Australia extends the stratigraphic range of 'archaic' ophiuroids into the Permian, unlocking a lost fossil record of this group. Hitherto such protasterid ophiuroids had been known from strata no younger than early Carboniferous. We describe this ophiuroid within a proposed new subfamily. The temporal coexistence of this form with Permian ophiuroids with a 'modern' morphological architecture, demonstrates that rather than 'modern' ophiuroids having replaced 'archaic' ophiuroids in the early Carboniferous, the two forms became separated biogeographically. 'Archaic' ophiuroids persisted in high-latitude seas, having been replaced in the shallow water, low-latitude niches by the 'modern' ophiuroids.

In modern oceans, ophiuroid gigantism similar to that in the described ophiuroid is only known from cold, high-latitude oceans. It has been argued that the frequent occurrence of gigantism in such environments is due to the much lower levels of predation pressure. Unlike other echinoderm classes, the morphological and ecological transformation that resulted in the evolution of 'modern' ophiuroids had already taken place well before the events of the Permo–Triassic mass extinction. With the increase in diversity of durophagous predators in low-latitude shallow water communities during the Mesozoic, ophiuroids were displaced into regimes of lower predation pressure in high-latitude oceans, which, as with the high-latitude boreal oceans during the Permian, appears to be an environment that favours the evolution of very large ophiuroids.

Phosphate, facies and fossilisation of early Cambrian molluscs

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The molluscan fauna from carbonates in the lower Cambrian Hawker Group, South Australia displays a remarkably patchy stratigraphic distribution. Some stratigraphic levels are exceptionally fossiliferous, with molluscan taxa dominating faunal composition, while in adjacent beds they are virtually absent. This study identifies and investigates depositional facies and taphonomic processes controlling molluscan preservation by integrated lithological, compositional and palaeontological data. Fossil material for this study is derived from a stratigraphic section on the eastern limb of the Arrowie Syncline in the northern Flinders Ranges. Detailed petrography of the carbonates reveals a high preservation potential for taxa in a range of facies types. Six depositional Facies Sequences are identified up-section including (in ascending order), restricted and open lagoonal systems, high-energy inner ramp shoal complex, mid-shelf to proximal ramp, mid- to outer ramp, and outer ramp environments. The facies that preserve the most abundant molluscan taxa are those with increased phosphate precipitation and sedimentation rates, and higher-energy regimes, especially in firmgrounds, incipient hardgrounds and transported deposits. The strong association between phosphate and molluscan preservation has far-reaching implications for biostratigraphy and palaeoecology, and highlights the importance of establishing taphonomic controls of molluscan faunas prior to their use in applied studies.

Simulated range of motion and hindfoot posture of *Rhoetosaurus brownei* Longman 1926 (Sauropoda, Gravisauria)

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Although the basal sauropod *Rhoetosaurus brownei* is the largest terrestrial vertebrate known from Australia's Middle Jurassic, many aspects of its palaeobiology are poorly understood. It is also one of Australia's most complete dinosaur fossils, represented by a partial skeleton that includes a near-complete right hind limb. In this study, we used 3D computer modelling to analyse the biomechanics of the foot of *Rhoetosaurus*, utilising a combination of photogrammetry and digital reconstruction. Virtual models were used to calculate the Range of Motion (ROM) for each of the autopodial joints (metatarsophalangeal [MTP] and interphalangeal [IP]), providing new information on pedal flexibility and posture. *Rhoetosaurus* was capable of significant digit mobility in the sagittal plane at the MTP joint (dorso-/plantarflexion), and in the sagittal, transverse and frontal planes at the distalmost IP joint. In addition, flexion of the cranially convex metatarsal bridge would have been impeded by the triangular profile of the astragalus, making a skeletally digitigrade pedal posture

more likely. The elevated metatarsals are likely to have been supported by a compliant fibrous pad, consistent with that implied from sauropod track impressions. The resultant pedal posture was therefore likely to have been functionally plantigrade, as has been suggested previously based on gross morphology. On hard surfaces, plantarflexion of the unguals would have been restricted during walking, indicating that this type of movement might have been used for 'substrate gripping' on more compliant surfaces or other activities, such as digging. Although our results provide new insights into the simulated ROM and posture of the hind foot of *Rhoetosaurus brownei*, additional parameters (such as loading regimes and inferences from ichnological data) need to be incorporated into the model before we can fully understand the pedal biomechanics of this sauropod.

The importance of ancient cave deposits for understanding early Mesozoic lepidosaurian reptiles

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Ancient caves have made a major contribution to our understanding of the evolution of amphibians, mammals, and reptiles. A notable example is provided by the Late Triassic-Early Jurassic fissure fills of England and Wales. These sites preserve the diverse fauna of a subtropical island archipelago from a key time period. As well as cynodonts (*Oligokyphus*), procolophonids, archosaurs and mammaliforms (e.g. *Morganucodon*), the fissures have provided a stem-lepidosaur (the gliding *Kuehneosaurus*) and ten species of lepidosaur in six genera. Characters of the teeth and jaws show that these species are early members of Rhynchocephalia (related to the modern tuatara of New Zealand, *Sphenodon punctatus*) rather than their sister group Squamata (lizards and snakes). The fossil material is often broken and disarticulated but can preserve exquisite surface detail, and the sample size permits an appreciation of intraspecific variation. These ten species represent a significant proportion of all named rhynchocephalian species (18.5%) and contribute to their tallest peak in taxic diversity between the oldest known material from the Middle Triassic and today. Several of these taxa are unknown from anywhere else in the world and have been key to revising our understanding of lepidosaur evolution. The fossil taxa showed that several features of the modern *Sphenodon* are not primitive and that Rhynchocephalia were previously much more diverse, particularly with respect to tooth shape and arrangement. Here, for the first time, we describe postcranial and articulated cranial material of *Diphydontosaurus* from one of the English Triassic fissure-fills and show that previous interpretations of the skull based on isolated bones are essentially correct, e.g. the lower temporal bar is incomplete. One minor difference is a relatively shorter postorbital region. The postcranial skeleton is gracile with unusually long forelimbs. The number of presacral vertebrae is similar to that of other terrestrial rhynchocephalians (24-26) but considerably less than the number recently calculated to be ancestral for lepidosaurs (39).

Middle Ordovician (Darriwilian) radiolarians from Piccadilly, western Newfoundland

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Understanding the evolution of early Palaeozoic radiolarian faunas remains problematic as only a handful of well preserved, isolated Ordovician localities are known. Detailed study relies on the ability to observe complete internal structural details in specimens that commonly have densely latticed multiple shells. Species level identification is currently based on combinations of external as well as internal morphological characteristics. Until now the most commonly used observational method (scanning electron microscopy) has only provided a view of surface details. The introduction of 3D X-ray microtomography makes it possible to observe the complex internal details of specimens non-destructively. This allows us to more accurately and quantitatively describe radiolarians with measurable precision at submicrometre scales.

An extremely well preserved Middle Ordovician (mid-Darriwilian) radiolarian fauna from the top of the Table Point Formation in the Piccadilly Quarry, western Newfoundland, provides a rare opportunity to investigate details not yet observed in most early Palaeozoic radiolarian faunas. This exposure is a well known graptolite and sponge spicule locality, but until now the radiolarians have never been examined in any detail. The Piccadilly Quarry exposes a succession of rhythmically interstratified beds of dark grey fossiliferous and peloidal limestone with a predominance of pelagic organisms. Exceptionally well preserved radiolarian assemblages, together with age-diagnostic conodonts and diverse assemblages of disarticulated sponge spicules, were recovered from thirteen samples. Systematic investigation of radiolarians freed by acetic acid digestion from their host rocks documents a dominance of species attributable to the spherical Inaniguttidae. Spicular forms are also conspicuous but not abundant. An initial study of the radiolarian assemblages was made using

scanning electron microscopy. The detailed internal structure of several problematic radiolarian specimens was then investigated using 3D X-ray microtomography in order to answer outstanding systematic and biostratigraphic questions.

Phylogeny, fossil history and biogeography of Ripogonaceae

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We are exploring the evolutionary relationships of newly discovered, undescribed leaf macrofossils of the monocot genus *Ripogonum* (Ripogonaceae) in comparison to extant members of the genus. *Ripogonum* fossils from late Eocene, Oligocene and Miocene deposits in New Zealand are being examined and compared with already described early Eocene fossils from Australia, New Zealand and South America. Macrofossils from sites across New Zealand's South Island show differing morphological features, suggestive of a greater historic species diversity for the genus within New Zealand. Morphological analysis of these macrofossils will be correlated with morphological data from extant taxa and cross-referenced to a modern, multi-gene, chloroplast and nuclear DNA sequence-based molecular phylogeny of the family. A revision of the historical diversity of fossil *Ripogonum* species in New Zealand and their evolutionary relationships will help us to better interpret the past biogeography of the genus. In particular, it would help to shed light on vicariance versus dispersal between various elements of Gondwana during the Palaeogene and historic speciation within the genus. Understanding these fossils better will also help to interpret their palaeobiology in response to factors such as climate and insect damage.

Systematic account of Miocene Rhinocerotidae from the Siwaliks of Pakistan

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The Neogene Siwalik deposits of Pakistan are famous worldwide for their rich mammalian faunas, which have been known for almost two centuries. The rhinoceroses are an important component of the Siwalik mammalian fauna; however, they are not an easy group to deal with, as cranial remains are very rare and fragmentary in nature. The rhinocerotid fossils presented in this paper were collected from various localities of the Siwaliks of Pakistan ranging in age from late early Miocene to the late Miocene. The sample comprises well preserved maxillary and mandibular fragments together with isolated teeth belonging to six rhinocerotid genera. The generic and specific recognition of the fossil material is based on morphometric comparison with the previously known rhinocerotid records from various Siwalik strata. The lower Siwalik Kamlial Formation has yielded three rhinoceros genera including *Brachypotherium, Mesaceratherium* and *Alicornops*; whereas *Brachypotherium*, *Gaindatherium*, *Chilotherium* and *Caementodon* were collected from various localities of the Chinji Formation. In the Nagri Formation of the middle Siwaliks three rhinoceros genera including *Brachypotherium*, *Gaindatherium* and *Chilotherium* are identified; whereas in the Dhok Pathan Formation, *Alicornops* and *Brachypotherium* are present. The present fossil material will add new information to the Siwalik rhinocerotid records and will help in updating the systematics and palaeobiogeography of this ecologically important taxon.

Tragulids (Artiodactyla, Ruminantia, Tragulidae) from the Siwaliks of Pakistan

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Tragulids are the best represented ruminants after bovids in the Siwalik Group of the subcontinent. Two genera *Dorcatherium* and *Dorcabune* are common in the Siwalik freshwater deposits. *Dorcatherium* is represented by four species: *D. minimus, D. minus, D. nagrii* and *D.majus*, and *Dorcabune* by two species: *Db. nagrii* and *Db. anthracotherioides.* Most of the species differ in size. The remains described in this paper comprise predominantly isolated teeth, maxillae and mandible fragments. The collection of tragulid fossils from Pakistan is the most extensive record of this group in the Siwaliks. The tragulids suggest a humid habitat with abundant cover.

Bayesian analysis and the origin of the jawed vertebrate body plan

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The phylogeny of early jawed vertebrates (gnathostomes) has remained stable since the first large-scale cladistic analysis of the group at the end of the last decade. In the current paradigm, placoderms (an extinct group of armoured fish) form a paraphyletic assemblage of stem gnathostomes. This phylogenetic framework has been used to address questions of how major vertebrate features first evolved, including the origin of internal fertilisation, teeth and the jawed vertebrate face. A major overhaul and expansion of the data matrix underlying this phylogeny shows that morphological support for placoderm paraphyly is virtually non-existent, with uncertainty about the position of the root of the tree due to lack of a suitable outgroup. Analysis in a Bayesian framework, using recently developed morphological clock methods, instead shows strong support for placoderm monophyly, which, if correct, would require rethinking major aspects of the origin of the gnathostome body plan. This analysis also shows elevated evolutionary rates during the Silurian and Early Devonian periods following the origin of jaws, potentially providing an explanation for the topological uncertainty at the root of the tree.

Ajax Mine archaeocyaths: a preliminary biozonation for the upper Hawker Group

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Within the Australian-Antarctic province, a key area for elucidating an archaeocyath-based biozonation is the Arrowie Basin of South Australia. Within the basin, Gravestock (1984) and Zhuravlev & Gravestock (1994) recognised a threefold zonation of the pre-Flinders Unconformity interval of the Hawker Group, a package that spans much of the early Cambrian. For the post-Flinders Unconformity interval, they proposed the informal *Syringocnema favus* beds, based primarily on the fauna of the Koolywurtie Limestone Member in the Stansbury Basin. This assemblage is widespread in Australia and Antarctica. The stratigraphic span of the *Syringocnema favus* beds was depicted as restricted to the timespan of the host member, correlated to an interval in the medial Hawker Group, leaving the bulk of the group unzoned.

The aim of the present project is to establish an archaeocyath-based biozonation for the post-Flinders Unconformity interval, to replace this informal nomenclature. Within this interval, the great majority of known Australian-Antarctic archaeocyath taxa have been described from Ajax Mine.

Two measured sections across the archaeocyath-bearing Ajax Limestone interval at Ajax Mine were sampled for the present study. A total of 81 archaeocyath, one acanthinocyathide, one coralomorph, one radiocyath and the small skeletal fossil *Tunkia incerta* R. Bedford & J. Bedford have been identified - 85 species in total. In a composite section of notional thickness 154 m, identified potential levels for the definition of zone bases are at the first appearance datum (FAD) of *Putapacyathus regularis* R. Bedford & J. Bedford at a level notionally 11.0 m above the section base, the FAD of *Kisasacyathus subacutus* (R. Bedford & W.R. Bedford) at 17.2 m above the section base, and the FAD of *Kruseicnema gracilis* (Gordon) at 19.8 m above the section base. Detailed studies of further suitable sections need to be undertaken to test the biostratigraphic value of these proposed guide species.

Giant early postembryonic stages of trilobites reveal the evolution of lecithotrophic development in the Cambrian

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The early postembryonic stages (protaspides) of the Cambrian trilobites *Hydrocephalus carens* and *Eccaparadoxides pusillus* show unusual morphology, which is characterised by an inflated glabella, reduced fixigenae and significantly larger dimensions than most of the other Cambrian protaspides. While the earliest instar of *E. pusillus* is about 0.9 mm wide, the corresponding instar of *H. carens* reaches 1.9 mm in transverse width. We suggest, based on morphology, size, growth patterns and distribution of these early instars, that *H. carens* had lecithotrophic development. A similar type of development is proposed for *E. pusillus*, although the data are less convincing in this case. Analysis of protaspides of other Cambrian trilobites shows a correlation between protaspid sizes, excursions of $\delta^{13}C$ and palaeogeography. The largest protaspides are related to a prominent negative excursion at the base of the Drumian (DICE) and/or to the higher latitudes of the West Gondwanan margin. These specific environmental conditions may have led to the evolution of lecithotrophic

development in some trilobite taxa.

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Timescale 'paradigm shift': CA-IDTIMS and Permian palynostratigraphy

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The prime correlative tools for the Permian Time Scale are marine zonations (conodonts, ammonoids, fusulinids and benthic forams), which define nine stages. The base of each stage is (or will be) defined at a GSSP in the northern hemisphere, and all these sites were at low latitudes at the time of deposition. Australia, on the other hand, was at high latitudes throughout the Permian and as a consequence, fusulinids are unknown, conodonts are rare (Western Australia) or absent (Queensland, New South Wales, Tasmania), and ammonoids are rare (Western Australia) or very rare (Queensland, New South Wales, Tasmania). Furthermore, much of the succession in the eastern Australian coal basins (Sydney, Gunnedah, Bowen) is nonmarine, and the main correlation tool is a spore-pollen zonation. Palynomorphs are often rare in marine sediments, so correlation of the spore-pollen zonation to the Permian standard is based on rare conodont and ammonoid occurrences in intervening marine sediments. Unfortunately, Australian Permian marine faunas are endemic, such that even correlation from eastern to western Australia is difficult, and correlation to the Permian Time Scale is exceptionally difficult.

Zircon U-Pb dating has long been plagued by spuriously young ages reflecting cryptic, post-crystallisation loss of radiogenic Pb. However, the advent of Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) has largely overcome this problem, and improved accuracy and precision in dating magmatic zircons. In the eastern Australian coal basins, the presence of ashfall tuff layers throughout the succession has allowed direct calibration of the Permian spore-pollen zonation against the numerical timescale, showing that some of the previous purely biostratigraphic correlations were wildly inaccurate.

Volcanoes were active in eastern Australia over most of the Phanerozoic, giving us the opportunity to recalibrate local biostratigraphic schemes directly to the numerical timescale, thereby overcoming the problem engendered by the faunal and floral endemism so common in Australia's sedimentary record.

Biodiversity and palaeoecology of Hindon and Foulden Maars: two early Miocene Konservat-Lagerstätten from New Zealand

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We highlight the biodiversity and palaeoecology of the early Miocene Hindon and Foulden Maars, two Konservat-Lagerstätten deposits from southern New Zealand. The 1000 m diameter, *ca* 200 m deep volcanic crater lakes were closed systems with anoxic bottom waters which captured and preserved a cornucopia of organisms from the lakes and adjacent rainforests including thousands of leaves with cuticular preservation, flowers with *in situ* pollen, fruits, seeds, fish and many families of arthropods. Hindon Maar was surrounded by a mixed *Nothofagus* podocarp forest whereas an evergreen Lauraceae-dominated notophyll vine forest with a diverse understorey grew around Foulden. Fish include larval to adult stages of articulated *Galaxias*, some with preserved soft tissue, and eels resembling *Anguilla*. The arthropod faunas comprise *ca* 20 families in the orders Araneae (spiders), Plecoptera (stoneflies), Odonata (dragonflies), Isoptera (termites), Hemiptera (true bugs), Diptera (true flies), Coleoptera (beetles), Trichoptera (caddis flies) and Hymenoptera (wasps, ants and bees), representing faunas typical of soil, leaf litter, forest floor or freshwater habitats. Many fossil taxa have close relatives in the extant New Zealand biota; others are now locally extinct. Coprolites containing quartz sands sourced from outside the lake, and newly discovered feathers indicate the presence of volant birds, presumably waterfowl. Similarities and notable disparities between the biota at the Hindon and Foulden sites will be highlighted and discussed. The Hindon and Foulden Maar Lagerstätten are proving to be key sites for reconstructing early Miocene Southern Hemisphere terrestrial ecosystems.

True or not: end-Guadalupian mass extinction in the Boreal Realm

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The end-Guadalupian extinction event, which preceded the Permian-Triassic mass extinction, has been suggested as a severe biotic crisis comparable to the big five mass extinctions of the Phanerozoic. However, there is still debate about its global significance. In particular, this event in the Capitanian has been mostly recognised from equatorial (Tethyan) localities while it has seldom been identified in higher latitudes.

A recent study on the Kapp Starostin Formation in Spitsbergen (Boreal Realm), claimed biostratigraphic and chemostratigraphic evidence that the end-Guadalupian extinction was followed by a recovery phase. However, our studies on the brachiopod faunas of the same formation casts doubt on this interpretation. We recognise a total of five brachiopod assemblages from the type section of the Kapp Starostin Formation at Festningen. The most striking assemblage change is observed at the interval between the lowermost Vøringen Member (late Artinskian) and the overlying member (Kungurian), rather than in the Capitanian as previously claimed. This faunal turnover can be linked to a significant climatic shift (cooling) during the Artinskian–Kugurian transition in the northern margin of Pangaea.

Our result shows that the Capitanian event in Spitsbergen does not seem to represent a catastrophic mass extinction, rather it records a faunal transition. This faunal transition is accompanied by some major changes in lithology, suggesting a degree of control by local environmental changes, especially substrate and water depth, on the composition of the benthic faunas. The Wegener Halvø Formation (Wuchiapingian) in central East Greenland contains a diverse brachiopod fauna comparable to that from the upper parts of the Kapp Starostin Formation. It implies that the brachiopods in the northern margin of Pangaea did not suffer a severe extinction in the Capitanian and instead migrated southward with the development of the Zechstein seaway.

Priority effects over macroevolutionary time scales

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Arrival chronologies, either globally or at a local scale, for different biotic groups are emerging from information derived from both the fossil record and molecular phylogenies. These allow us for the first time to measure the impact of different origination times on the diversification and abundance of different lineages and biota in modern communities, first suggested as important for island systems early this century. We present evidence from New Zealand biomes showing that arrival chronologies, rather than time since arrival *per se*, are formative in shaping the diversity and abundance of taxa in modern forest and grassland communities. These priority effects endure over tens of millions of years and persist through major environmental and geographic changes. They appear to be the result of competitive advantage associated with early occupancy of new habitats, coupled with rapid speciation caused by either polyploidy or episodic habitat fragmentation. In this presentation we explore the evidence for long-term priority effects in New Zealand vegetation and discuss when, where and why these have occurred. These contingent legacy effects provide a new perspective on the critical eco-evolutionary processes forming modern communities and merit investigation in other terrestrial groups and in marine environments with an exemplary fossil record.

The Weeks Formation Lagerstätte (Utah, USA): a unique window on the evolution of animal life during the late Cambrian

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Exceptionally preserved fossil assemblages have proved critical to our understanding of the evolution of early–middle Cambrian animals, providing unparalleled insights into their anatomy and ecology. Similarly detailed data are increasingly available for Ordovician marine communities, thanks to recent discoveries of remarkable assemblages. By contrast, the late Cambrian fossil record of non- or weakly biomineralising animals remains particularly scarce, with only a single diverse macroscopic assemblage of that kind known yet: the late Guzhangian Weeks Formation fauna. As presented herein, our recent field investigations in the House Range of Utah (USA) have greatly improved our understanding of this remarkable

fauna and the environment it inhabited. This biota comprises at least 80 species, belonging to 9 phyla, and is dominated by arthropods and to a lesser extent sponges and brachiopods. In this respect, it is comparable to middle Cambrian exceptional faunas of Laurentia. However, analysis of the intra-phylum composition reveals a more complex picture. Cnidarians, hyolithidid molluscs, priapulids or sponges are all represented by taxa known from older strata. Bradoriid, megacheiran and anomalocaridid arthropods are also components more typical of early–middle Cambrian times. However, the presence of aglaspidid arthropods, a large tergomyan mollusc, a solute and possibly a crown-group annelid, documents the onset of a restructuring of marine animal communities in the early late Cambrian. This restructuring is also demonstrated by the introduction of a set of newcomers (mostly arthropods) of uncertain affinities, and the absence of some iconic Burgess Shale-type taxa. Detailed logging and microfacies analyses revealed that exceptional preservation in the Weeks Formation occurs within two 20 metre thick intervals, which were deposited in a quiet, oxygen-depleted environment on a distal carbonate ramp below storm wave base. This setting is much like that of most Cambrian Lagerstätten.

Subdivision of the Cambrian Terreneuvian Series: a biostratigraphic or a chemostratigraphic marker?

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The lowest Cambrian Terreneuvian Series includes the Fortunian and unnamed Stage 2, but how to subdivide the Terreneuvian is an urgent task for Cambrian colleagues. Biostratigraphy of small skeletal fossils (SSF) has been one of the important tools for correlation and subdivision of the pre-trilobitic Cambrian strata. Some SSF have a worldwide distribution and are useful index fossils for correlating lower Cambrian sequences between different blocks. Among these, the micromollusc *Watsonella crosbyi* has been recovered from Siberia, Mongolia, North America, France and South Australia. It mainly occurs in the upper Terreneuvian and has been taken as a nominal fossil for biozonation in these areas. In particular, the occurrence of *W. crosbyi* in southern France and South Australia was recently proven to be in Stage 2. Its wide occurrence in both carbonate and siliciclastic environments indicates that *Watsonella crosbyi* is an important fossil for global correlation of the pre-trilobitic strata. The FAD of *Watsonella crosbyi* can be suggested as a candidate GSSP marker for defining the base of Stage 2. The FAD of *Aldanella attleborensis* approximates to, or is a little above this marker and could also be a potential biomarker for defining the base of Cambrian Stage 2, since it is especially widely distributed in the Tommotian across the Siberian Platform. But in South China, the occurrence of this fossil is not widespread and in eastern Yunnan its FAD is higher than that of *W. crosbyi*.

The FAD of *W. crosbyi* could be calibrated with chemostratigraphic data. In northeastern Yunnan, the FAD of *W. crosbyi* is near the base of the Dahai Member and is below the major positive $\delta^{13}C$ excursion in the Terreneuvian. But caution is needed regarding use of the peak of a carbon isotope excursion for defining the base of Stage 2.

Complex hierarchical shell microstructures in a Cambrian micromollusc: *Pelagiella madianensis*

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The shell microstructure and mineralogy of *Pelagiella madianensis*, a widespread micromollusc in the Cambrian Period, are investigated based on abundant and extraordinarily well preserved shells. Six types of microstructure have been identified. The lamello-fibrillar microstructure that was previously known from *P. subangulata* and other early Cambrian molluscs constructs the outermost shell layer of *P. madianensis*, while the remaining five types are reported here for first time, i.e. fibrous aragonite, foliated aragonite, crossed bladed, crossed foliated and isolated tablet. The animal accretes these six types of microstructure to construct the shell in a complex hierarchical pattern with five orders: lamellae, folia, lath, crystallite column and nanogranule. Inwardly, bladelike lamellar microstructures, e.g. fibrous aragonite, foliated aragonite and crossed bladed are secreted in the early stage of shell increments. The innermost shell layer is characterised by large euhedral hexagonal tablets of aragonite. The crossed foliated microstructure was contiguously secreted, aligning with the bladelike lamellar microstructure, during the late stage of shell ontogeny. New discoveries demonstrate that the capability of building complex shell microstructures had evolved by the early Cambrian. New evidence also suggests a three-step evolution of early molluscan shells from the loosely organised lamello-fibrillae of Terreneuvian molluscs, through well organised bladelike lamellar microstructures, to the isolated tablet and crossed foliated microstructures that are common in Cambrian Series 2 and 3, and respectively represent the ancestral types of nacre and crossed lamellar microstructures of living gastropods.

Microbially induced sedimentary structures from the Fortunian strata of South China

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Microbially induced sedimentary structures (MISS), suggested as the fifth group of sedimentary structures in the classification of primary sedimentary structures, are microbial traces in sandy deposits. They are formed by various modes of microbial behaviour in response to the prevailing physical dynamics, and occur from the early Archaean Eon to today. However, it is notable that research on fossil MISS from the Archaean and Proterozoic have received much more attention from world scientists than those from the Phanerozoic during the past decade. Recently, a new horizon of fossil MISS has been found within the Zhongyicun member (Fortunian Stage, South China), which contains a specific type of MISS referred to microbial laminated levelling structures induced by the growth of microbial mats. Lithologic characteristics enable identification of different sedimentary layers including the fine phosphatic grain layer, the coarse phosphatic grain layer, the dolomite layer and the microbial mats layer. SEM examination demonstrates that the microbial mats are mainly formed by filamentous microbes. The microbial laminated levelling structures are formed in two steps. Firstly, the microbial mats are developed at the bottom of the centimetre-sized valleys formed by the weathering of the dolomite layer. Then, the microbial mats extend to form the planar mat surface after the valleys are filled in by the mats. The microbial laminated levelling structures are associated with an SSF assemblage transition event from the *Anabarites trisulcatus-Protohertzina anabarica* zone to the *Paragloborilus subglobosus-Purella squamulosa* zone. This may support recent claims that Phanerozoic microbial mats were opportunistic disaster forms that flourished during periods of faunal turnover.

A novel metatree approach to generating large phylogenetic hypotheses of extinct taxa

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Phylogenetic hypotheses are essential to a wide range of macroevolutionary and biogeographic approaches, however large phylogenies (thousands of tips) are not generally available for extinct clades. The labour- intensive nature of morphological data collection makes such direct inference approaches unfeasible. Instead, previous studies have relied on formal or informal 'supertree' approaches that combine published trees into larger composite phylogenies. Here I suggest a novel meta-analytical approach that instead uses published character matrices, allowing more of the original information to be included in the resulting 'metatree'. I introduce an established metadata framework that serves as a relational database of published character-taxon matrices. Importantly, this accounts for redundancy between data sets due to the high frequency of matrix reuse. Reanalysis of original matrices allows consistent procedures to be used, all taxa to be retained, and enables future 'supermatrix' approaches, none of which is possible within standard 'supertree' approaches. A significant problem in combining data sets concerns reconciling operational taxonomic units with a global taxonomy. Here this is achieved by linking metadata to the Paleobiology Database through their API, allowing taxonomy to be dynamically updated and providing temporospatial data for downstream analyses. I illustrate the full metatree pipeline using Mesozoic archosaurs as an example data set to generate a phylogenetic hypothesis of over 1500 species.

New advances in understanding the origin of tetrapods

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The evolution of fishes to land-dwelling tetrapods was one of the most dramatic events in the history of vertebrate evolution. Most studies focus on the character state changes observed within the advanced tetrapodomorph fishes, which include well known forms such as *Eusthenopteron* and *Tiktaalik*. New information on this transition is here provided by exceptionally well preserved new specimens of stem tetrapod fishes (tetrapodomorphs), studied through synchrotron and micro-CT microtomography. The Middle Devonian fish *Koharolepis* from the Aztec Siltstone of Antarctica shows the braincase and gill arches revealed through synchrotron tomography, demonstrating that the canowindridoids have standard stem-tetrapod endocranial features but appear to have a relatively short hyomandibular, an advanced feature in a basal group. A perfect 3D specimen of *Gogonasus andrewsae* from the Late Devonian Gogo Formation, Western Australia, shows reduction of functional gill-arch bones to just three ceratobranchials. This suggests that as spiracular breathing increased, the significance of aqueous gill respiration diminished. A new complete elpisostegalian fish,

Elpistostege watsoni, from the Late Devonian world heritage site at Miguasha, Quebec, also provides significant new details on the final stage of this transition. The new *Elpistostege* specimen offers insights into the transition of fins into limbs through the presence of digits within the robust pectoral fin endoskeleton. Preliminary phylogenetic analyses show that *Elpistostege* displaces *Tiktaalik* as the most advanced fish, the one that is the immediate sister group to all tetrapods.

Advanced methods of imaging and 3D printing applied to problems in early vertebrate evolution

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In recent years, the use of advanced imaging techniques has greatly revolutionised the amount of information available to describe important fossil specimens that inform us on the origin of the first jawed vertebrates (gnathostomes) and the fish-tetrapod transition. Here we show details of a variety of tomographic methods, imaging and 3D printing approaches applied to the study of early vertebrate evolution. We have used a range of techniques from simple radiography of fossil specimens to micro-CT, synchrotron and neutron beam imaging, and employing Drishti, Aviso and Mimics software to segment out anatomical details through a variety of early vertebrate specimens (e.g. placoderms, sharks and sarcopterygians). 3D printing of our material provides excellent results with Z-printing powder replicas and plastic extrusion methods. Each approach has its pros and cons, often involving time-consuming rendering or lack of detail sacrificed for gross anatomical clarity. Much depends on the nature of the fossil preservation, what kind of matrix enclosed it, and what anatomical features are to be targeted for resolution. Large fossils in thick rock matrix can now be imaged using ANSTO's newly developed Dingo neutron beam technology, which generates images based on chemical compositional differences. These various methods can reveal a wide range of fine anatomical structures in early vertebrates, including muscles and soft tissues, partially ossified skeletal structures and tissue microstructures, such as dental histology of the oldest toothlike structures in placoderms. There have been many spectacular successes using these methods; one recent example documents the first 3D preserved fossilised heart in any vertebrate (a 120 my-old actinopterygian fish), published by a team of Brazilian scientists. These techniques provide critical new layers of information for defining key character nodes and polarity of character states necessary to resolve the still conflicted phylogeny of lower vertebrates.

Microtubular structures as the youngest ambient inclusion trails from the early Middle Triassic phosphatised bromalites of southwestern China: new insights into an old intriguing phenomenon

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Ambient inclusion trail (AIT) is a particular type of microstructure often observed in Precambrian cherted deposits. It is often characterised by hollow, curved to coiled microtubes exhibiting salient longitudinal striations within. As an intriguing phenomenon, AITs are more commonly found in the Precambrian than the Phanerozoic. Certain Precambrian examples of AITs are also found to be associated with bio-organic matter, providing them as potential clues of early life on Earth. Here we report new occurrences of microtubular structures found in early Middle Triassic coprolite materials from the Guanling Formation in Yunnan, Southwestern China. Multiple salient characteristics of these microtubes, such as curved to coiled grooves with longitudinal striations, angular turns, cross-cuttings, starburst pattern, and terminal rounded pitting at one end of groove, together support their strong affinities to AITs. These newly found microtubular structures thus represent the youngest occurrence of AITs in the Earth's history, and strengthening the notion that AITs are not merely a Precambrian phenomenon. Like most other AITs found from the Ediacaran and Palaeozoic strata, the AITs from the Luoping coprolites are also preserved in a phosphatised substrate, based on a compilation of all reported AITs from all over the world. The formation of AITs in the Luoping coprolite is interpreted to be a microbially induced process that induces the precipitation of phosphate and also builds up sufficient fluid pressure driving the movement of pyrite through the sealing effect of the microbial mat. This new model might be different from the formation mechanism of Precambrian AITs, in which pyrite propulsion is more likely to be driven by metamorphism-induced fluid pressure, although a few of them were found to be microbially induced.

A can of cycloneuralian worms

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Cycloneuralia is a group of ecdysozoan worms, including Scalidophora (priapulids, loriciferans and kinorhynchs) and Nematoida (nematodes and nematomorphs). Together, they share a set of morphological characters, such as an anterior mouth, a cylindrical pharynx and a collar-shaped peripharyngeal brain. Although Cylconeuralia is morphologically well defined and often considered as the sister group to Panarthropoda (arthropods, onychophorans and tardigrades), it is hardly ever resolved as a monophyletic clade in molecular phylogenetic analyses. Instead, molecular data suggest that Scalidophora and Nematoida are paraphyletic, with Nematoida more closely allied to Panarthropoda. Therefore, the interrelationships among cyloneuralian phyla and their evolutionary affinities with panarthropods remain highly controversial. The fossil records of cycloneuralian worms can be traced to the earliest Cambrian where they were once dominant members of the benthic fauna in marine communities and played a significant role in marine ecosystems. These exceptionally preserved Cambrian cycloneuralian worms therefore provide crucial information for illuminating the early evolution of Cycloneuralia and Ecdysozoa. However, due to the limits of preservation and the preliminary status of existing research, the morphological details, classification, systematic position and phylogenetic relationships of these Cambrian worms are still sources of considerable debate, so a thorough systematic review of this Cambrian group of animals is overdue. Most Cambrian cycloneuralians are priapulid-like, and phylogenetic analyses have assigned them to variable positions within the total group of Priapulida/Loricifera/Kinorhyncha or even more deeply within the stem group of Scalidophora or Cycloneuralia as a whole. I will give a brief review of Cambrian cycloneuralians and their evolutionary significance, as well as remaining challenges.

Fossil collection management at Naracoorte Caves: 45 years in the making

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Following the discovery of an extensive fossil bed in Victoria Fossil Cave in 1969, palaeontological excavations from this and other sites within the Naracoorte Caves National Park and World Heritage Area has contributed a large fossil collection of scientific, heritage and educational significance. The collection is divided between the South Australian Museum under formal curation and within the field collection held onsite at the Naracoorte Caves under Department of Environment, Water and Natural Resources (DEWNR) care. At any given time, materials may be in the care of research institutions as part of an active research program. Materials held in the onsite field collection or being used in active projects are in various stages of preparation and have a variety of storage, labelling and data recording methods, reflecting the priorities and methods of the researchers involved in their collection or use over the last 45 years.

With the support of the Australian Government, DEWNR has completed an audit of the onsite collections and developed Local Collection Management Guidelines to establish a clear set of practices and protocols for the management of fossil materials held onsite at the Caves and involved in active research projects. The aim is to ensure consistent and best-practice fossil collection management for all palaeontological projects conducted at the Naracoorte Caves and to guide the retrospective management of existing collections.

We present here a summary of the outcomes of the collection management project, including aspects of onsite fossil storage and management and novel solutions for data and record keeping.

Applications of synchrotron computed tomography in palaeontology

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Synchrotron computed tomography (CT) scanning is a non-destructive imaging technique which allows a three dimensional visualisation of an object's internal structures. As palaeontological research often deals with extremely valuable and fragile samples, laboratory CT scanning has been successfully used to expose the internal morphology of fossils. However, a faster, more powerful CT scanning technique is synchrotron X-ray Computed Tomography. It is capable of imaging and reconstructing a full 3D map of objects. The Australian Synchrotron has recently commenced the operation of such advanced CT scanning. The facility, known as the Imaging and Medical Beamline (IMBL) is fast becoming one of the most advanced instruments of this type in the world. It is designed to provide a wide variety of

imaging modalities and its X-ray beam characteristics are far superior to laboratory-scale CT scanners in terms of both the time to scan and the resolution and detail of scans. The optimal performance parameters of the IMBL start at a resolution of five microns (for objects a few centimetres in size), up to a resolution of 200 microns (for objects 50 cm in size). The data acquisition system is directly linked to the MASSIVE high performance computing cluster, which is tuned for the on-the-fly reconstruction and 3D volume rendering. This combination of powerful X-ray characteristics, imaging and processing resources and free access for researchers makes the IMBL a unique CT instrument in the southern hemisphere. To date, it has been used to image a wide variety of fossil samples and is proving to be an extremely invaluable tool for palaeontological research.

In this talk I will give a brief overview of the IMBL's capabilities, how to access the facility, and will provide exemplars of some of the recent results obtained from palaeontology-related experiments.

Gondwanan ginkgoes: heralds of Cretaceous biogeographic and climatic change

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Members of the plant order Ginkgoales were abundant, diverse and had a global distribution throughout most of the Mesozoic Era. Today, this order has been reduced to a single species native to eastern Asia, *Ginkgo biloba*. The waning of this group coincides with the accelerating global diversity of flowering plants during the mid-Cretaceous. The Tupuangi flora of the Chatham Islands, New Zealand (palaeolatitude ~75–80°S), offers a unique perspective into the polar conditions during this pivotal interval of floristic replacement, concurrent with extreme mid-Cretaceous global hothouse conditions (Cenomanian–Turonian; *ca* 96–90 Ma). *Ginkgoites waarrensis* Douglas 1965 emend. Mays 2015, a species known previously from a single occurrence in Australia, is an abundant element of the Tupuangi flora with over 70 leaf specimens across six localities. *Ginkgoites waarrensis* is the youngest Mesozoic ginkgoalean taxon of Gondwana. Increasing diversity of Ginkgoales from the Early Cretaceous to the early Late Cretaceous supports a broader trend of floral provincialisation throughout this interval, most likely driven by concurrent global transgression and active tectonic extension across southern Gondwana. Excepting the isolated occurrence of *Ginkgoites* from the Eocene of Tasmania, Ginkgoales were extinct in Gondwana by the end of the Cretaceous, most likely due to the ecological pressure exerted by the angiosperms. Carbon dioxide has been inferred as the primary proximate cause of the mid-Cretaceous global hothouse. The leaf cuticles of *Ginkgoites waarrensis* were utilised to approximate atmospheric carbon dioxide (pCO_2) during the Cenomanian. Stomatal index (SI) data were collected from ten specimens, and the stomatal ratio method yielded a semi-quantitative pCO_2 estimate of 1150–1350 ppmv, which is consistent with most model and proxy estimates of the Cenomanian. We employ *Ginkgoites waarrensis* as a case study to demonstrate the theoretical limitations of the most widely utilised pre-Quaternary pCO_2 proxies, while offering solutions for future palaeo-pCO_2 proxies.

Priabonian: geohistory and biohistory in the Palaeogene-Neogene biospheric transition

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It is reasonable to think ontologically of the Palaeogene biosphere and Neogene biosphere as ever-changing but still coherent entities: the one beginning after the end-Cretaceous catastrophe; the other developing in the Oligocene and still with us. Several Palaeogene chronofaunas, having persisted for 15-22 my, were succeeded in due course by Neogene chronofaunas of comparable longevity. The transitional phase was centred on the Priabonian Age (Late Eocene) of about 4 my duration. The three central claims here are that: (i) this notion of a Priabonian fulcrum holds between the three environmental realms, the neritic, pelagic and terrestrial realms; (ii) that improving correlation and age determination are clarifying links between ecological-evolutionary shifts and environmental shifts; and (iii) that there are two turning points, close to the base and the top of the Priabonian Stage at ~38 Ma and ~34 Ma respectively.

At the earlier horizon there were major turnovers in the pelagic realm in the oligotrophic, photosymbiotic planktonic Foraminifera and the coccolithophorids, and in the ecologically disparate radiolarians; and coevally in the photosymbiotic benthic Foraminifera in Tethyan neritic biotas. The later horizon heralds the Neogene in the plankton and neritic benthos. And even the deep-oceanic benthic Foraminifera experienced prolonged turnover roughly spanning the Priabonian. Meanwhile, among the North American land mammals, the Eocene chronofauna gave way to the White River within the Duchesnean Age, late Bartonian and close to the 38 Ma marine horizon.

The Bartonian middle Eocene climatic optimum was succeeded by a cooling at or close to 38 Ma, signalled by the most pronounced oxygen-isotopic spike prior to the full icehouse conditions of Oi-1, and associated with a circum-Antarctic, oceanic and neritic, condensed glauconite event. Biofacies and biogeographic fluctuations in the Australo-Antarctic Gulf

and adjoining coal measures are a regional signal of global environmental instability perturbing the biosphere.

Reconstructing canopy closure in Cenozoic forests of Australia using carbon isotope ratios of fossil cuticle

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Forest canopy structure controls the penetration of light, relative humidity, and the concentration and isotopic composition of CO_2 in the understorey. These factors, in turn, influence the carbon isotope signatures of plants at different levels of the forest. Closed canopy forests have been shown to have, on average, more ^{13}C-depleted leaf tissue and more variable carbon isotope ratios than open forests. As a consequence, it should be possible to use the carbon isotope signature of fossil leaves to reconstruct the degree to which ancient forests were open or closed. Here we examine the applicability of this approach to reconstructing Cenozoic forest structure in southeastern Australia. We analysed the carbon isotope ratio of 40–50 individual angiosperm leaf cuticles each from the Eocene site of Anglesea in Victoria, and the Miocene site of Kiandra in New South Wales. In addition, we analysed combined samples of dispersed cuticle fragments as a measure of the overall community average carbon isotope ratios from a range of additional sites spanning the Eocene to the Miocene. Finally, we examine carbon isotope ratios of various gymnosperms and selected Myrtaceae.

Both Anglesea and Kiandra leaves record large variation among carbon isotope ratios, and average values suggestive of closed canopy environments similar to those of modern rainforests of Panama. Dispersed cuticle data are more complex to interpret because of the mixture of both angiosperm and gymnosperm, which are isotopically offset. However, this expected difference in the isotopic composition of angiosperms and gymnosperms is preserved in the individual leaf cuticles at Anglesea, indicating that original leaf carbon isotope ratios are faithfully preserved. In addition, the gymnosperms' range of values suggests that they, too, occupied diverse isotopic and light environments. Carbon isotope analysis holds promise for reconstructing both forest level canopy structure and the different light environments occupied by particular taxa.

Combining biostratigraphy, sequence stratigraphy and carbon-isotope geochemistry to define the base of Stage 10, the uppermost stage of the Cambrian system

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The international committee that will choose the base of Cambrian Stage 10 is considering horizons at two stratigraphic levels. The lower horizon is the lowest occurrence of the agnostoid *Lotagnostus americanus* (Billings 1860) in dysaerobic, deep-marine strata in Hunan, South China. The higher horizon is the lowest occurrence of the coniform euconodont *Eoconodontus notchpeakensis* (Miller 1969) (base of *Eoconodontus* Zone) in shallow marine limestone in the Ibex Area, Utah, USA.

Conodonts characteristic of the *Eoconodontus* Zone are cosmopolitan and are known from 55 localities on five continents, including deep-ocean radiolarian cherts, lower and upper slope deposits, deep-marine and shallow-marine limestones, carbonates mixed with siliciclastics, dolostones and nearshore cratonic sandstones. More importantly, the base of the *Eoconodontus* Zone is identified in published conodont successions in the USA, Canada, Korea, North China, South China, Kazakhstan, Australia and Argentina. Conodont zones have been established through most or all of Stage 10 in most of those areas and in all of the above lithofacies except deep-ocean cherts. Cosmopolitan conodonts subdivide Stage 10 into nine biostratigraphic units in Laurentia; Utah trilobites and brachiopods are less widely distributed.

Carbon-isotope geochemistry also characterises the proposed conodont boundary, which coincides with the base of the HERB Event, a stratigraphic interval with alternating positive and negative carbon-isotope excursion peaks. The highest-amplitude negative peak is within the relatively thin *Eoconodontus notchpeakensis* Subzone. That peak has been identified in Australia, USA, Canada, Argentina, Scandinavia and several parts of China, and it is used for international correlation. Carbon-isotope profiles from unfossiliferous strata can be correlated with Utah carbon-isotope profiles, allowing identification of the base of Stage 10.

The combination of globally distributed conodont faunas and isotope geochemistry produces a detailed framework within which to define a GSSP for the base of Stage 10 and also to correlate strata throughout Stage 10.

Visualising extinction and evolution using synchrotron radiation

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A recent successful trial using the Imaging and Medical (IMBL) at the Melbourne Synchrotron has revealed the internal anatomy and morphology of rare, three-dimensionally preserved, 30 my-old silicified fruits from Capella, in Central Queensland. These IMBL scans are the first application of this technique to the study of this material. Previous medical CT scanning did not reveal any internal information. During the permineralisation process silicates have replaced the organic material of the fruit and thus biological information (such as DNA) is impossible to obtain. This in turn makes accurate taxonomic classification extremely difficult. Physical sectioning of these rare fossils for visualisation has many risks as it invariably destroys the specimen and is not guaranteed to produce any additional information. However, the IMBL scans have provided us with accurate, detailed images of the internal reproductive structures of these enigmatic fruits, enabling, for the first time, a direct physical comparison between internal morphologies of extinct and extant rainforest fruits. This extra vital information effectively enables researchers to establish or confirm classifications to appropriate family, genus and species. Accurate species identification will help to advance knowledge of past environments and climates in Australia. Our collaboration specifically aims at combining art, science and technology to explore various approaches in the visualisation of this material, to drive content not only for scientific publication, but for exhibitions in galleries and museums and thereby attract entirely new audiences to this research.

Tiering and competition in Mistaken Point Ediacaran communities

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Bedding-plane assemblages of Ediacaran fossils at Mistaken Point, Newfoundland (~565 Ma), are among the oldest known examples of macroscopic communities. The preservation of these immobile organisms in large *in situ* bedding plane populations allows the original spatial distributions to be analysed, shedding light on their ecology including competitive interactions. Competition for vertical space has been suggested to be the primary structuring mechanism within Mistaken Point communities resulting in different taxa occupying different parts of the water column, known as tiering.

The connection between tiering and competition was examined using spatial analyses of the interspecific interactions of the four most diverse Mistaken Point communities: the 'D', 'E', 'G' and Lower Mistaken Point (LMP) surfaces. Spatial point process analyses offer a way to identify inter- and intraspecific segregation, enabling resolution of the magnitude and type of competition within these communities. Tiering was quantified in terms of the overlap of specimen height, stem height and 'active' height. These tiering metrics in combination with spatial analyses incorporating morphological variables were used to investigate the relationship between specimen morphology and competition.

Applying this combined approach, we found that tiering overlap decreases from the D to G to E to LMP surfaces but instances of large-scale spatial segregation become more frequent, suggesting an increase in the extent of resource competition. Additionally, specimens with larger discs are more strongly segregated than tall specimens and despite occupying different vertical tiers; *Fractofusus* and *Primocandelabrum* are spatially segregated. These findings suggest that, at least on some surfaces, competition for laterally distributed resources played a major or even dominant role in structuring these ancient communities.

Ediacaran palynology of Munyarai 1: lithostratigraphic implications for the Munyarai Trough, Officer Basin, South Australia

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The Ediacaran period is marked by dramatic changes in the Earth's atmosphere, lithosphere and biosphere. While some of these events can be correlated using isotope chemostratigraphy, much of the period remains poorly constrained geochronologically because of a lack of suitable lithologies. However, palynostratigraphy based on large, complex acanthomorphic acritarchs, has been effective in subdividing and correlating Australian Ediacaran successions, which are comparable with Siberian, East European Platform and, to a lesser extent, Siberian and Indian Neoproterozoic successions. A biostratigraphic framework established in Australia for the lower to mid-Ediacaran period has allowed

correlation between the Officer and Amadeus Basins, Stuart Shelf and Adelaide Rift Complex. However, the upper boundary of this framework remains poorly defined. Palynological samples from partially cored drillhole Munyarai 1 in the Munyarai Trough were analysed with the aim of refining this upper boundary. Preliminary results suggest that Munyarai 1 stratigraphic units, previously assigned to the late Ediacaran to late early Cambrian, are considerably older than previously assumed and are mid-Ediacaran in age. This implies that the Munyarai Formation, previously recognised only in Munyarai 1, does not exist and that the stratigraphy of the drill hole up until at least the middle Devonian requires substantial revision, as will a considerable area of the Munyarai Trough.

Investigating the possible common ancestry and cnidarian affinities of sphenothallids, byroniids and hyolithelminthids

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Shelly fossils exhibit unique mineralogical and morphological diversity in the Cambrian. Based on this observation, hypotheses suggest that multiple clades of animals independently evolved phosphatic shells during the Cambrian radiation of life. However, no consensus exists about the number of times that phosphatic shells independently evolved among animals, as the phylogenetic relationships among major groups of phosphatic shelly fossils generally remain controversial. To contribute to addressing this issue, we investigated the preservation of three groups of tube-shaped phosphatic shelly fossils from the Cambrian of South China—sphenothallids, byroniids and hyolithelminthids—which have variously been interpreted as cnidarians and 'worms'. For our investigation, we collected sphenothallids and hyolithelminthids—represented by *Sphenothallus* and *Hyolithellus*—from the Shuijingtuo Formation (Stage 3) in Hubei Province as well as byroniids—represented by *Byronia*—from the Kaili Formation (Series 2-Series 3) in Guizhou Province, and studied the fossils using a combination of light microscopy, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS). Our data from these analyses provide new insights to the taphonomic and morphological similarities of the three groups. In particular, we show that the groups have similar lamellar ultrastructures and that the *Sphenothallus* and *Hyolithellus* specimens may have originally been covered by both transverse and longitudinal ridges, which are generally only preserved in byroniids. Overall, this work shows that the shells of all three groups closely resemble the periderm of modern solitary scyphozoan coronate polyps, and thus, they may belong to a clade of biomineralising cnidarians that evolved during the Cambrian radiation.

Evolution of the panarthropod ventral nerve cord: a palaeobiological perspective

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Understanding the evolution of the central nervous system (CNS) is fundamental for resolving the phylogenetic relationships within Panarthropoda (Euarthropoda, Tardigrada, Onychophora). The ground-pattern of the panarthropod CNS remains elusive, however, as there is uncertainty on which neurological characters can be regarded as ancestral among extant phyla. Fortunately, the fossil record offers a unique opportunity to reconstruct the early character evolution of the nervous system via exceptional preservation of extinct representatives. Here, we describe the ventral nerve cord (VNC) in *Chengjiangocaris kunmingensis*, an early Cambrian euarthropod from South China. The VNC comprises a homonymous series of condensed ganglia that extend throughout the body, each associated with a pair of biramous limbs. Submillimetric preservation reveals numerous intersegmental nerve roots that emerge from both sides of the VNC, which correspond topologically to the peripheral nerves of Priapulida and Onychophora. The VNC of *C. kunmingensis* evinces a unique neurological organisation, demonstrates the persistence of ancestral neurological features of Ecdysozoa in derived stem-group euarthropods, and illuminates the VNC ground-pattern in Panarthropoda.

Origin and early evolution of the phylum Mollusca

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Phylum Mollusca is the largest metazoan group after arthropods; it includes about 70,000 described fossil and 130,000 described recent species, with an estimated 70,000+ recent species awaiting formal description. Beside the high taxonomic diversity, molluscs are characterised by high disparity. Molluscs occur in extremely variable habitats in marine and freshwater basins, and on land. Such a diversity and evolutionary success of molluscs was achieved after prolonged evolution, over the entire Phanerozoic. The earliest molluscs are from the terminal Ediacaran–basal Cambrian transition. Study of these ancient taxa can shine a light on the enigma of the origin of the phylum. The major problems in the study of the earliest molluscs are their systematic position and their phylogenetic relationships with younger high-ranked taxa.

A summary of research on ancient molluscs reveals several important points: 1) Functional-morphological studies of helcionelloids facilitate reconstruction of important details of their anatomy, i.e. endogastric shell orientation, three pairs of shell muscles in cap-shaped forms and single columellar muscle in spirally coiled forms, and anterior pallial cavity with postero-anterior circulation. Such a bauplan characterises helcionelloids as ancestral gastropods. 2) Taxonomically and morphologically, helcionelloids were the most diverse group of Cambrian molluscs. The subclass Archaeobranchia, with two orders, Helcionelliformes (families Helcionellidae, Coreospiridae, Carinopeltidae, Securiconidae, Stenothecidae, Yochelcionellidae) and Pelagiellіformes (families Aldanellidae, Pelagiellidae), is a major group of Cambrian gastropods. 3) Archaeobranchia are likely the ancestral stock for gastropod evolution. The following gastropod branches are descendants of Archaeobranchia: subclasses Cyclobranchia (=Patellogastropoda), Scutibranchia (=Vetigastropoda without Trochoidea, Turbinoidea, Seguenzioidea), Pectinibranchia (Trochoidea, Turbinoidea, Seguenzioidea + Caenogastropoda) and all Heterobranchia (subclasses Divasibranchia, Dextrobranchia, Sinistrobranchia, Opisthobranchia). 4) Classes Polyplacophora, Monoplacophora, Gastropoda and Bivalvia originated near the Ediacaran-Cambrian boundary, in other words, since the palaeontologically documented history of phylum Mollusca. The remaining classes appeared later: Cephalopoda in the Late Cambrian, Scaphopoda in the Ordovician and Aplacophora in the Silurian.

The early Cambrian Emu Bay Shale Konservat-Lagerstätte of South Australia: diversity, palaeoecology and preservation

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The early Cambrian (Series 2, Stage 4) Emu Bay Shale (EBS) Konservat-Lagerstätte, situated on the northeastern coast of Kangaroo Island in South Australia, provides an important source of data on the composition of early animal communities and modes of soft tissue preservation from the main window of the Cambrian Explosion in East Gondwana. Our recent excavations at Buck Quarry (since 2007) and an adjacent quarry (since 2012) have divulged a considerable taxonomic diversity, with over 50 species now known. The EBS biota is dominated by arthropods (in terms of diversity and abundance), including anomalocaridids, a variety of trilobite-like artiopods, 'bivalved' taxa and cheliceramorphs, with the trilobite *Estaingia bilobata* being the most prevalent taxon. Many of the EBS arthropods have a strong biogeographic connection with taxa from South China, especially the Chengjiang Biota. The remaining species diversity comprises various other ecdysozoans (e.g. palaeoscolecids and a lobopodian), a vetulicolian (*Nesonektris*), molluscs, brachiopods, a polychaete annelid, sponges and a variety of problematic forms. Although the constituent taxa represent a typical Burgess-Shale-type (BST) fauna, EBS fossils commonly display a range of taphonomic modes for a variety of anatomical features—particularly phosphatisation and pyritisation of labile and extracellular tissues—a situation that is otherwise rare in most other BST deposits. Also, many of the soft-bodied fossils exhibit a degree of three-dimensionality. This contrasts with many other BST deposits wherein recalcitrant tissues such as cuticle typically preserve as featureless, two-dimensional carbon films, or where pyritisation or phosphatisation is typically restricted to more labile tissues, such as midgut glands. The prevalence of early diagenetic mineralisation of soft tissues seen in EBS fossils can provide much better anatomical resolution in some instances (e.g. details of compound eyes) than other Cambrian Konservat-Lagerstätten.

Candidate section for the base of Cambrian Stage 10 at Wa'ergang, Hunan, China

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A well exposed section through the lower Shenjiawan Formation (uppermost Cambrian-lowermost Ordovician) has been proposed as a candidate stratotype for the GSSP of provisional Stage 10 (Cambrian: Furongian Series). The section contains remains of the agnostoid trilobite *Lotagnostus americanus*, which is the guide fossil that marks the provisional base of the stage. This section is notable because it is one of few known that also yields the conodont *Eoconodontus notchpeakensis*.

Trilobite biostratigraphy has been documented through the entire Shenjiawan Formation in the Wa'ergang section. The lower 32 m of the Shenjiawan Formation has been especially well studied, leading to the recognition of three agnostoid zones and identifying the first appearance of *L. americanus* at 29.65 m above the base of the formation. Most of the Shenjiawan Formation has been intensively sampled for conodonts, leading to recognition of four conodont zones. *E. notchpeakensis* has been identified at eight sample horizons, with the lowest occurrence being 145 m above the base of the formation, or roughly halfway through the projected thickness of Stage 10. Dense sampling for carbon isotopes ($\delta^{18}C$) reveals a curve showing a negative excursion having a peak of -1.0‰ close to the FAD of *L. americanus*.

Morphometrics of feeding anatomy in stereospondyl amphibians

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Stereospondyls were a very successful radiation of early tetrapods. The key to their success is not resolved but could lie in diverse feeding strategies, reducing interspecies competition. The toothrow and subtemporal vacuities, representing functional morphology of feeding, were assessed for allometry and morphospace occupation. Toothrow length affects prey holding ability and the subtemporal vacuity (STV) is the attachment site for the muscle responsible for jaw closure, so influences ability to close the jaw and to keep it closed.

Relationships between skull length, as measure of size, and either toothrow length or STV area were investigated using phylogenetically controlled regression and principal component analysis of size-controlled semilandmarks. Taxa studied represented a range of families and geological eras. Linear models were tested for Brownian evolution. Semilandmarks around the outline of the STV assessed shape differences and morphospace occupation.

There was a strong, significant isometric relationship between toothrow length and skull length ($r^2 = 0.916$, $P < 0.00001$). The lambda (λ) value was not significantly different from zero, indicating that there was no evidence of Brownian evolution. In addition, ANCOVA showed no effect of family. From this and the power function, we can accurately predict the toothrow length of stereospondyls (toothrow length = 0.68 x skull length$^{1.037-0.37}$), which is 68% of the skull length.

There was positive allometry in STV area and skull length, with Brownian evolution ($r^2 = 0.71$, $P < 0.0001$, $\lambda = 1$). Larger species had a proportionally larger STV. There was a lot of variation in morphospace occupation, differing between families and over geological time. The Permian stereospondyls had significantly narrower and longer STVs than their Triassic counterparts. Late Triassic taxa possessed wider and posteriorly extended STVs compared to Early Triassic species.

We concluded that the toothrow length is conserved in stereospondyls, but that the jaw closing action and strength varied considerably.

Silurian (Wenlock-Ludlow) brachiopods from Quidong, New South Wales, Australia

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The last major brachiopod fauna of Silurian age in New South Wales that remains undescribed occurs at Quidong, on the Delegate River east of the Snowy Mountains in far southeastern NSW. Here the Silurian succession commences with the unfossiliferous Tombong Formation, succeeded by the Merriangaah Siltstone containing graptolites of the late Llandovery *Oktavites spiralis* Zone, in turn unconformably overlain by the Quidong Limestone which yields conodonts of Wenlock age. Relatively few brachiopods, including *Kirkidium*, *Leptaena* and rare *Atrypoidea*, occur in the limestone. The transition to the overlying Delegate River Mudstone is gradational, passing from massive to bedded limestone into pyritic bioturbated mudstone with a diverse and abundant brachiopod fauna dominated by strophomenates, particularly *Mesoleptostrophia*,

Mesopholidostrophia, *Leptaena* and *Epelidoaegiria* as well as *Eopholidostrophia (Megapholidostrophia)*. Also commonly present are *Isorthis* (*Arcualla*), *Salopina*, *Morinorhynchus*, *Nucleospira*, *Retziella* and *Howellella*, and less frequent *Ascanigypa*, *Atrypoidea*, *Atrypa*, *Endospirifer*, *Janius* and *Dolerorthis*. Several of the species recognised are endemic to Quidong, whereas others are known also from Homerian (late Wenlock) to earliest Gorstian (early Ludlow) strata of the Canberra and Yass districts. Associated fossils include less common trilobites (an encrinurid and a scutelluid), bivalves and gastropods.

The depositional environment of the Delegate River Mudstone is interpreted as predominately slow, quiet sedimentation below storm base. Above the *Epelidoaegiria*-rich mudstones at the base is a deepening-upward sequence, in which the brachiopod-dominated communities are progressively characterised by *Leptaena*, leptostrophiids and eopholidostrophiids. Then, as water depth shallows, these strophomenates are replaced by the small spiriferide *Howellella*, culminating in a fauna mainly of *Ascanigypa* and *Atrypa*. The upper layers include cross-bedded fine sandstones, and towards the preserved top of the Silurian succession there is a recurrence of bedded limestone with stromatoporoids, indicative of a subtidal environment at or above storm base.

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Protecting fossils in South Australia – what works, what doesn't, and what can we do to improve?

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South Australia is home to a wealth of significant palaeontological heritage, ranging from the World Heritage-listed Pleistocene mammal fossils at Naracoorte Caves to the pivotal Ediacaran sites in the Flinders Ranges. These fossils not only have irreplaceable scientific value, they can also have a considerable monetary value. And this can place them at risk.

Some fossil sites are protected through heritage listing or because of their location in National Parks. However, there are large volumes of fossils being traded that have either been taken from protected sites without permission, or have been taken from unprotected sites. The result is that some of our significant fossil sites are being damaged, and irreplaceable values lost. How can we best protect these fossils and their sites, and what are some of the issues that we face when trying to do so?

This presentation will explore some of the challenges of protecting fossils and fossil sites through legislation and policy, including heritage listing and designation. It will consider options for other methods of protection (including based on intrinsic value of individual fossils), and look at some of the lessons to be learnt from around the world. What is best practice for managing fossils? What might work in South Australia? What possibilities do we have for improving fossil protection into the future?

Evolution of the nitrogen cycle in the context of changing redox conditions during the late Neoproterozoic: the Ediacaran nitrate revolution?

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Nitrogen (N), a major limiting nutrient for the marine primary production, may exist in the environment in six different oxidation states, from N3- in ammonium to N5+ in nitrate, with the oxidation state dictated by the ambient environmental redox conditions: in the absence of O_2, fixed (non-gaseous) inorganic N is stable in the form of ammonium, while in the presence of dissolved O_2, nitrate is the main form. Therefore, the prevalence of nitrate vs ammonium most likely reflects the availability of dissolved O_2, but geologic records of oceanic nitrate have not been previously explored. Here I will present a novel approach of determining nitrate content in carbonates, Carbonate Associated Nitrate (CAN), as a proxy for the oceanic nitrate. To investigate changes in the global O_2 and marine nitrogen cycles through time, concentrations of CAN have been evaluated in both limestones and dolostones from multiple localities around the world, spanning the ages from ~3 Ga to modern. The highest CAN values were found as several distinct peaks in the Ediacaran carbonates from two locations: Sonora province in northwestern Mexico, within a stratigraphic sequence deposited during ~630-550 Ma, and within the Johnnie oolitic dolostone of the Johnnie Formation in Death Valley, California, likely deposited at the onset of the Shuram $\delta^{13}C$ excursion at ~580 Ma. The sharp increases in nitrate recorded in these rocks may reflect a rapid, possibly multi-stage increase in the atmospheric O_2 during this time. Transformation of the fixed N from the reduced to the oxidised forms (from ammonium to nitrate) may have caused a major restructuring of the global N cycle, possibly contributing to the diversification of the eukaryotic phytoplankton communities, forced to adapt to using nitrate instead of ammonium as the major nitrogen source.

Fossil bats from Quaternary cave deposits at Naracoorte, South Australia

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Quaternary fossil deposits of the World Heritage listed Naracoorte Caves National Park (NCNP) are renowned for their record of vertebrate faunas spanning at least 500,000 years. Despite four decades of palaeontological research at Naracoorte, the bats have never been studied in depth. As part of previous studies, bat fossils have been sorted from excavated material and at least one species identified (*Miniopterus schreibersii*). Another Pleistocene cave site in the nearby Henschke's Quarry yielded a single specimen, tentatively assigned to *Nyctophilus geoffroyi*.

Currently, there are 17 bat species living in the South East region of South Australia. At least two have been observed frequenting caves at Naracoorte. NCNP is a significant breeding and over-wintering site for the Southern Bent-wing Bat (*Miniopterus orianae bassanii*). This species is listed as Critically Endangered under the Commonwealth EPBC Act due to population decline and its reliance on only two breeding sites (Bat Cave at Naracoorte and Starlight Cave at Warrnambool). Recent palaeontological excavations in the entrance chamber of Bat Cave have revealed a diverse late Quaternary fauna, with abundant bat material providing a unique opportunity to study a threatened species in the past and present.

We analysed fossil bat specimens from Bat Cave and four other sites in NCNP. Overall, species diversity is low and assemblages are dominated by *Miniopterus*. The low diversity and lack of evidence for predation suggest they were primarily accumulated via natural deaths of cave dwelling individuals. This is further demonstrated by guano derived minerals present in the cave sediments, often occurring in cyclical bands over time. Changes in cave usage by *Miniopterus* in the past may reflect environmental variability; however, the presence of bats over several hundred thousand years suggests resilience in the long-term. Any current threat to their conservation is likely a result of human activity since European settlement.

Celebrating Jim Gehling's contributions to the palaeobiology, stratigraphy and sedimentology of the Ediacaran Period of Earth history

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Ever since 1970, when Mary Wade put Jim Gehling firmly in the literature by acknowledging that 'the [field] assistance of Mr Gehling has been outstanding', Jim has been a *tour de force* in the Ediacaran worlds of South Australia, Namibia and Newfoundland. If he were a Donald Trump-like person, this would be obvious to everyone. But as he is not, we need to highlight the many contributions he has made to Ediacaran palaeobiology, and to the geological contexts of the fossils over the past half a century. This is an appropriate time to do so, for this is Jim's 70th year. It is also 70 years since Reg Sprigg found his first Precambrian fossil—the holotype of *Ediacaria flindersi*—at Ediacara in March 1946. Thus, we celebrate both Jim and Reg as we review Jim's outstanding achievements.

Jim was drawn to palaeobiology by the enthusiasm of Martin Glaessner, the man who put Ediacaran organisms on the map with an article in *Scientific American*. Glaessner followed Sprigg by embracing the idea that Ediacara was the resting place of innumerable jellyfish stranded by tides. Jim disagreed. He moved the ediacarans into deep shelf waters touched occasionally by storms. The organisms were not stranded; they were toppled and buried where they lived. Furthermore, the disks were the holdfasts of fronds, not jellyfish.

In the Ediacaran business, getting things right is a rare commodity. We all have made mistakes, much to our chagrin. Think jellyfish—even box jellyfish—by-the-wind-sailors, octocorals, sponges, placozoans, flatworms and flat worms, molluscs, echinoderms, chordates, xenophyophores and lichens. It's hard to be more comprehensive. Jim has had his share of regrettable assignments, but he—more than most—has found the way forward. We highlight his central contributions to palaeobiology, taphonomy (microbial mats, death masks), sedimentology and stratigraphy (Ediacaran GSSP), and heritage (SAM, Nilpena).

3D digital analysis of non-avian dinosaur tracksites at Lark Quarry and Minyirr: implications for understanding Australia's Cretaceous dinosaurian faunas

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Most of Australia's non-avian dinosaur body fossils come from the 'mid' Cretaceous (Aptian–Turonian), with only two taxa known from the Jurassic. Australia's non-avian dinosaur ichnite record is arguably more comprehensive, extending from the Upper Triassic (Carnian) to the Upper Cretaceous (Cenomanian–Turonian). Some ichnites additionally provide the only evidence for the presence of some types of dinosaurian taxa in Australia (e.g. stegosaurs), or records of specific trackmaker taxa in certain parts of the continent or at specific times (e.g. sauropods in the Lower Cretaceous of Western Australia). As such, ichnites provide an important, but often overlooked, complement to the body fossil record in terms of what they can say about the composition and nature of Australia's non-avian dinosaurian fauna. Ichnites also offer an improved understanding of some aspects of dinosaurian behaviour and palaeoecology that can be difficult to glean from body fossils.

Historically, Australian non-avian dinosaur tracks have been documented and interpreted using a combination of photographs and schematic representations derived from either photographs or *in situ* tracings. Because of the 2D nature of this style of documentation, much of the 3D information associated with the tracks is lost, obfuscating detailed ichnotaxonomic and kinematic analysis. Recent advances in digital photogrammetry now make it possible to create detailed 3D digital surface models (DSMs) from multiple photographs taken at different angles. DSMs offer a powerful tool with which to reevaluate previously described and new non-avian dinosaurian tracks and tracksites, with important implications for our understanding of Australian dinosaurian palaeobiology.

As an example, we show how the use of DSMs has facilitated a detailed reevaluation of the world famous dinosaur 'stampede' at Lark Quarry Conservation Park, near Winton, central-western Queensland. In Western Australia, a combination of ground and aerially generated DSMs is permitting the first detailed assessment of historically significant non-avian dinosaur tracksites at Minyirr (Gantheaume Point), near the town of Broome in the western Kimberley.

Evolution, systematics and biogeographic studies of new fossil remains of giraffids from the Lower Siwalik Hills of Punjab, Pakistan

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A taxonomic study from a late Miocene fossil locality Dhok bun Ameer Khatoon, Lower Siwalik Hills of Pakistan has been conducted. New fossil remains have been collected which belong to the family Giraffidae. Specimens include right and left maxilla, isolated upper premolars and molars which have been collected during extensive field work. After morphological and comparative analysis the collection is attributed to *Giraffokeryx punjabiensis* and *Giraffa priscilla.* Size variation in dentition is taxonomically important from the point of view of vertebrate evolution and this is the main reason for conducting this study at this specific site to add additional information about family Giraffidae in the field of palaeontology. The fossil site comprises well exposed Chinji and Nagri formations and is dated at approximately 14.2-9.5 Ma. In this study, different aspects of evolution, taxonomy and biogeographic distribution as well as the relation of Giraffidae with Procerotidae are discussed comprehensively. Palaeoenvironment, biostratigraphy and geology of the locality are also discussed. The coexistence of *Giraffokeryx punjabiensis* with its mammalian palaeocommunity reveals the persistence of mosaics of diverse habitats ranging from tropical evergreen forest to subtropical forest, closed seasonal woodlands to wooded savannas during the deposition of the Dhok Bun Ameer Khatoon, Chinji Formation.

An enigmatic new 'petaloid' organism from the Emu Bay Shale (Cambrian Stage 4), Kangaroo Island, South Australia

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Ongoing excavation of the Cambrian Series 2, Stage 4 Emu Bay Shale has revealed a diverse biota, which is taxonomically similar to other Cambrian Konservat-Lagerstätten, especially from South China. While most Emu Bay Shale taxa can be readily assigned to known animal phyla, one relatively common organism referred to as 'petaloid', for its superficially flower-like form, poses a taxonomic conundrum, even among other strange Cambrian forms. Thus far, over 400 petaloid

specimens have been collected since excavation commenced at Buck Quarry in 2007. Articulated petaloids have a size range of *ca* 15-55 mm in diameter and consist of a variable number (up to ~50) of splayed, rigid, petal-shaped bracts, whose proximal ends converge at the centre. Bracts can also occur as single, isolated 'petals'.

As is the case with the majority of EBS non-biomineralised fossils, most petaloids are preserved as part and counterpart moulds, but are often replicated by iron oxide, suggesting pyritisation as the most typical mode of preservation. However, the EBS is also known for the remarkable preservation of labile tissues such as gut structures and muscle, via phosphatisation, as well as extracellular structures such as the visual surface of arthropod eyes, via pyritisation or phosphatisation. Both these disparate modes of preservation are found in petaloids, where early diagenetic mineralisation has replicated the internal surfaces of the bracts in exceptional detail.

Here we present new data on the morphology, original histology, possible affinities and preservational pathways of this enigmatic organism.

The earliest known vertebrates and the Cambrian Explosion

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The Kingdom Animalia comprises over 30 phyla, which in turn are grouped into three subkingdom-rank superclades, i.e. Diploblasta, Protostomia and Deuterostomia. The essence of the Cambrian Explosion has been recognised as a three-episode event which successively gave rise to the three superclades, rather than a single-episode event that led to a 'Big Bang' of metazoan diversity at the genus- or species-level. The first episode (as a prelude) took place during the latest Precambrian and gave rise to diploblasts and a few possible stem-group triploblasts (or pioneer bilaterians) as represented by Ediacaran faunas. The subsequent two episodes were within the early Cambrian, corresponding to evolutionary aspects of the Terreneuvian and Cambrian Epoch 2, respectively. The second episode resulted in the rapid appearance of protostome lineages represented by Terreneuvian small skeletal fossils (SSFs) and trace fossils. The final episode during the Cambrian Epoch 2 led to the first appearance of at least six phylum-level groups of the Deuterostomia, which are all well documented in the Chengjiang fauna, including the most 'advanced' member, Vertebrata, and an extinct Phylum Vetulicolia with simple gill slits.

Important early Cambrian representatives of the Deuterostomia are the earliest known vertebrates, Myllokunmingiida, including *Myllokunmingia, Haikouichthys* and *Zhongjianichthys*, nicknamed 'the first fish' by P. Janvier. They bear large paired eyes and salient protovertebrae (coexistence of notochord and cartilaginous vertebrae). Here we present additional evidence, which further supports placement of myllokunmingiids at the base of the vertebrate tree. On the contrary, the controversial yunnanozoans (*Yunnanozoon* and *Haikouella*) possess neither eyes nor vertebrae, and hence may have nothing to do with craniates or vertebrates. These enigmatic creatures share a similar body plan with vetulicolians and could be treated as a side-branch within the lower deuterostomes.

Cretaceous time capsules: remarkable preservation of fish and crustaceans inside the bivalve *Inoceramus sutherlandi* M'Coy 1865 from the Allaru Mudstone (late Albian), Eromanga Basin, Queensland

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The preservation of gregarious smaller organisms inside empty mollusc shells is extremely scarce in the fossil record. Despite the rarity of this phenomenon there have been a handful of reported cases all throughout the Phanerozoic. The best known of these are Cambrian to Silurian trilobites found inside hyolith and cephalopod conchs. However, there are several other examples including well preserved echinoderms, ammonites and even smaller fishes recorded within the shells of much larger molluscs. Various interpretations exist to explain these strange co-occurrences, ranging from the larger shells acting as refuges from predation, to the smaller animals being washed in post mortem. This unusual mode of preservation offers a situation where normal taphonomic processes (such as scavenging and currents) that cause disarticulation are avoided, allowing more delicate specimens to be preserved in their entirety.

Presented as part of this talk is the first description of this unique mode of preservation from the Early Cretaceous of Australia. Two specimens of the bivalve *Inoceramus sutherlandi* M'Coy 1865 from the Allaru Mudstone (late Albian), Rolling Downs Group, Eromanga Basin were found to contain well preserved fossils enclosed within their shells. One specimen hosted over thirty near-complete teleost fish (belonging to the Clupeidae); while the other contained three potentially pyritised decapod crustaceans (likely members of the Caridea). Both of these taxa inside the bivalves were previously unknown from the basin and likely represent new species. Taphonomically this material is similar to younger

reported examples from the Late Cretaceous of Kansas, USA, wherein schools of fish have also been preserved within shells of the inoceramid bivalve *Platyceramus platinus* Logan 1898. This study highlights the potential usefulness of this unusual preservation in examining smaller or more delicate taxa which typically do not fossilise under normal conditions.

The Cambrian HERB excursion (Furongian) from the Martin Point Formation of the Cow Head Group, western Newfoundland, Canada

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The (Hellnmaria-Red Tops Boundary) HERB negative excursion is well known from the deep water, distal slope deposits at the Green Point section, western Newfoundland, Canada. However, the absence of fossils prohibits the precise biostratigraphic constraint of the HERB excursion at the Green Point section. The deeper water strata at the nearby Martin Point South section represent middle to distal slope deposition and are here used to present the continuous carbon-isotope stratigraphy for the upper part of the Furongian Series in the allochthonous Cow Head Group, western Newfoundland, Canada. The Furongian strata are characterised by moderate to low sedimentation rates and the investigated succession at the Martin Point South section provides a complete sedimentary record. The Furongian strata are referred to the Martin Point Member of the Green Point Formation of the Cow Head Group and consist of black, dark grey and green shale, ribbon lime mudstone and grey, brown weathering siltstone.

A total of 33 samples were microdrilled from the most micritic material and analysed for carbon isotope geochemistry from the lower part of the succession (*ca* 58 m thick) at Martin Point to reconstruct a $\delta^{13}C$ profile. The most striking carbon-isotope anomaly detected is the HERB isotope carbon excursion with a clear double peak at the base of the *Eoconodontus notchpeakensis* conodont Zone. Up section, the HERB is succeeded by a second significant negative excursion in the lower middle part of the *E. notchpeakensis* Zone and the isotope curve of the *E. notchpeakensis* Zone concludes with a positive carbon isotope event that marks the beginning of the *Cordylodus proavus* conodont Zone. The HERB excursion is well developed, complete and biostratigraphically constrained in the Martin Point South section, thus it forms an important proxy for regional and intercontinental correlation and for the discussion on the base of unnamed Stage 10.

Orthothecide hyoliths from the Mantou Formation (Cambrian Stage 5) of Hebei Province, North China

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Orthothecides are a group of hyoliths with a conical conch and a retractable planar operculum, with a stratigraphic range extending from the earliest Cambrian to Devonian. So far, apart from an inferred benthic deposit-feeding mode of life, little is known about this group because of the lack of complete skeletons and anatomical information. Orthothecides from China are generally documented as part of small shelly fossil assemblages from the early Cambrian. Here we report a new occurrence of orthothecides from the Cambrian (Stage 5) Mantou Formation in Hebei Province, North China. The specimens are commonly preserved as moulds within purple-red shale. Two morphotypes are recognised, *Cupitheca holocyclata* Bengtson 1990 and *Decoritheca cyrene* (Walcott 1905). *Cupitheca holocyclata* has a global distribution, stratigraphically ranging from Cambrian Stage 3 to Stage 5. Newly discovered opercula of this taxon are characterised by a series of growth lamellae, inflated interior and a pair of bilobate cardinal processes; some specimens preserve pitlike structures on the internal surface. The first discovery of possible initial apical part of the conch may shed new light on the growth mode of *Cupitheca*. The apical ends of decollated segments display various sculptures, which may associate with decollating stages or represent intraspecific variation. *Decoritheca cyrene* has a kidney-shaped cross-section with a stratigraphic range from Cambrian Stage 5 to Stage 10 in western Laurentia, Baltica, and North and South China. The dorsal surface is covered with tubercles scattered or in rows, which may represent casts of channel openings in the body wall and possibly played a role in reinforcing the skeleton. The fossils reported herein offer clues to the evolution and radiation of Cambrian orthothecide hyoliths.

Ediacaran body fossils and trace fossils from the Hotpet Sandstone of the Bhima Group in the Bhima Basin, southern India

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Ediacaran body fossils and trace fossils now have been found from the Hotpet Sandstone, the uppermost unit of the Bhima Group, in the Bhima Basin, southern India. The body fossils are represented by a frondose species, temporarily named '*Charniodiscus*' sp. nov., a complete body of which should have a holdfast, stalk and frond. The holdfast was bulbous; the stalk was thick and strong, extending upward into the frond to form a median rachis; and the frond consisted of a median rachis and two rows of primary branches, without distinct secondary branches. Compared with all the known *Charniodiscus* species, this new species from India is most similar to *Charniodiscus oppositus* from the Flinders Ranges, South Australia, especially in showing a broad, smooth and exposed median rachis, but it differs significantly from the type species C*harniodiscus concentricus* from Charnwood Forest, England. As the type species has been found with three rather than two rows of primary branches by Dzik, to propose a new generic and specific name for '*Charniodiscus*' sp. nov. seems to be necessary in the future. The trace fossils may be assigned to *Neonereites uniserialis*, which is characterised as a chain of small, spherical or irregular pellets, usually attributed to a coelomate or pseudocoelomate metazoan and known to be a common Ediacaran ichnospecies. Although only a few specimens have been found and collected, these findings are so invaluable that they show for the first time the occurrence of the Ediacara biota on the Indian Peninsula, and suggested an estimated age in the range of 551-542 Ma for the top of the Bhima Group in the Bhima Basin, southern India, through a correlation with the Shibantan Member, Dengying Formation of the Ediacaran System in the Yangtze Gorges district of China.

Living by the Eromanga Sea: taphonomy of crocodyliform and osteichthyan fossils from the Lower Cretaceous Winton Formation at Isisford, Queensland

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Articulated and near-complete vertebrate fossils have been found in sandstone concretions from the Lower Cretaceous (upper Albian) portion of the Winton Formation near Isisford, central-western Queensland. Fossils recovered so far include osteichthyans (*Cladocyclus geddesi* and an indet. Halecomorph), crocodylomorphs (*Isisfordia duncani*), and non-avian dinosaurs. The Winton Formation is thought to have formed in a fluvial channel or flood basin setting, but with minimal outcrop available at Isisford for analysis, the local depositional environment had not been ascertained.

We examined the *ex situ* concretions at Isisford and available outcrop, and found that the concretions comprise feldspathic litharenite cemented with calcite. The lack of fossil deformation along with the cement-supported fabric indicates that concretions formed during early diagenesis. Stable isotopic analysis of calcite $d^{18}o_{vpdb}$ and $d^{13}c_{vpdb}$ indicates the cement precipitated from a mixture of marine and meteoric pore water during both sulphate reduction and methanogenesis. We propose that a lower delta plain or estuary was present at Isisford during the late Albian, and that the final regressive phase of epicontinental Eromanga Sea was underway at this time.

We used this depositional context to inform our taphonomic analysis of fossil material. We found that the articulated vertebrate fossils showed little sign of abrasion or weathering, indicative of burial either during the 'fresh' stage of decay before 'bloat and float' could occur, or during the early stages of 'active' decay. Along with the presence of mud rip-up clasts and fossil plant debris, this suggests these carcasses were buried in a distributary channel as part of the prograding deltaic or estuarine system. This aligns with earlier suggestions that large-bodied, typically shallow marine predatory fishes such as *Cladocyclus* sp. could only have inhabited a fresher water setting if the area was continuous with coastal habitats.

Taphonomic history of the Ediacara Member, Rawnsley Quartzite, South Australia

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The Ediacara Biota, Earth's earliest complex, macroscopic, multicellular ecosystem, is preserved in terminal Ediacaran strata worldwide, deposited in the wake of the 'Snowball Earth' glaciations and just prior to the Cambrian Explosion. Ediacara fossil assemblages consist of exceptionally preserved soft-bodied forms of enigmatic morphology, ecology and affinity which represent a critical stepping-stone in the evolution of complex animal ecosystems. However, the means by which Ediacara assemblages became fossilised remains poorly constrained. Without a mechanistic understanding of how these organisms are preserved, it is impossible to confidently and accurately reconstruct the structure of Neoproterozoic ecosystems or distinguish real biostratigraphic signals (e.g. the timing of origination and extinction events) from preservational artefacts.

We present palaeontological, geochemical and petrographic data in support of a new mechanistic and empirically supported model for the preservation of Ediacara-style fossil assemblages. Moreover, we link Ediacara fossilisation processes to the operation of a unique global-scale taphonomic window reflecting the evolution of global marine biogeochemical cycles and substrate conditions. We find evidence that preservation of Ediacara organisms is non-selective and ubiquitous across a wide range of morphologically disparate groups, demonstrating the importance of a pervasive and persistent environmental control upon Ediacara fossilisation, and confirming that Ediacara-style fossil assemblages can indeed be used to reconstruct the diversity and ecology of these oldest complex ecosystems.

Oldest record of *Metrosideros* (Myrtaceae): fossil flowers, fruits and leaves from Australia

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The iconic flowering genus *Metrosideros* (*Myrtaceae*), more commonly known by its Māori name as Rātā, has long proven a biogeographic anomaly for Southern Hemisphere phytogeographers. It grows throughout the Pacific, from the sub-Antarctic islands of New Zealand, to the Bonin Islands near Japan, from Africa to Hawaii, and on many other smaller Pacific islands between. However, it does not grow in Australia and has never been found in the Australian fossil record, despite a clear disposition towards long-distance dispersal. Previously, it has been speculated that it may have evolved in and subsequently dispersed throughout the Pacific from New Zealand, since its highest species diversity is there, as well as the oldest definite fossil records of the genus, from the Miocene. However, new fossil fruits, flowers and leaves described by the authors, from Eocene and Oligocene deposits in Tasmania, show that *Metrosideros* was present on the Australian mainland during the mid-Cenozoic. These fossils exceed the oldest confirmed fossil record in New Zealand by more than ~10 million years and may indicate an Australian origin of the genus.

Reduced relief: elucidating the Sirius Passet biota with lasers

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The Sirius Passet biota from northern Greenland is perhaps the most poorly understood, and possibly the oldest of the Cambrian Lagerstätten. Only 31 taxa have been described over the past three decades and while it may not be as aesthetically impressive or as biologically diverse as the Burgess Shale or Chengjiang Lagerstätten, the deposit has yielded taxa of great phylogenetic interest, including stem-group euarthropods, the oldest total-group annelids, articulated halkieriids and palaeoscolecids and an assortment of arthropods. Entombed within black laminated mudstones and siltstones, fossils of the Sirius Passet biota typically show little contrast with the surrounding rock and only show minor surface relief. This has hindered our ability to adequately image and decipher morphological details that will allow for an accurate reconstruction of these significant early animals.

An alternative to conventional photographic approaches is high-precision, three-dimensional laser scanning. Laser scanning of fossil surfaces is a non-destructive technique that provides a highly detailed digital topographic map of the specimen that can then be manipulated for various types of image analysis. Mapping of the surface topography produces not only surface details but also cross-sectional profiles down to an accuracy of 0.06 mm. Each of these 3D data sets can then be easily rotated to any desired angle and remain fully in focus, overcoming many of the difficulties associated

with conventional photography. This technique has proven valuable in studies of Ediacaran fossils, but has yet to be utilised in elucidating specimens from Cambrian Lagerstätten. Here we combine laser scanning and conventional imaging techniques to scrutinise and elucidate morphological details of key members of the Sirius Passet biota.

A pre-European mammal assemblage of the northwestern Flinders Ranges, South Australia from subfossil deposits

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Community structure of pre-European Australian mammal faunas can be difficult to determine. Many mammal species became extinct in some areas before there was scientific interest in them, meaning they were not recorded as being present in early surveys. Caves are useful facilitators of the collection and preservation of fossil material which can be brought into caves by a variety of ways. One method is via owls which act as natural biological surveyors. Owls regurgitate non-digestible remains of prey as pellets. The animals represented in the pellets are biased based on the prey preferences of the owl; however, they are still unparalleled samples of the small local fauna.

I examined the contents of 127 well protected Barn Owl pellets that were located under a large boulder, and disarticulated owl pellet remains from the floor of the same small cave in Aroona Dam near Leigh Creek in South Australia to determine the original small mammals of the north western Flinders Ranges in South Australia. The deposits were located in a small cave that, at some point in the past, parts collapsed from the roof on to the pellet deposit effectively sealing them off from modern additions, weathering and dispersal. The preservation of pellets from burial by boulders provided a unique sample that acted as a time capsule for the original small mammals of the area.

The pellets were radiocarbon dated to 1547-678 yr BP. A total of 22 mammal species were identified from the assemblage. Over 34% of these species are now completely extinct, with over 21% locally extinct from the surrounding area. When data from my study is combined with existing Holocene records for the northwestern Flinders Ranges, it is evident there has been an overall drop in small mammal species diversity of around 56% since European settlement. Subfossil deposits are useful indicators of the original mammal assemblages in Australia and provide data that is relevant to conservation of vulnerable species.

A relative chronology and preliminary palaeoenvironmental interpretation of recent marsupial fossil finds from the Nepean Peninsula, Victoria

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The Nepean Peninsula is located at the western end of the Mornington Peninsula in Victoria, Australia. The area is dominated by dunes and cliffs composed of laterally extensive aeolianites, unconsolidated sand and palaeosols. It also features localised calcretes, dissolution chimneys, arches, stacks and rhizoconcretion 'forests'. The dune and cliff sequences are contemporaneous with, and can be considered part of the regionally extensive Bridgewater Formation that stretches along the coast from South Australia to Victoria.

The first recorded marsupial fossil find from the Nepean Peninsula was in 1900 from Fowlers Beach (a partial lower incisor of *Palorchestes azael*). There have been very few finds since then. Recently, an increase in keen-eyed beach walkers, combined with ongoing erosion, have uncovered several new fossils, which are:

- An *in situ* emu (*Dromaius sp.*) egg and probable emu footprint located near Diamond Bay. This is presented in an unpublished Honours project by Rajapaksa (2011). An averaged OSL age of 200 ka has been attributed to the footprint, encompassing late OIS 7 to early 5e.
- In 2012 an almost complete skeleton of *Zygomaturus trilobus* was found, fallen from an eroding arch at the Bay of Islands (age pending).
- A skull, with associated maxillae, of *Simosthenurus occidentalis* was located in 2015, on the shore platform within the intertidal zone at Gunnamatta Beach (age pending).

Until new OSL dating is completed, a relative age for the newly found marsupial fossils has been applied, based on their stratigraphic position relative to the known OSL dated (emu) horizon. The relative correlation utilises several laterally continuous and extensive palaeosol and aeolianite units.

Combined with current palaeoenvironmental work, there are indications of a depositional chronology that could cover periods older than OIS 7 and younger than OIS 6.

New insights from New Zealand and Italian Eocene fossils that inform marine angiosperm evolution

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Understanding the evolutionary trends among the aquatic plant lineages that include the marine angiosperms (seagrasses) are complicated by a convergence of factors. These include: a highly reduced whole plant morphology associated with adaptation to the aquatic habit; loss of cuticles due to submerged aquatic habit; ephemeral and often cryptic reproductive structures; very poor pollen record associated with water pollination (hydrophily), many species having lost, or exhibiting a highly reduced, pollen exine; and the rarity of material generally being preserved in habitats of coastal marine environments, likely due to the high degree of detrital microbial processes in these habitats. Among the more interesting groups are the seagrasses, which are phylogenetically included in the flowering plant order Alismatales, a basal monocot lineage with significant divergence among families. Many fossils have been purportedly called 'seagrasses', only to be shown to be otherwise when analysed. In addition, fossils loosely recognised as aquatic plants from well known Eocene marine deposits at Bolca, Italy, confirm the presence of a well established marine flora in the Mediterranean at this time. Well preserved seagrass fossils in New Zealand Miocene–Pliocene South Island marine deposits have been discovered recently. These fossils are affiliated with or may be determined to be tropical species and this new material requires we revise our concepts of the distribution of marine angiosperm environments in the New Zealand region. In this presentation, we discuss the new insights the discovery of these fossils will give in understanding the evolutionary trends of this unusual flowering plant group.

Fossils of the East Indiaman Ridge: first palaeontological assemblages from the western Perth Abyssal Plain, eastern Indian Ocean

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The East Indiaman Ridge, on the western limit of the Perth Abyssal Plain, eastern Indian Ocean comprises two microcontinental blocks, the Batavia and Gulden Draak knolls. The first sedimentary samples from this region were recovered in late 2011 and analysis of these revealed a hitherto undocumented palaeontological suite. These are the first fossil remains ever reported from this part of the planet. The assemblage consists of 22 species of Mollusca (Bivalvia, Gastropoda, Scaphopoda, Cephalopoda), including five species of gastropod new to science. In addition, serpulid, ostracod and echinoid taxa were recovered. Microfossils of foraminifers, dinoflagellates, acritarchs, and sparse spore/pollen were also discovered. Palaeontological and taphonomic analyses of these assemblages provide strong evidence of a shallow marine depositional setting, under differential energy conditions (e.g. mass flow, quiescence, reducing). Biostratigraphic range data of the preserved faunal assemblages delimit an age of latest Albian (*ca* 103 Ma) for rocks recovered from Batavia Knoll, and a similar to possibly Late Cretaceous age for some strata from Gulden Draak Knoll. This new fossil suite allows the East Indiaman knolls to be biostratigraphically correlated with conjugate strata in the Carnarvon Basin, Western Australia and the Cauvery Basin in southern India. The Albian age is contemporaneous with the rifting of the knolls from the Greater Indian continental margin during the broader India-Australia-Antarctica divergence of the final break-up of East Gondwana in the mid-Cretaceous.

Digitally reconstructed Neanderthals meet finite element analysis and computational fluid mechanics: so why the long face?

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The most obvious diagnostic feature of Neanderthals (*Homo neanderthalensis*) is their markedly prognathous face. Why this is so is less obvious. Adaptation to sustain high biting loads in the anterior dentition, adaptation to cold climates, and random genetic drift are the three primary explanations on offer. Here we present meticulously reconstructed biomechanical models of three of the world's best-preserved Neanderthal crania, a single *H. heidelbergensis* (Broken Hill 1) and a late Pleistocene modern human (Mladec 1), as well as cranial models of ten Holocene modern humans, as bases for addressing this question. Our results lead to a conclusive answer.

Carbon isotope composition of upper Furongian to Lower Ordovician carbonates in North China and global correlation implications

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With reference to the scale of conodont zones, samples for chemostratigraphic study were intensively collected from the upper Chaomidian Formation to the lower Sanshanzi Formation in the Cambrian–Ordovician carbonate transition interval of the Fanzhuang and Yaowangshan sections, Shandong Province, North China. The data reveal that $\delta^{13}C$ and $\delta^{18}O$ values of near-primary micrite range from 3.4‰ to +1.3‰ (VPDB) and from 7.8‰ to 4.3‰ (VPDB) respectively in the Fanzhuang section. In the Yaowangshan section, $\delta^{13}C$ and $\delta^{18}O$ values of near-primary micrite range from 6.2‰ to +1.4‰ (VPDB) and from 8.1‰ to 4.4‰ (VPDB) respectively. The carbon isotope records show that three negative and three positive excursions appear alternately in the Fanzhuang section, and four negative with three positive excursions in the Yaowangshan section. The bases of the *C. intermedius* Zone and *C. lindstromi* Zone mark the onset of negative ^{13}C shifts; the $\delta^{13}C$ negative excursion (TOICE) of the Lower Ordovician in the top of the Chaomidian Formation appears at the top of the *C. angulatus* Zone. The carbon isotope records, curves and trends across the upper Furongian-Lower Ordovician boundary in North China can be correlated with key Cambrian–Ordovician boundary sections in other locations. These correlations suggest that the Cambrian-Ordovician boundary in the Fanzhuang and Yaowangshan sections can be positioned in the top part of the Chaomidian Formation.

Remarkable change of microbiota around the Cambrian *Oryctocephalus indicus* trilobite Zone

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In the Wuliu–Zenjiaya section, southeastern Guizhou, China, close to the Cambrian Series 2–Series 3 boundary based on the first appearance of the trilobite *Oryctocephalus indicus*, a diverse spinose acritarch assemblage abruptly appears, and is quite distinct from the acritarch assemblages from Series 2. Obviously, the remarkable biotic change represented by both acritarch assemblages and trilobite zones indicates that a major geological and biological event had taken place during the transition from Series 2 to Series 3. The existence of this event has been strongly supported by geochemical studies of $\delta^{13}C_{carb}$ and $\delta^{34}S_{CRS}$ and biomarker evidence from the Wuliu–Zengjiaya section. More recently, new data on the acritarch assemblages from the stratigraphic sequence incorporating the trilobite *Oryctocephalus indicus* Zone in the Cambrian Kunzam La (Parahio) Formation at the Kaltarbo locality in the Parahio Valley, northwestern Himalaya, also show a distinct change of microbiota.

The onychophoran-like myoanatomy of the Cambrian gilled lobopodian *Pambdelurion whittingtoni*: implications for the early evolution of arthropod skeletomusculature

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Arthropods are characterised by a rigid, articulating, exoskeleton operated by a lever-like system of segmentally arranged, antagonistic muscles. This skeletomuscular system evolved from an unsegmented body wall musculature acting on a hydrostatic skeleton, similar to that of the arthropods' close relatives, the soft-bodied onychophorans, although this transition is only partially understood. Taxa from the Cambrian Lagerstätte of Sirius Passet, Greenland, including the soft-bodied stem-arthropod, *Pambdelurion whittingtoni*, and the hard-bodied arthropods, *Kiisortoqia soperi* and *Campanamuta mantonae*, frequently exhibit preserved musculature. *Pambdelurion's* myoanatomy has previously been interpreted as intermediate between arthropodan and onychophoran-like systems, based on the apparent presence of oblique musculature running through the body cavity, in combination with peripheral longitudinal musculature. However, the present study, supplemented by newly collected specimens, reveals that *Pambdelurion's* myoanatomy conforms closely to that of extant onychophorans, with unsegmented dorsal, ventral and longitudinal muscle groups in the trunk, and extrinsic and intrinsic muscles controlling the legs. *Pambdelurion's* oblique musculature, previously interpreted as an arthropodan characteristic, appears confined to the cephalic region and first few body segments, and does not represent

a shift towards arthropodan myoanatomy. Rather, this oblique musculature possibly operated a protrusible pharynx and mouth cone homologous to that of cycloneuralians. The Sirius Passet arthropods, *Kiisortoqia* and *Campanamuta*, also possess large longitudinal muscles in the trunk, although, unlike *Pambdelurion*, they are segmentally divided at the tergal boundaries. Thus, the transition towards an arthropodan myoanatomy from a lobopodian ancestor likely involved the division of the peripheral longitudinal muscle into segmented units.

Revision of the biostratigraphy of oryctocephalid trilobites during Cambrian Stage 4 and Stage 5 interval

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Based on revision of the genus *Arthricocephalus* Bergeron 1899 by Peng *et al.* (2015) and other research on oryctocephalid trilobites, six oryctocephalid trilobite zones can be established in the Duyunian Stage (Cambrian Stage 4) and lower Taijiangian Stage (Cambrian Stage 5). In descending order, these are: *Oryctocephalus indicus* Zone (lower Taijiangian), *Ovatoryctocara sinensis-Bathynotus kueichouensis* Zone, *Protoryctocephalus arcticus* Zone, *Arthricocephalus intermedius-Oryctocarella sibirica* Zone, *Arthricocephalus chauveaui-Oryctocarella duyunensis* Zone, *Oryctocarella jiangkouensis* Zone (Duyunian). *Oryctocephalus indicus* (Reed 1910) includes as synonyms *Oryctocephalus orientalis* Saito 1934 (in part), *O. kobayashii* Saito 1934, *O. incurvus* Lu & Chien in Lu *et al.* 1974, *O. indicus latus* Zhao & Yuan in Yuan *et al*. 2002, *O. americanus* Sundberg & McCollum 2003, *Oryctocephalops tongrenensis* Lu & Qian 1983 and *Oryctocephalina reticulata* Lermontova 1940 (in part). *Arthricocephalus* (*Arthricocephalites*) Chien & Lin in Lu *et al.* 1974 and *Haliplanktos* Blaker & Peel 1997 are considered synonymous with *Arthricocephalus* Bergeron 1899; *Arthricocephalus* (*Arthricocephalites*) *intermedius* Chow in Lu *et al.* 1974 therefore becomes *Arthricocephalus intermedius* Chow in Lu *et al.* 1974, and includes the synonyms *Arthricocephalus* (*Arthricocephlites*) *jishouensis* Zhou in Zhou *et al*. 1977, *Arthricocephalus taijiangensis* Yin in Yin & Lee 1978, *Arthricocephalus* (*Arthricocephlites*) *balangensis* Lu & Chien in Yin & Lee 1978 and *Arthricocephalus* (*Arthricocephlites*) *pulchellus* Zhang & Qian in Zhang *et al.* 1980; we consider *Arthricocephalus* (*Arthricocephlites*) *xinzhaiheensis* Chien & Lin in Lu *et al.* 1974 and *Arthricocephalus* (*Arthricocephlites*) *tongrenensis* Yin in Yin & Lee 1978 as synonymous with *Arthricocephalus chauveaui* Bergeron 1899. *Oryctocarella jiangkouensis* (Yin in Yin et Lee, 1978) is the earlist species of the genus. *Oryctocarella* migrated from South China via Siberia, North Greenland and North America to Australia, and has potential for intercontinental correlation. The FAD of *Oryctocephalus indicus* (Reed 1910) is taken as the base of Cambrian Series 3 and Stage 5.

Small shelly fossils from the lowest Cambrian bioclastic limestones on the southwestern margin of North China: composition and biostratigraphy

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The Xinji Formation (Longxian area) represents the oldest known Cambrian unit on the southwestern margin of the North China Platform where it unconformably overlies the late Ediacaran Dongpo Shale. The bioclastic limestone unit of the Xinji Formation yields diverse skeletal fossils, including sponge spicules, chancelloriid sclerites, hyoliths, micromolluscs, trilobites, echinoderm ossicles, archaeocyath fragments, cambroclaves, tianzhushanellids and other small shelly fossils. This fossil assemblage provides an important window to investigate faunal evolution and biostratigraphy of North China during the Cambrian Explosion. The dense concentration of skeletal fragments in the assemblage indicates a heterochthonous burial process. Statistical analysis shows that sessile organisms are dominant in the lower part of the limestone while vagile organisms dominate the upper part. Thus a two-step depositional process of this bioclastic shoal association can be formulated. The presence of fossil elements with biostratigraphic significance, e.g. *Pelagiella madianensis*, *Cambroclavus absonus*, *Stenotheca drepanoida* and *Apistoconcha siphonalis*, correlates the assemblage to the *Stenotheca drepanoida* Zone of South Australia, which approximately correlates through the *Pararaia bunyerooensis* to *P. janeae* trilobite zones. The occurrence of the trilobite *Estaingia* in the Xinji fossil assemblage provides further evidence for a close correlation to the *P. janeae* Zone of Australia, which corresponds to the lower Canglangpuan Stage of South China, and lower to middle Botoman Stage of Siberia.

Reconstruction of the body plan of *Kunmingella* (Bradoriida) and discussion of its relationship with Ostracoda

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The Cambrian bivalved arthropods bradoriids have previously been considered as ancestral ostracods. In 1996, fossil specimens with soft parts suggested that bradoriids, at least *Kunmingella*, should be excluded from Ostracoda. Until now, however, not all the limb structures of *Kunmingella* have been recovered. The structure of appendage bristles, especially, remains poorly known. Based on published data and newly discovered material, a more detailed reconstruction of the body plan of *Kunmingella douvillei* is provided. Comparison between it and extant ostracods (especially podocopids) raises the possibility that some Cambrian bradoriids could be related to Ostracoda.

Macroscopic fossils from the late Ediacaran Dongpo Shale of North China

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The central mountain ranges, known as the backbone of China, separate the country into North China and South China, which differ from each other in geology, geography, climate and culture. The Precambrian-Cambrian transition of South China has received much attention from world scientists for its beautiful sections and numerous fantastic fossil Lagerstätten. In contrast, the Ediacaran and Cambrian rocks in North China have been less well studied, as much less attention has been paid to them. The lowermost Cambrian of North China (uppermost Stage 3), enriched with SSFs, unconformably overlies Precambrian rocks of various ages, ranging from Archean to late Ediacaran. Ediacaran rocks developed in marginal regions and cratonic basins. Along the south margin of North China, the Dongpo Shale immediately underlies the unconformity and overlies the Luoquan Diamictite of unknown age. Two fossil horizons have recently been found within the Dongpo Shale. The lower horizon at the middle part of the shale unit yields a diverse form of macroscopic, soft-bodied fossils, e.g. the annulated tubular form *Shaanxilithes*; the form of a string of beads, *Horodyskia*; the WiFi symbol-like form *Palaeopascichnus*, and an unnamed form resembling a string of rings, which might be a segmented organism composed of many repetitive units. Algae and trace fossils are abundant but simple in complexity and low in diversity. The presence of *Shaanxilithes* and *Palaeopascichnus* suggests an age of late Ediacaran. The upper fossil horizon, nearly at the top of the Dongpo Shale, contains small clawlike fossils of unknown affinities. New findings indicate that the Dongpo Shale would be an important target for investigating the evolution of organisms during the Ediacaran, particularly in North China.

The diversity and morphology of Cambrian lophotrochozoans: a perspective from the Chengjiang Lagerstätte of China

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Lophotrochozoa (sometimes equated with the Spiralia), a clade of non-ecdysozoan protostomes, mainly comprise the two phyla Annelida and Mollusca within the Trochozoa and the Lophophorata. Until now, only a few specimens of polychaete worms and *Wiwaxia* have provided insights into the evolution of the character states of annelids and molluscs from Chengjiang. The Lophophorata (Bryozoa, Entoprocta, Phoronida and Brachiopoda) are united by the presence of a fan of ciliated tentacles surrounding the mouth, and so have been treated as a monophyletic group. Although considerable advances have been made recently in unveiling the Cambrian morphology and diversity of brachiopods, and other pivotal lophophorate animals including bryozoans and entoprocts, the most conspicuous phylogenetic gap in the Cambrian fossil record is for the Phoronida. Here we reinterpret abundant, well preserved material of *Archisaccophyllia kunmingensis* from Chengjiang as a stem-group phoronid with actinotroch-like larval characters. The phoronid affinity is supported by the sessile body plan and interior soft anatomy. The body consists of an upper agglutinated calyx and a lower stout stalk with a basal holdfast. The soft anatomy includes a U-shaped gut with a mouth surrounded by a fan of flexible tentacles. *Archisaccophyllia kunmingensis* differs from extant phoronid actinotroch larvae in being much larger and having a sessile lifestyle, as well as exhibiting a calyx covered with agglutinated quartz grains, reminiscent of the agglutination that is known both in extant adult phoronids and in the enigmatic lophophorate *Yuganotheca,* recently described from the Chengjiang fauna. The occurrence of an actinotroch-like phoronid in the Chengjiang biota traces the ancestry of yet another lophotrochozoan phylum back to the Cambrian radiation, and has important implications for the earliest evolution of lophotrochozoans, showing that an agglutinated body plan may have evolved earlier than previously suspected.

Morphology and ontogeny of the earliest acrotretid brachiopod *Eohadrotreta* and its implications for brachiopod phylogeny

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A large number of exquisitely preserved acrotretoid brachiopods assigned to *Eohadrotreta zhenbaensis* Li & Holmer 2004 are described from the lower Cambrian Series 2 Shuijingtuo Formation of the Three Gorges area, South China. *Eohadrotreta* is hitherto known from Cambrian Stages 4 to 5 in South China, Himalaya and possibly in Australia and Siberia, and its occurrence in the Shuijingtuo Formation may represent a potential index fossil for correlation of lower Cambrian strata. *Eohadrotreta zhenbaensis* shows some recognisable variations in shell morphology through ontogeny based on articulated and complete shells recovered from the Three Gorges area. In the juvenile stage, the shell is subcircular in outline, biconvex in profile, with an average length:width ratio about 0.84. At this time, the ventral apical process and the dorsal median septum are vestigial or absent. The pedicle foramen is not enclosed within the larval shell, remaining as an open notch until the shell reaches around 550-600 μm in size. By contrast, the shell in the adult stage shows a transversely oval outline and a ventribiconvex profile. The ventral shell becomes highly conical with a distinct long intertrough, and the ventral pseudointerarea varies from catacline to procline. Meanwhile, the apical process, cardinal muscle scars and median septum, as well as the *vascula lateralia*, are developed progressively. Pitted larval shells in the two valves remain the same size, while the peripheral larval shell progressively becomes larger during ontogeny. Observation of developmental shell valves of *Eohadrotreta* at different sizes demonstrates that an enclosed acrotretid brachiopod foramen may have evolved from an *Obolus*-like brachiopod with a shallow pedicle groove, which will shed new light on the early origin and evolution of the Acrotretida and the phylogeny of linguliformean brachiopods.

Suitability of the Wuliu-Zengjiayan section, Guizhou, China as a stratotype for Cambrian Stage 5

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The Working Group studying the Cambrian Stage 5 boundary has recommended using the FAD of an oryctocephalid trilobite, *Oryctocephalus indicus*, as the primary chronostratigraphic tool for recognising the base of the stage and the conterminant base of Cambrian Series 3. *Oryctocephalus indicus* is intercontinentally distributed but not cosmopolitan, and global recognition of the base of Stage 5 will require reliance on secondary chronostratigraphic tools. To facilitate correlation into all Cambrian regions, it may be desirable to designate a GSSP and an ASSP in another palaeogeographic region that contains important guides for correlation that may not be available in all areas.

One leading contender as a stratotype for the Stage 5 GSSP is the Wuliu-Zengjiayan section in Balang County, Guizhou, China. The Wuliu-Zengjiayan section includes a 214.2 m-thick succession of the Kaili Formation, an outer-shelf deposit mainly composed of grey mudstone intercalated with grey, thin-bedded limestones. Sedimentation is inferred to have taken place predominantly in quiet water, with episodic storm-generated influxes. The Wuliu-Zengjiayan section is highly fossiliferous and accessible year round. It has been studied repeatedly, leading to a number of refinements in the ranges of guide fossils. Three polymerid trilobite zones and two acritarch assemblage zones are recognised. *Oryctocephalus indicus*, the presumptive primary biostratigraphic guide for the base of Stage 5, first appears 52.8 m above the base of the Kaili Formation in this section. Sequence stratigraphic evidence suggests the onset of a transgression just below the FAD of *O. indicus*. The Stage 5 base can be further constrained by the close stratigraphic positions of the LADs of *Bathynotus*, *Ovatoryctocara*, *Oryctocarella* and redlichiid trilobites. The position of the ROECE $\delta^{13}C$ excursion, and the position of a $\delta^{34}S$ excursion, both of which nearly coincide with the FAD of *O. indicus* and which are recorded in the Wuliu-Zengjiayan section, provide further guidance for correlation to the Great Basin (USA), North Greenland, Siberia, India, Spain and elsewhere.

Exceptionally preserved fossils from the Jianhe Biota in the 'Tsinghsutung Formation', Balang, Guizhou, China

Zhao, Yuan-Long[1]; Yang, Xing-Lian[1]; Babcock, Loren E.[2,3]; Peng, Jin[1]; Yang, Yu-Ning[1]; Sun, Hai-Jing[4]; Esteve, Jorge[5]; Wang, Ming-Kun[1]; Chen, Wan-Yi[1] & Wang, Yuan[1]

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The Tsinghsutung Formation (Cambrian Stage 4), exposed in the Songshan section, near Balang village, Guizhou Province, South China, yields a diverse assemblage of biomineralised and non-biomineralised organisms. Exceptionally preserved fossils occur in limestones and mudrocks of the *Protoryctocephalus arcticus* Zone in the middle to upper part of the formation. Collecting so far has produced representatives of at least 53 genera including macroscopic algae, sponges, cnidarians, molluscs, brachiopods, priapulids, arthropods and echinoderms. Similar to other Burgess Shale-type biotas, the Jianhe Biota is dominated by arthropods, of which 17 genera are trilobites, six are large bivalve arthropods, one is a bradoriid and three are dinocarids. Six brachiopod genera have been recognised. The Jianhe Biota adds to a growing list of major Burgess Shale-type deposits in the Cambrian, and provides further information about the scope of marine biotic diversity reached during relatively early phases of the Cambrian radiation.

Revised oryctocephalid trilobite zonation and intercontinental correlation through the Cambrian Series 2-Series 3 boundary interval at Balang, Guizhou, China

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Oryctocephalid trilobites rank among the most useful biostratigraphic tools for intercontinental correlation of Cambrian strata through the Series 2-Series 3 boundary interval. Strata exposed at Balang, Guizhou, China, have been well studied because they provide a long, continuous stratigraphic record through the upper part of provisional Series 2 and provisional Series 3. The section includes three formations, the Balang, Tsinghsutung and Kaili formations. Based largely on this section, a revised oryctocephalid zonation for South China is proposed. The new trilobite zonation in ascending order is: 1) *Arthricocephalus jiangkouensis* (*Oryctocarella jiangkouensis*) Zone, which occupies the lower Balang Formation; 2) *Arthricocephalus intermedicus* Zone, which occupies the middle-upper Balang and lower to middle Tsinghsutung formations; 3) *Protoryctocephalus arcticus* Zone, which occupies the middle-upper Tsinghsutung Formation; 4) *Bathynotus kueichouensis-Ovatoryctocara sinensis* Assemblage Zone, which occupies the lower Kaili Formation; 5) *Oryctocephalus indicus* Zone, which occupies the middle-upper Kaili Formation and 6) *Peronopsis taijiangensis* Zone, which occupies the upper Kaili Formation. Strata of the *A. jiankouensis* Zone to *P. arcticus* Zone are inferred to correlate with the *Eoagostus roddyi-Arthricocephalus chauveaui* Assemblage Zone in the Henson Gletscher Formation of Peary Land, North Greenland, and the *Olenellus* Zone (in part) of greater Laurentia. Strata of the *B. kueichouensis-O. sinensis* Assemblage Zone are inferred to correlate with the *Ovatoryctocara granulata* Zone of Siberia, the *Bonnia-Pagetides* Zone in the Henson Gletscher Formation of North Greenland, and the *Nephrolenellus multinodus* Zone of Laurentia. The *O. indicus* Zone in South China correlates with the *O. indicus* Zone of Laurentia and India and presumably, the *Oryctocephalus reticulatus* Zone of Siberia.

Conodont biozonation of the Australian Upper Ordovician – advancing towards a fine-scaled regional biostratigraphic correlation

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Seven conodont biozones are recognised in the Upper Ordovician of Australia. The *Pygodus anserinus*, *Belodina compressa* and *Phragmodus undatus-Tasmanognathus careyi* biozones are successively represented through the Sandbian. Although the *Erismodus quadridactylus* Biozone of the late Sandbian North American Midcontinent succession was previously recognised in the Stokes Siltstone of the Amadeus Basin and the Mithaka Formation of the Georgina Basin in central Australia, we argue for a middle-late Darriwilian age for these two units. Four conodont biozones, from oldest to youngest; the *Taoqupognathus philipi*, *T. blandus*, *T. tumidus-Protopanderodus insculptus* and *Aphelognathus grandis* biozones, have been established in the Katian of eastern Australia. *Taoqupognathus* species are particularly useful in

correlating the lower-middle Katian successions of eastern Australia with contemporary rocks in other parts of eastern Gondwana and peri-Gondwana, such as those in the three major terranes of North and South China, and Tarim. These regions, together with Sibumasu and eastern Australia, were part of the Australasian Superprovince during the Late Ordovician, with a strong palaeobiogeographic identity signalled by domination of *Taoqupognathus, Tasmanognathus* and *Yaoxianognathus* in conodont faunas. Longstanding difficulties in precise correlation of the local biozonation with the well established North American Midcontinent or Baltoscandian successions of the Late Ordovician are mainly due to strong endemism of the Australian faunas, particularly from shallow water settings. These have been resolved by the recognition that differentiation of palaeogeographical entities within the Shallow Sea Realm depends on detailed analysis of the constituents of shallow water faunas, leading to better understanding of conodont biofacies architecture. The conodont biozonation of the Australian Upper Ordovician reviewed here also provides a crucial chronological reference for better constraining the temporal and spatial range of Late Ordovician tectonostratigraphic events across the Gondwana craton of central and northern Australia and orogenic belts of eastern Australia.

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The Ediacaran acanthomorphic acritarch biostratigraphy of South China

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The Ediacaran Period represents a critical transition from the Precambrian marine biosphere characterised by low diversity, longranging microscopic organisms to the Phanerozoic one with diverse, large organisms exhibiting rapid evolutionary turnovers. Palaeontological investigations, integrated stratigraphic correlations, and a ratified Ediacaran geological time scale are crucial for understanding the evolutionary history of this transitional period. Previous studies indicate that the Ediacaran Period can be palaeontologically divided into two parts, with the early Ediacaran being characterised by abundant and diverse microscopic acanthomorphic acritarchs and the late Ediacaran by the macroscopic Ediacara organisms. This evolutionary turnover may occur concurrently with the middle Ediacaran pronounced negative carbon isotope shift—the Shuram excursion and a non-global glaciation event—the Gaskiers glaciation (~ 580 Ma), and can be used as a biostratigraphic marker to subdivide the Ediacaran Period. Numerous palaeontological and chemostratigraphic studies from the Ediacaran successions in South China have revealed a similar evolutionary pattern. In the Yangtze Gorges area of South China, previous palaeontological investigations indicate that the Doushantuo-type acritarchs disappear abruptly at the horizon that yields a pronounced negative carbon isotope excusion (EN3). Our recent palaeontological study on the early Ediacaran Doushantuo Formation in Hunan, South China, however, indicates that the acanthomorphic acritarchs occur in horizons both below and above the pronounced negative carbon isotope excursion, which can be lithostratigraphically correlated with EN3 in the Yangtze Gorges area. The chemostratigraphic correlation with EN3 and the Shuram excursion is supported by the elevated strontium isotopic values in the upper Doushantuo Formation. The new finding suggests that the Doushantuo-type acanthomorphic acritarchs may have occurred concurrently with the Ediacara mega-organisms, and the temporal relationship of their disappearance with the Shuram excursion and the Gaskiers glaciation needs to be reconsidered.

Late Cambrian Guole biota from South China

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Burgess Shale-type biotas are critically important in understanding the early evolution of the Metazoa. The well known Cambrian Burgess Shale-type biotas, such as the Burgess Shale, Chengjiang, Sirius Passet, Emu Bay Shale and Kaili, are all restricted to the early and middle Cambrian time interval and such biotas not been found in strata younger than Guzhangian.

A new Burgess Shale-type biota, the Guole Biota, was found in the late Cambrian (Furongian) Sandu Formation near Guole Town, Jingxi County, Guangxi Zhuang Autonomous Region, South China. The associated trilobites indicate that this biota is equivalent to the *Probilacunaspis nasalis-Peichiashania hunanensis* Zone of the Jiangshanian (middle Furongian, Cambrian Stage 9) of northwestern Hunan.

Eight major fossil groups have been recognised in the Guole biota. It includes very diverse trilobites, non-trilobite arthropods, brachiopods, echinoderms, cnidarians, graptolites, hyoliths, palaeoscolecids and algae.

The discovery of the Guole biota extends the geographic and temporal range of the Konservat-Lagerstätten in South

China. The Guole biota represents the first discovery of a late Cambrian Burgess Shale-type biota in the world, filling the gap in the chronological sequence of exceptionally well preserved biotas. Comparison of the common elements of such Lagerstätten provides more insight into their evolution and time succession.

A novel quantitative methodology for assessing taphonomic abrasion on fossil bone

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Damage through fluvial transport often leaves taphonomic evidence for accumulation processes in fossil assemblages. Most noticeable is the distinctive abrasion of bone surfaces, due to interaction with fine-grained sediment. The intensity of surface abrasion is typically assessed using a simplistic qualitative scale, akin to grain angularity in sedimentology. Assessment requires, but rarely achieves, consistent and accurate identification of alteration features. Reliance on visual assessment makes current scales vulnerable to observer bias, which limits researchers' ability to test prior studies or compare results between sites. A new methodology is suggested to improve the reliability of determining the extent of abrasion in taphonomic analysis.

This study describes a novel method for objectively measuring bone surface abrasion. It is applied in a pilot study of fossil pedal phalanges of the extinct kangaroo *Macropus titan* from the Lancefield megafauna site (Museum Victoria collection, Australia). A NextEngine laser surface scanner produces three-dimensional mesh models of bones. These are normalised with respect to size and morphology using Rhinoceros 5 graphics software. Then, relative difference in mesh volume is measured between abraded fossils and an unabraded control to produce a continuous percentage statistic for abrasion intensity.

Quantifying abrasion intensity for multiple fossils in an assemblage is anticipated to produce a continuous taphonomic scale. We project results that are objective, replicable, and achieve higher-resolution analyses than qualitative scales. When validated, this technique will facilitate inter-site comparisons and testing of past results. Initial data collection suggests commercial scanning equipment produces sufficiently detailed models to analyse subtle abrasion taphonomy.

POSTER ABSTRACTS

Calibrating the temporal relationships between the AHC acritarch assemblage and carbon isotope chemostratigraphy in the Yangtze Platform, South China

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Biostratigraphically important microfossils were studied from the basal Cambrian chert-phosphorite units of the Yanjiahe Formation, Yangtze Gorges area, and the Zhujiaqing Formation, eastern Yunnan. The microfossils found from the studied sections are as follows: *Asteridium tornatum, Heliosphaeridium ampliatum* and *Comasphaeridium annulare* as major acritarch components; and *Megathrix longus* and *Archaeophycus yunnanensis* as another group of phytoplankton extracted from chert layers. Among these taxa, the acritarch species *A. tornatum, H. ampliatum* and *C. annulare* (the AHC acritarch assemblage) were used to correlate lowermost Cambrian successions between the Yangtze Gorges area and eastern Yunnan, together with SSF biostratigraphy and carbon isotope chemostratigraphy. The result shows that the AHC assemblage temporally precedes the *Anabarites trisulcatus-Protohertzina anabarica* assemblage, and spatially fits into the large negative carbon isotope anomaly of the lowermost Cambrian (BACE) in both localities. This implies that the radiation of phytoplankton was slightly before the radiation of skeletal metazoans, and the AHC acritarch assemblage can be another important chronological reference to the lowermost Cambrian successions in South China, and potentially to global correlations.

Ecosystem change through the Neogene in Australia: documenting the rise of C4 vegetation

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Plants that utilise C4 photosynthesis are adapted to arid environments, and expanded in many regions during the Miocene and Pliocene. However when this expansion occurred in Australia is unclear, in spite of C4 photosynthesis being prevalent today. In Australia, C4 photosynthesis occurs in chenopods and grasses, both of which also contain C3 taxa. Evidence for the expansion of grass- and chenopod-dominated ecosystems spans the late Miocene and Pliocene geological record in Australia. During the late Miocene, herbivores with morphological adaptations for chenopod and grass diets emerged, diversifying in the Pliocene. Pliocene marine sediments off the coasts of Australia reveal increases in phytoliths, likely derived from grasses, and pollen from both chenopods and grasses. Nonetheless, these data cannot detect when C4 vegetation first expanded in Australia.

C4 plant photosynthesis fractionates carbon isotopes differently compared to C3 plants, resulting in ^{13}C-enriched carbon isotope ratios in materials such as leaf wax compounds (e.g. long-chain *n*-alkanes) that can be preserved in sediments for millions of years. We aim to analyse carbon isotope ratios of *n*-alkanes to reconstruct the photosynthetic landscape for Neogene Australia. Concentration, average chain length and carbon preference index has been measured from *n*-alkanes for 23 IODP samples spanning the late Miocene through to the Pleistocene for sites off the east (Site 591) and west (Site 763) coasts of Australia. Average chain length increases through the late Neogene, coincident with previously documented increases in phytolith and grass pollen abundance. These data demonstrate the presence of *n*-alkanes of terrestrial plant origin in immature marine sediments and the feasibility of their use in compound specific isotope analyses. Ongoing work will use carbon isotope ratios of leaf wax *n*-alkanes to constrain the timing of the expansion of C4-dominant ecosystems, with possible drivers of this change on the Australian continent evaluated for their plausibility.

Microvertebrate fish remains from the Early Cretaceous Toolebuc Formation (Albian) of Richmond, central-northern Queensland, Australia

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The Early Cretaceous Toolebuc Formation of central-northern Queensland is a richly fossiliferous unit deposited during the time of inundation of the Eromanga Sea. Vertebrate macrofossils representing fishes (both actinopterygians and chondrichthyans), marine turtles, pliosaurs, ichthyosaurs, pterosaurs, a dinosaur and a bird have previously been described.

Recently, limestone disaggregated using acetic acid has revealed that the Toolebuc Formation preserves a microfossil fauna comparable to macrofossils already described, in addition to taxa not recorded in the macrofossil record. The

microvertebrate remains consist of isolated fragments of fin elements, ribs, skull elements and fragmented jaws, together with teeth and scales dominantly of teleost fishes.

The most numerous and easily identifiable microfossils are isolated teeth belonging to the bramble shark *Echinorhinus australis*. Its teeth are characterised as being compressed labiolingual with short low-angled cusp, often with the nutrient foramen and groove preserved. The sheer number of individual teeth preserved in the Toolebuc Formation is unusual, as in other Mesozoic occurrences usually only a single tooth is recovered from entire formations.

Teleost teeth that are smooth and laterally compressed with two cutting edges and carinae are thought to represent ectopterygoid and mandibular teeth of a basal Aulopiformes fish previously unrecognised from the formation. These teeth dominate the teleost microvertebrate assemblage. Conical teeth with little carinae are thought to represent ichthyodectiformes, possibly *Cooyoo australis*.

The isolated scales preserved within the microremains are difficult to assign as fishes from the Toolebuc Formation are yet to have their scale morphology described in detail.

The identification of isolated actinopterygian teeth, scales and bone is difficult as different genera of teleosts often share similar bones and morphology. The identifications offered here are preliminary and comparisons with more complete material are pending.

Application of benthic Foraminifera to infer Holocene sea-level changes in northern Spencer Gulf, South Australia

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In contemporary marine environments, there are established correlations between the distribution of Foraminifera species and water depth. Thus, fossil Foraminifera of the same species, recovered from sediments several thousand years old, are useful proxies for inferring past environments. The application of fossil benthic Foraminifera in this study enabled the reconstruction of a Holocene sea-level history for northern Spencer Gulf, South Australia. Three shallow marine environments: Port Gawler and Onkaparinga Estuary in South Australia, and Shark Bay in Western Australia, provided baseline data to represent modern analogues of fossil Foraminifera. Marine core samples from northern Spencer Gulf recovered Holocene successions of bioclastic sediment. Analysis of benthic Foraminifera provided evidence for the postglacial marine transgression. Changes in numerical distributions of shallow water foraminiferal species versus species that favour deeper waters indicate environmental changes. The shallow water species *Nubecularia lucifuga*, *Peneroplis planatus*, *Cribrobulimina mixta* and *Discorbis dimidiatus* provided credible evidence for an intertidal to shallow subtidal marine environment. *Massilina milletti*, which favours deeper waters, provided credible evidence for the postglacial marine transgression and subsequent marine regression. The log ratio between the numerical distribution of *Elphidium crispum* (common shallow water species) and *Elphidium macelliforme* (a species favouring deeper waters) had previously shown a strong correlation with water depth. This study showed that this relationship was not applicable to water depths of less than 15 m. The species-depth relationship also revealed a 'missing' interval at the beginning of the transgression. Radiocarbon ages revealed that the onset of the postglacial marine transgression into northern Spencer Gulf occurred at *ca* 7000-6200 yrs BP in the upper reaches. Maximum water depth occurred between 4000 and 3000 yrs BP, followed by marine regression. This is attributed to hydroisostatic uplift of northern Spencer Gulf. The foraminiferal record provided no credible evidence for late-stage Holocene sea-level rise.

Adaptive significance in the hind limbs of extant and extinct emus (*Dromaius* species)

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The modern emu *Dromaius novaehollandiae* has two extinct relatives: the King Island Emu *D. ater* and the Kangaroo Island Emu *D. baudinianus*. These extinct emu taxa are distinguishable from the modern emu by their smaller stature. Previous studies suggested that isolation from the Australian mainland, through sea level rise, contributed to differences between the mainland and island populations.

The vegetation, area, topography and climate on King Island and Kangaroo Island are significantly different from those of the Australian mainland. The mainland form *D. novaehollandiae* displays a cursorial locomotion that is suitable to the vegetative patchwork of wet and dry sclerophyll forests and grasslands. In contrast, the King and Kangaroo islands, prior to white settlement, were characterised by low-lying, scrubby and often dense vegetation.

The modern emu *D. novaehollandiae* was compared with the extinct island emus *D. ater and D. baudinianus*. The

island emus *D. ater and D. baudinianus* were also compared with each other. These comparisons are based on collections from New South Wales, Tasmanian, Victorian and South Australian museums. The hind limbs (tarsometatarsi, tibiotarsi and femora) were measured to highlight possible variation in dimensions between *D. novaehollandiae*, *D. ater* and *D. baudinianus*.

A previous assumption was that the smaller stature was due to insular dwarfism (Fosters Island Rule). However, the preliminary results from the island emus show an increase in robustness and length between the tarsometatarsus and the tibiotarsus and femur, when compared to the mainland emus. This is consistent with the idea that isolation and environmental differences, in particular vegetation, have contributed to graviportal development.

A Palaeocene fossil bee hair from New Zealand: ancient evidence of small-flower pollination?

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A ~60 Ma Palaeocene fossil bee hair from New Zealand with affinities to Colletidae or possibly Halictidae is described. Colletidae represent the vast majority of bee species present in modern New Zealand, much like Australia, and the family is predominantly Austral, with numerous sister lineages shared between Australia, Africa and South America. Extant colletids in New Zealand are mostly *Leioproctus* spp. and are part of a lineage spread between Australia and South America which is thought to have arisen about the time of the New Zealand fossil. Some *Leioproctus* in Australasia show very strong pollination associations with particular Proteaceae genera, suggesting a long coevolution for these syndromes. Extant New Zealand Halictidae are mostly represented by species of the globally distributed *Lasioglossum* subgenus *Austrevylaeus.* This subgenus is common in Australia and New Zealand, but its presence in New Zealand is thought to be relatively recent and *Lasioglossum* in Australia is estimated to have arrived from the Northern Hemisphere only ~30–25 Ma. The long-term presence of small bees in New Zealand provides support both for the widespread development of small-flower pollination syndromes there, and for previously noted plant macrofossil evidence of reproductive niche conservatism in the flora.

Trilobite moulting behaviour from the Emu Bay Shale, South Australia

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The Emu Bay Shale (EBS) is dominated by both preserved carcasses and moulted exoskeletons of two extremely numerous trilobite species, *Estaingia bilobata* and *Redlichia takooensis.* The low levels of disruption from biotic and abiotic (i.e. water movement) processes, along with rapid burial, have facilitated exceptional fossil preservation at the EBS, and so virtually undisturbed moulted trilobite exoskeleton assemblages have been preserved in great numbers. These moult assemblages capture the movement of the trilobite and pattern of sclerite disarticulation during moulting, allowing for an unprecedented interpretation of detailed behavioural information.

The extensive collections of *E. bilobata* and *R. takooensis* housed in the South Australian Museum, Adelaide, were surveyed, and a number of specimens displaying the full observable range of variation in moulting behaviour chosen for closer examination. Moulting behaviour was described and movement during exuviation interpreted for each of these specimens. These observations were contrasted to the moulting behaviour described for two other extremely common trilobite species from other localities also with exceptional fossil preservation (*Ogygopsis klotzi* from the Burgess Shale in British Columbia and *Elrathia kingii* from the Wheeler Shale in Utah).

Observations and inferences on movement during moulting are much more detailed for the EBS trilobites in comparison to those from the other localities, and very rare moulting events requiring unusual patterns of movement are discernible. For example, both species generally disarticulate the free cheeks; these are often flipped vertically for *R. takooensis*, and associated with the rostral plate in *E. bilobata*. Both species rarely demonstrate moulting by disarticulating the cephalon (resulting in 'Salter's Configuration'). These are not preserved at other localities with greater transportation prior to burial as the positioning of disarticulated sclerites is disrupted. These observations suggest that trilobite moulting is more variable within a single species than expected and that, as a group, trilobites displayed flexibility in moulting behaviour to adapt to different conditions and circumstances.

Trilobites from an archaeocyath-bearing level of Cambrian Stage 4 in the Cantabrian Mountains (northern Spain)

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The youngest archaeocyathan assemblage of the Iberian Peninsula has been recorded in the upper part of the lower member of the Láncara Formation from the Esla nappe (Cantabrian Mountains, northern Spain). This level has been assigned to Archaeocyath Zone X (lower Bilbilian; lower Cambrian), and correlated with the upper part of the Cambrian Stage 4 in several archaeocyath beds worldwide: the *Archaeocyathus yanjiaoensis* beds in South China, *Archaeocyathus abacus* beds in South Australia, *Archaeocyathus okulitchi* beds in Siberia, and *Tegerocyathus greenlandensis-Pycnoidocyathus pearylandicus* Zone from North America. New sampling of this archaeocyath bed at the Valdoré locality has yielded an interesting trilobite assemblage, which includes specimens identified as *Palaeolenus* sp. and *Neocobboldia* n. sp. The specimens of *Palaeolenus* sp. show a morphology close to that of *Palaeolenus fenyangensis*, an index species of the homonymous Chinese biozone that is roughly coincident with the *Archaeocyathus yanjiaoensis* beds of South China. The eodiscide *Neocobboldia* n. sp. is morphologically close to *Neocobboldia* aff. *dentata* from the *Ornamentaspis*? *linnarssoni* Assemblage Zone of Scandinavia, which has been correlated with the *Hupeolenus* Zone in southeastern Newfoundland and the '*Protolenus*' zone in England. This age is in accordance with the age of the Spanish material in the *Protolenus dimarginatus* Zone. These data reinforce previous archaeocyath correlation and provide a new tool for correlating these archaeocyath levels with the upper part of Cambrian Stage 4 in Scandinavia.

Agamid lizard fossils from South Australian caves and their implications for environmental change during the Quaternary

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Fossil lizards are known from the caves of South Australia but their identification is problematic due to an incomplete understanding of lizard osteological variation. Very few detailed studies exist of variation among or within species. This deficiency of baseline knowledge limits the reliability of species designations and in turn any potential for tracing faunal change and making environmental interpretations.

We examined 17 agamid maxillae from Kelly Hill Caves on Kangaroo Island (KI), and Naracoorte Caves of South Australia. These specimens have an age range of 47,000–6,500 yrs BP, and were dated using parallel methods. Selected specimens were subjected to Computer Tomography (CT) and 3D computer models were constructed. We examined a range of extant agamid taxa to establish patterns of variation within a set of discrete morphological characters. This character set was used to score each fossil and tentatively identify them. 52 landmarks were used to represent the computer models. These were used to carry out a geometric morphometric analysis, which involved a Procrustes alignment, followed by a Principal Component Analysis (PCA). The variation found among extant taxa facilitated objective comparisons between them and fossils.

The discrete character set allowed three species of agamid to be identified from Kelly Hill Caves, and five from Naracoorte Caves. Several specimens closely resembling *Rankinia diemensis* were found in both locations from sediments older than 6,800 yrs BP. Today, *R. diemensis* is absent from KI and restricted to cooler and wetter environments over 900 km south and east of the fossil sites. Thus during the glacial maximum, when the climate was coldest, this species may have had a wider distribution that reached as far west as Kangaroo Island and subsequent contraction of its range may be related to climate warming and increased aridity.

A new primitive rostroconch mollusc from the latest Late Ordovician of the Boda Limestone, Sweden

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A new genus of a small, primitive rostroconch mollusc along with a 'true' rostroconch *Conocardia* was recovered from the latest Ordovician Boda Limestone of Sweden. The new genus possesses a univalve, bilaterally compressed, wedge-shaped shell with a dorsal anterior gap that almost reaches the protruding, slightly backward bent tube-shaped protoconch with rounded apex. The protoconch occupies the central part of the dorsum. The pseudobivalve shell of this primitive mollusc shares common morphological features with the early Cambrian stem-group mollusc *Watsonella*, as well as with the middle Cambrian *Eotebenna* and *Pseudomyona*.

New illustrated history of life time scale

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We present a new reconstruction of extinct organisms to illustrate the history of life against the geological time scale. The fossil record stretches from Precambrian to Quaternary and covers all important groups of fossils. All illustrations are made in a cross-hatching black ink technique. The illustrations will be used in the outreach program of the Museum of Evolution, Uppsala University for exhibits, displays, posters and educational material. Two types of time lines will include these new illustrations, providing an up-to-date teaching tool for teachers and students.

Sizing up *Rugoconites*: a study of the ontogeny and ecology of an enigmatic Ediacaran genus

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Fossils of the soft-bodied organisms of the Ediacara Biota are exceptionally well preserved in the ~555 Ma Ediacara Member of the Rawnsley Quartzite cropping out west of the Flinders Ranges, South Australia. At the Nilpena Ediacara Fossil Site, successions of large beds have been excavated, enabling the study of *in situ* Ediacaran communities.

Rugoconites, a relatively common genus of the South Australia Ediacara Biota, occurs on ten excavated beds and is found in four of the five fossiliferous facies of the Ediacara Member. It is the dominant genus on one bed and occurs in smaller numbers on others. We made latex molds of 181 *Rugoconites* specimens from the South Australia Museum and South Australian field sites and measured the diameter of each. *Rugoconites* has an average diameter of ~28 mm, but can vary greatly in size, ranging by nearly 100 mm in diameter (3.93–100.39 mm). Importantly, this large size range is not observed on individual bedding planes. The range of diameters on the only *Rugoconites*-dominated bed is nearly an order of magnitude smaller (16.98–28.73 mm), and the bedding plane with the second-most *Rugoconites* has a similar range of sizes (9.00–21.58 mm). Furthermore, on each of these beds, about two thirds of the *Rugoconites* have diameters within a 5 mm range of one another.

Morphologically, *Rugoconites* is a round to conical, triradially symmetric fossil, distinguished by branching ridges that radiate outwards from its center. The large size range of *Rugoconites* is ideal for studies of its ontogeny. Preliminary results indicate that *Rugoconites* adds primary ridges in sets of three, resulting in specimens with six, nine, twelve and fifteen primary ridges; larger specimens have more ridges than smaller ones. New primary ridges may result from secondary branches becoming separate primary ridges as the organism grows, potentially providing insight into the ontogenetic patterns of this enigmatic genus.

Climate-controlled marine palynomorph distribution over the last 210 ky from offshore West Coast, New Zealand

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A mixed marine palynomorph assemblage has been analysed from a core taken in the Tasman Sea about 110 km west of South Island, New Zealand. Independent dating based on $\delta^{18}O$ suggests that the core represents a continuous record stretching back to 210 ka (MIS 7).

Fossil dinocysts are the dominant elements of the flora, with most individuals being assigned to either *Spiniferites* spp. or *Impagidinium* spp. At their peak these two genera make up over 80% of the assemblage. Relative abundances of these two genera appear to be antithetical, with *Spiniferites* dominating during 210–130 ka and again during 60–14 ka, and *Impagindinium* dominating the intervals between. The boundaries between these alternating assemblages (130, 60 and 14 ka) approximately coincide with boundaries between marine isotope stages (MIS 6/5, 4/3 and 2/1 respectively), suggesting some climatic control over these large-scale fluctuations.

The most common non-dinocyst palynomorphs are prasinophyte algae. Consisting mainly of species of *Tasmanites* with a persistent presence of cymatiosphaerids, prasinophytes make up under 10% of the total assemblage (with spikes of up to 20%) between 210 ka and 120 ka. However, between 120 ka and 20 ka their abundance rises to about 15%, with spikes as high as 40%. At 20 ka there is a very sharp drop in their abundance and they are essentially absent for the final 10 ky. Prasinophytes flourish in areas of high freshwater runoff, suggesting that the climate was becoming increasingly wet between 210 ka and 20 ka, followed by a rapid drying which extends to the present day.

Morphology of Family Leanchoiliidae (Megacheira, Euarthropoda) from the Chengjiang Biota and its significance

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Members of the Family Leanchoiliidae represent an iconic fossil group of arthropods from the Cambrian Explosion, characterised by a pair of post-ocular great appendages, each of which bears three long flagella. Within the Chengjiang biota (Cambrian Series 2, Stage 3), two morphological types have been identified in this group, tentatively assigned into two different taxa, *Leanchoilia illecebrosa* and *Alalcomenaeus* sp., primarily due to the difference in the morphology of the cephalic shield and the telson. An investigation of thousands of leanchoiliid specimens deposited in the Yunnan Key Laboratory for Palaeobiology, Yunnan University revealed a third morphotype from Chengjiang. The new morphotype can be distinguished from *L. illecebrosa* and *Alalcomenaeus* sp. in the general body shape, the great appendages, the cephalic shield and the telson, all of which are currently taken as valid diagnostic characters in the classification of generic or specific ranks. Further comparisons with leanchoiliids from other Cambrian fossil sites (the Burgess Shale and Emu Bay Shale) indicate that the new morph type has a combination of mosaic characters within the Family Leanchoiliidae.

The new morphotype increases the known morphological diversity of Leanchoiliidae in the Chengjiang biota, and confirms that taxonomic diversity of this group within the Chengjiang is real, rather than a taphonomic artefact or sexual dimorphism. It also indicates that the ecological differentiation of this predatory group was already established in the early Cambrian. Together with the dominance of leanchoiliids from Chengjiang, the observed diversity and dominance of leanchoiliids in the younger Burgess Shale is thus considered a result of the success of its feeding strategy, with prey being manipulated by the flagellate great appendages, an innovation at the beginning of the Cambrian Explosion.

The artiopod arthropod *Acanthomeridion* from the lower Cambrian Chengjiang Lagerstätte, China and the phylogenetic significance of the genus

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New material of the rare arthropod *Acanthomeridion* from the lower Cambrian Chengjiang Lagerstätte, China, allows a more detailed appraisal of the morphology of this artiopod arthropod. The material includes a specimen with paired gut diverticulae along the length of the midgut that resemble structures in other artiopods such as naraoiids.

A number of key characters remain unknown in *Acanthomeridion*. Previous phylogenetic analyses have suggested a petalopleuran/xandarellid affinity for the genus. Our phylogenetic analysis is tentative, although we have applied cautious coding with respect to missing data to minimise biases. For our analysis, we coded *Acanthomeridion* in a dataset containing a variety of artiopods and other related groups. Reweighted analyses recover a monophyletic Artiopoda comprising five main clades: Aglaspidida + Trilobita, Nektaspida, Cheloniellida + Xenopoda, Conciliterga and Petalopleura. *Acanthomeridion* is placed outside the main subclades as the most basal artiopod, close to the Chengjiang arthropod *Squamacula*. This placement is supported by the strongly curved posterior tergites and absence of a discrete tailpiece in *Acanthomeridion*. We recovered a similar basal artiopod position for *Acanthomeridion* using the datasets of Paterson *et al.* (2010) or a reduced dataset of Legg *et al.* (2012, i.e. the subset of trilobitomorph taxa and relevant characters). *Acanthomeridion* lacks evidence for eyes, eye slits, and overlap of multiple trunk tergites by the head shield, making a petalopleuran/xandarellid affinity unlikely. Many of the characters that would shed further light on the phylogenetic placement of *Acanthomeridion* (e.g. the nature of the appendages or the hypostome) and, by extension, the evolution of artiopods, are not observable from the new or previously described material. Nevertheless, on the basis of currently available fossil data and phylogenetic datasets, the position of *Acanthomeridion* appears stable as a basal artiopod. In many ways this is a reflection of its simple morphology relative to other arthropods. Aside from that, the shifting placement of trilobites resulting from the inclusion of *Acanthomeridion* indicates that the placement of major artiopod clades is very sensitive to taxon inclusion and coding. The presence of a facial suture in *Acanthomeridion* suggests that this character may have evolved early in the artiopod clade, and was secondarily lost in other artiopod taxa, including the Aglaspidida.

Taphonomy of leaf wax *n*-alkanes in soils: field transect and experimental degradation experiment

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Leaf wax *n*-alkanes (C25-C35) are widely used biomarkers for terrestrial plants, but little consideration is given to their accumulation and modification (taphonomy) in soils and sediments. Leaf wax *n*-alkanes are integrated into soils and sediments and can be preserved for many millions of years. It has been hypothesised that the average chain length (ACL) of sedimentary *n*-alkanes can provide insight into plant communities and climate at the time of deposition. Field studies were conducted to determine whether the *n*-alkane ACL signals recorded in soils is representative of the current plant communities' ACL; a study analogous to live-dead studies in taphonomy. Additionally, experimental studies were conducted to determine whether biodegradation alters the *n*-alkane signals.

In the field study, modern plant and soil samples were obtained from a bioclimatic transect comprising a number of TERN biodiversity monitoring plots (AusPlots and TREND) across Australia. Samples of the top three dominant plant species (determined by percent cover, n = 59) present at each plot and the surface soil (n = 20) at each plot had *n*-alkanes extracted and analysed for ACL. Results show that soil ACL does not match with the ACL expected based on modern vegetation. This live-dead mismatch may be due to factors such as differences in time averaging between the living and death assemblages, or due to the strength of the preservation of *n*-alkanes from past plant communities that may have differed greatly to the present plant community.

To examine the effects of biodegradation on *n*-alkane signatures, organic amendments (e.g. green waste and garden clippings) were mixed with soil and incubated for 18 months. The concentration of *n*-alkanes decreased by 12–85% over the 18 months. Nonetheless, ACL was not significantly affected by biodegradation. These results suggest that inputs to soils have a greater influence on *n*-alkane ACL than post-depositional modification.

Bringing a Cambrian trilobite to life: reconstructing *Redlichia*

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Cambrian fossils present some interesting challenges to artists attempting to bring them to life; they are enigmatic and puzzling but very rewarding. Trilobites are possibly the most recognisable animals from this period.

Redlichia takooensis is the largest trilobite (more than 20 cm long) from the lower Cambrian Emu Bay Shale Lagerstätte at Big Gully, Kangaroo Island. As a common species from that locality it provides ample fossil material, including soft parts (antennae, exopods and endopods), for visual analysis, with readily available diagnostic information and reference papers. The poster presents the process of 2D reconstruction using traditional materials through to the application of digital technologies such as Zbrush and Photoshop.

It is a visual journey from the artist's point of view.

Three-dimensional morphometric investigation on the variation of sulcal development in some neospiriferine brachiopods

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Numerous brachiopod clades exhibit considerable intra- and interspecific morphological variations. Of these morphological variations, the differential development of the sulcus and fold has been widely noted in many articulated brachiopod taxa including extinct spiriferide brachiopods, and their development and variability has been interpreted as a function (reflection) of the efficiency of inhalant/exhalant currents affecting the brachiopods in the habitats. However, detailed investigations on how the shape of a sulcus varies within a spiriferide species or how the shape of a shell outline is affected by the variation of sulcal development have never been undertaken.

We here focus on the morphological variation of the sulcal development in a Permian large neospirifeine genus *Fasciculatia* Waterhouse 2004. Qualitatively, the sulcal tongue of the genus can be categorised into three types according to the degree of sulcal development: short, long and geniculate. Interestingly, all three types of sulcal tongue seem to be present in each species of the genus, regardless of the substrate occupied by the species.

In order to quantify the morphological variation of the genus both in sulcal development and whole shell outline, 51 brachiopod shells have been scanned with a three-dimensional (3D) surface imaging device (NextEngine multistripe laser scanner) at a resolution of 381 μm, and 3D models constructed. Using two landmarks (ventral beak and anterior tip of sulcal tongue), 18 semilandmarks along the midline of the sulcus and 40 additional semilandmarks along the commissure of the valves of the reconstructed models, a 3D landmark morphometric analysis has been performed. The result demonstrates considerable intraspecific variation in the sulcal development in all species of *Fasciculatia*. However, it also indicates that there are significant interspecific distinctions in the shell outline despite the high intraspecific variation in sulcal development.

Late Cambrian (Furongian) exceptional fossils from the McKay Group of British Columbia, Canada

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Documentation of non- or weakly biomineralising animals that lived during the Furongian period is essential to a comprehensive understanding of the diversification dynamics of metazoans in the early Palaeozoic. Unfortunately, no significant macroscopic soft-bodied fauna is known from this critical time interval between the Cambrian Explosion and the Great Ordovician Biodiversification Event. Only rare exceptionally preserved fossils have been found in a dozen localities scattered around the world. Here we report new occurrences of exceptional preservation in Furongian (Jiangshanian) strata of the McKay Group near Cranbrook in British Columbia, Canada. Specimens of the trilobite *Pterocephalia norfordi* exhibiting phosphatised guts had already been recovered from a *ca* 10 m thick interval at this locality. Two stratigraphically higher intervals with soft-tissue preservation are now documented. One has yielded a ctenophore and an aglaspidid arthropod; the other a specimen of the trilobite *Orygmaspis* (*Parabolinoides*) *contracta* with exquisitely preserved digestive structures. The ctenophore represents the first Furongian record of the phylum. The aglaspidid, which belongs to a new species of *Glypharthrus*, is unusual in having twelve trunk tergites and an anteriorly narrow tailspine. The bearing of these features on the evolution of aglaspidid trunk tagmosis, the presence of this arthropod in a typical open-marine deep-water setting, and the composition of aglaspidid exoskeleton will be discussed. The trilobite is preserved upside down, showing previously unknown ventral details of the gut such as medial fusion of digestive glands. These fossils demonstrate that conditions conducive to exceptional preservation repeatedly developed in the outer shelf environment represented by the Furongian strata near Cranbrook. Future exploration of the *ca* 600 m thick, mudstone-dominated upper part of the McKay Group might result in further discoveries of possibly more abundant exceptional fossils.

New exceptionally preserved arthropods from the middle Cambrian of Utah and Nevada, USA

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The Great Basin region (Utah, Nevada and California) of the western United States is home to at least nine Cambrian Konservat-Lagerstätten. None of these localities competes with the celebrated Burgess Shale (middle Cambrian, Canada) regarding the abundance of exceptionally preserved fossils, but with time some have eventually yielded rather diverse biotas. For instance, the middle Cambrian faunas of the Wheeler and Marjum Formations in Utah comprise 108 and 106 species respectively, among which 48 and 37 respectively represent soft-bodied animals. Still, discoveries of new exceptional material in these deposits remain essential, for most of these non-biomineralising taxa are known from a few incomplete specimens. Here we present exceptionally preserved arthropods recently discovered in middle Cambrian strata of Nevada and Utah. One specimen from the Comet Shale Member of the Pioche Formation (Nevada) is assigned to the 'megacheiran' genus *Alalcomenaeus*, and represents the first occurrence of this taxon in the Great Basin region. A large megacheiran has also been recovered from the Wheeler Formation (Utah). Characterised by hook-shaped pleurae; it is regarded as a new taxon. The Marjum Formation (Utah) has yielded the rest of the exceptional material described herein. This includes a new arthropod displaying anteriormost cephalic appendages composed of two antenniform branches, a median eye and large phosphatised digestive glands. Two specimens of the trilobite *Modocia typicalis* also exhibit phosphatised digestive structures. These three fossils constitute the first examples of preservation of internal organs via phosphatisation in the Marjum Formation. An agnostid displaying remains of cephalic appendages and a nicely preserved specimen of *Naraoia compacta*, the fifth to be found in these deposits, are described.

A new lower Cambrian trilobite from the Pusa Formation of Spain: biostratigraphic and evolutionary consequences for the older opisthoparian trilobites

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New trilobites from the upper part of the Pusa Formation (early Cambrian) in central Spain have been analysed from a systematic and biostratigraphic perspective. The trilobites *Abadiella*? n. sp., *Abadiella*? sp. and an undetermined genus and species are recorded with archaeocyaths known only from the Spanish Zone I, which is an equivalent of the base of the *Serrania* trilobite Zone or earlier. The morphology of *Abadiella?* n. sp. is intermediate between that of the oldest genera of the Abadiellidae and the Bigotinidae, indicating that this new taxon is the common ancestor of both of these trilobite families and confirming the estimated age based on the archaeocyathan assemblage.

Analysis of the first trilobite records in Europe, Siberia, Africa and Laurentia indicate that specimens of different primitive families of both olenellide and redlichiide trilobites have a very closely similar first appearance in the fossil record. This suggests that the beginning of the trilobite record was mainly due to a generalised skeletal mineralisation event and that the origin of trilobites occurred in earlier Cambrian times or even before. This may explain the morphological complexity of *Abadiella?* n. sp. despite its age.

Integrated Cambrian stratigraphy of the Tomten-1 drill core, southern Sweden

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The Tomten-1 drilling at Torbjörntorp in Västergötland, southern Sweden, penetrated 29.85 m of Cambrian Series 2, Cambrian Series 3, Furongian and Lower–Middle Ordovician strata. The biostratigraphy, sedimentology and carbon isotope ($\delta^{13}C_{org}$) stratigraphy of the core have been analysed. The succession includes the File Haidar, Borgholm and Alum Shale formations, and the Latorp and Lanna limestones. In the Cambrian Series 3 to Furongian Alum Shale Formation, agnostoids and trilobites allowed subdivision of the succession into nine biozones (in ascending order): *Ptychagnostus gibbus*, *P. atavus*, *Lejopyge laevigata*, *Agnostus pisiformis*, *Olenus gibbosus*, *Parabolina spinulosa*, *Ctenopyge tumida*, *C. bisculata* and *C. linnarssoni* zones. The succession is interrupted by numerous stratigraphic gaps of variable magnitude, as is evident from the biostratigraphy and conspicuous unconformities. Two negative $\delta^{13}C_{org}$ excursions have been recorded from the lowermost part of the Alum Shale Formation. The most distinctive of these has a net shift of ~2‰ and occurs in strata that seem to be equivalent to the *P. gibbus* Zone. It may correspond to an unnamed excursion that has been recorded

from Cambrian Stage 5 in southern Sweden and South China, but in the absence of useful biostratigraphic evidence, this identification is problematic. Another, but poorly developed excursion in the lower *P. atavus* Zone possibly represents the Drumian Carbon Isotope Excursion (DICE) as described from the GSSP section in the Drum Mountains of Utah, western United States. However, the values are not low enough to be considered diagnostic for the DICE. The Steptoean Positive Carbon Isotope Excursion (SPICE) has been recorded with some uncertainty, probably because of diagenetic overprint affecting the $\delta^{13}C_{carb}$ values in the lithologically highly variable Kakeled Limestone Bed and the incompleteness of the lower Furongian (Paibian Stage).

The Cambrian molluscs of Australia – overview of taxonomy, stratigraphy and palaeogeography

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The Cambrian malacofauna of Australia is among the most taxonomically diverse for the Period. Based on the number of valid mollusc species, Australian Cambrian strata competes with Siberian and Chinese formations in terms of taxic diversity. More than 70 named species plus over a dozen forms in open nomenclature, apparently representing new undescribed taxa, have been recorded from the lower-middle Cambrian successions of Australia. In addition, about 20 species names can be considered as junior synonyms. Distribution ranges of mollusc species plotted over the modern stratigraphic scheme reveal four major molluscan evolutionary assemblages in the interval from the Tommotian to the Undillan stages. The oldest assemblage was reported by Daily (1974, 1976) and Jacquet *et al.* (2015, in press) from the Mount Terrible Formation on Fleurieu Peninsula, South Australia. The assemblage includes several forms in open nomenclature and *Watsonella crosbyi*, and can be approximately correlated with the Tommotian in Siberia. The second assemblage is the most diverse taxonomically (48 morphospecies). It is recognised in South Australia (Bengtson *et al.* 1990, Gravestock *et al.* 2001, Brock & Paterson 2004, Topper *et al.* 2009, Jacquet *et al*. 2015) and spans late Atdabanian to Toyonian interval. Four assemblage 'biozones' were established here using mollusc fauna, i.e. *Pelagiella subangulata*, *Bemella communis*, *Stenotheca drepanoida* and *Pelagiella madianensis*. The third molluscan assemblage was reported (Runnegar & Jell 1974, 1976, Kruse 1990, 1991, 1998, etc.) from the regional Ordian Stage and includes about 20 species from numerous localities in Queensland, New South Wales and the Northern Territory. The youngest molluscan assemblage comes from the medial middle Cambrian (Floran-Undillan) and includes 14 species, with few transiting forms (Runnegar & Jell 1976, Hinz-Schallreuter 1997, Brock 1998, Vendrasco *et al.* 2010, 2011). In the palaeogeographic aspect, the Cambrian malacofauna of Australia has over 25 morphospecies in common with the Siberian Platform, Kazakhstan, Altay Sayan, Transbaikalia, Mongolia, South and North China, Morocco, Antarctica, Europe (Denmark, Germany), Greenland, North America and New Zealand, providing important correlation links between these regional stratigraphic schemes.

The trilobite *Bathynotus kueichouensis* (Cambrian Series 2) and its implications for stratigraphy

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Based on specimens from the Georgia Formation in Vermont, USA, *Bathynotus holopygus* was first established by Hall in 1859. Since then, more than 14 species have been found in Siberia and the Altay Sayan fold belt of Russia, South China, the Tarim Basin of China, and Australia and they occur in the traditional late early Cambrian and early middle Cambrian. *Bathynotus* has a global distribution and specimens were often assigned to *B. holopygus* wherever they were found. However, based on new specimens and data, it is now clear that there are three species belonging to the genus. They are *B. holopygus* Hall 1859*, B. kueichouensis* Lu in Lu et Chien 1964 and *B. elongatus* Zhao, Huang & Gong 1987. Apart from its occurrence in Vermont, the type species of *Bathynotus, B. holopygus*, has been found in the Pinzhai section at the base of the Kaili Formation at Yanyin, Danzhai, southern Guizhou. *Bathynotus elongatus* occurs only in Siberia and South China, often co-occurring with *B. kueichouensis*. *Bathynotus kueichouensis* is the most widespread species, occurring in Siberia, China, North America and Australia. In addition, *B. kueichouensis* is also the most widespread species in China, occurring near the top of the traditional lower Cambrian of Guizhou, Hunan, Hubei, Anhui and Xinjiang. The last appearance datum (LAD) of *B. kueichouensis* is 0.8 m below the first appearance datum (FAD) of *Orycotocephalus indicus* in the Wuliu- Zengjiayan section of the Kaili Formation, which is a proposed candidate for the GSSP defining the base of Cambrian Series 3. Therefore, because of its wide distribution, *B. kueichouensis* could be a useful marker for the top of Stage 4 of the Cambrian.

Middle to late Cambrian (Stage 4–Jiangshanian) linguliform brachiopods from Australasia and their biogeographic affinities

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Cambrian linguliform brachiopods occur widely in intracratonic basins of northern and central Australia. The Ordian Thorntonia Limestone in the southern Georgina Basin (and its correlatives) belongs to Depositional Sequence 1, and is disconformably overlain by the Arthur Creek Formation which spans most or all of Depositional Sequence 2 (latest Ordian to at least Boomerangian age, or Stage 5 to early Guzhangian). Brachiopod assemblages of the two depositional sequences differ entirely at species level. Cambrian faunas from the eastern Georgina Basin are mostly younger, partly overlapping with those of Depositional Sequence 2 and extending through the Floran (early Drumian) to Mindyallan (late Guzhangian) and Idamean (Paibian) stages. The Delamerian Orogen, forming the eastern margin of Gondwana, includes Ordian faunas on the Gnalta Shelf of far western New South Wales, correlating with the youngest of four successive brachiopod assemblages from the Arrowie and Stansbury basins of South Australia. Later Cambrian brachiopods inhabiting oceanic islands east of the cratonic margin occur in the Murrawong Creek Formation (northeastern New South Wales), limestone at Dolodrook in Victoria, and the Tasman Formation of the Takaka Terrane in New Zealand. A younger (Paibian to Jiangshanian) fauna from the Sluice Box Formation of the Takaka Terrane shares no common taxa with the nearby Tasman Formation, nor with the Dolodrook limestone which it partially overlaps in age.

Biogeographic affinities of Australasian Ordian to Iverian brachiopods were analysed using the statistical program PAST, and compared with faunas from the Maliy Karatau Range (Kazakhstan) and the Huaqiao Formation (Drumian-Guzhangian) of South China. The latter shares affinities with those faunas mentioned from oceanic islands and terranes, and from the Floran to Mindyallan of the eastern Georgina Basin. Brachiopods from the lower Sluice Box Formation are closely related to genera from Kazakh terranes, specifically the Maliy Karatau Range and the northeastern part of central Kazakhstan.

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Another enigmatic tooth from the Leaf Locality, Miocene, Lake Ngapakaldi, South Australia

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The ‘Leaf Locality’ was discovered by Stirton’s 1962 expedition, members of which noticed patches of anomalous ferruginous conglomerate with fragments of bone on the eastern shore of Lake Ngapakaldi. Excavation disclosed a channel deposit rich in bone fragments, with rare mammal teeth and jaws. It included several unusual teeth that puzzled Stirton for months. They reminded him of multituberculates, but were oriented ‘wrongly’. Other aspects made him conclude that the teeth were from a monotreme, named as *Ektopodon*, ‘the odd or strange toothed’ mammal. Subsequent discoveries revised this interpretation into a weird type of possum.

Now, another unusual mammal tooth has emerged from the Wipajiri conglomerate, found in a concentrate collected in 1996. Its biological affinities have not yet been determined. The specimen is small (length *ca* 2.7 mm) and quite irregular in form; it appears to consist of most of the enamel cap of a tooth. An arbitrary orientation is adopted here but no recognisable features can be identified. With ‘a high coefficient of weirdity’, this specimen has been compared, unsuccessfully, with the dental precursor of the degenerate horny pad or ‘cornule’ of the modern platypus. There is no homology between the fossil and the embryonic true teeth of the platypus, nor with the teeth of the fossil platypus *Obdurodon* spp. The tooth appears to be bilophodont but is not considered to be marsupial. If the tooth is rotated about 90°, the ‘posterior loph’ could be interpreted as an ‘ectoloph’. In this interpretation, the tooth might be from a chiropteran. Finally, the specimen might represent a fossil echidna. Modern echidnas have no teeth and crush their food between hard pads on the palate and tongue, but no homologous features can be detected between them and this Leaf Locality fossil.

Rapid diversification of Ediacaran acanthomorphic acritarchs after the Marinoan glaciation: the fossil record from the Ediacaran Doushantuo Formation in South China

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The rise of large acanthomorphic acritarchs marks a significant evolutionary event in the Ediacaran Period, yet when and how these unique microorganisms come to thrive have not been clarified. Chert nodules in the Ediacaran Doushantuo Formation in the Yangtze Gorges area of South China yield abundant acanthomorphic acritarchs, and two taxonomically different assemblages have been established in the lower and upper Doushantuo Formation respectively. The lower assemblage is believed to be simple in composition and dominated by an endemic genus *Tianzhushania*, while the upper assemblage is far more productive and diversified, and has been correlated with the complex acanthomorphic acritarch assemblage in Australia and elsewhere.

Our recent work, however, reveals that the lower assemblage of the Doushantuo Formation is not as plain as previously thought. Abundant new spiny acritarchs were discovered from the lower assemblage, including *Knollisphaeridium maximum*, *Taedigerasphaera lappacea* and several new forms, some of which have been tentatively assigned to genera *Weissiella* and *Variomargosphaeridium*. As well, some of them become common or even predominant in certain horizons. As the lower assemblage was less focused upon in previous studies, its real diversity may increase as the sample size grows. Thus, the new findings indicate that the radiation of large acanthomorphic acritarchs in the wake of the Marinoan glaciation may have been more rapid and more complicated than previously believed, and detailed palaeontological and biostratigraphic investigations are needed.

An Ediacaran pioneer community: possible evidence of primary succession in a juvenile-dominated assemblage from the Flinders Ranges, South Australia

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Ediacaran bedding assemblages can provide an unparalleled window into the earliest megascopic sea-floor communities (*ca* 555-500 Ma). The first significant sample of an Ediacaran sea-floor assemblage was excavated from the Crisp Gorge fossil locality (central Flinders Ranges, South Australia) in 1993 and offers excellent preservation over a semi-contiguous surface of 6.5 m^2. Comprising megascopic taxa and textured organic surface impressions characteristic of a microbial mat substrate, this community has been placed stratigraphically within a wave-base sand facies unit of the Ediacara Member. Like many Ediacara assemblages, this community suffered catastrophic burial by the sediment that subsequently preserved it, in a disturbance event likely similar to an earlier event that provided the new substrate onto which this community established.

Documented on the surface are 299 identifiable fossils comprising eight taxa and the biogenic structure 'Mop'. Of note, *Dickinsonia costata*, *Tribrachidium heraldicum* and *Parvancorina minchami* are present in juvenile size only, whereas *Rugoconites enigmaticus* and *Coronacolina acula* preserve both juvenile and adult sizes. Two informally described taxa, termed here 'striped banana' and 'holdfast form', lack sufficient representation elsewhere for size comparison. Statistical analysis describes an intermediate Shannon diversity measure of 1.27, and an evenness value of 0.57, with three taxa dominating the relative abundance of this community. Together, *D. costata* (53.5%), 'striped banana' (26.8%) and *C. acula* (11.7%), comprise a total 92% of the biota present.

Successional progression as a community-scale response to disturbance events has been considered by other authors in the study of Ediacaran communities. The highly uneven spread of individuals between taxa and abundance of juvenile-sized organisms, characteristics of modern early successional communities, suggests that this may represent a pioneer community in the early stages of primary succession following establishment on new substrate. The results further suggest a mechanism analogous to successional progression may have been at work in Ediacaran sea-floor communities.

Southeastern Australia's Cretaceous polar tetrapods in a greenhouse world

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Although most of the earth in the Cretaceous can be characterised as a 'Greenhouse World', that was not the case in southeastern Australia in the late Early Cretaceous. In the shallow 'Eromanga Sea' of northern South Australia and western Queensland, dropstones indicate the former presence of floating ice, and glendonites suggest seawater temperatures close to 0°C.

To the southeast, Victoria was located either within the Antarctic Circle of the time or close to it. There, cryoturbation structures indicative of the former presence of permafrost occur within 3 m stratigraphically of one of the richest early Cretaceous tetrapod localities. Temnospondyl amphibians which had thrived from the Carboniferous to the end of the Triassic occur there, apparently having survived longer in that polar environment than elsewhere because their ecological equivalents, crocodilians, could not tolerate the frigid conditions that these amphibians could.

Euornithopods or hypsilophodontids were more diverse in polar Victoria than at lower palaeolatitudes. An enlarged area of the brain that processed the visual signals from the eyes, the optic lobes, together with the enlarged eyes characteristic of this group, suggest that they were well adapted to living in polar regions, able to forage through the cold winter darkness. This supports the hypothesis that this group of dinosaurs was endothermic or warm blooded.

Dinosaurs (13 genera minimum) and mammals (6 genera minimum) dominate the known late Early Cretaceous tetrapod biota of southeastern Australia. It is the most diverse assemblage of Mesozoic polar tetrapods known on earth.

Reanalysis of Ediacara-type fossils from the lower Cambrian (Fortunian) Uratanna Formation of South Australia

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Ediacara-type frond-shaped fossils that co-occur with characteristic basal Cambrian trace fossils and microfossils (acritarchs) were reported from the Uratanna Formation in the Flinders Ranges, South Australia over 15 years ago (Jensen *et al*. 1998), but have since received very little attention. The affinities of these and other Ediacara-type fossils in younger Palaeozoic sediments have been controversial, as comparisons with superficially similar but older Ediacaran forms are not straightforward. Differing styles of preservation (which remain incompletely understood), lack of comparative detail, and difficulties in identifying convincing morphological homologies between fossil taxa and with true animals have hindered our understanding of these early organisms.

Fossil assemblages that preserve soft-bodied organisms are essential for our understanding of the diversity and evolution of past life. The Ediacara Biota (575-541 Ma) is important in that it represents an array of soft-bodied organisms that predate the major burst of skeletonisation, as well as the unequivocal appearance of most animal phyla, which occurred near the start of the Cambrian Period.

Cambrian occurrences of these enigmatic Ediacara-type fossils, albeit rare, appear to contradict the supposed extinction of these forms at the end of the Ediacaran. However, such claims can only be confirmed or refuted by conducting a detailed comparative morphological analysis of these Cambrian and Ediacaran fossils. This study aims to decipher whether the Ediacara-type fossils from the Uratanna Formation represent true Ediacaran holdovers, perhaps with an affinity to the frondose taxa, or if they form a part of the new evolutionary regime of body building that took place during the Cambrian Explosion.

A stratigraphic and geochronological analysis of the *Simosthenurus occidentalis* site, Gunnamatta Beach, Nepean Peninsula, Victoria

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The recent discovery of a fossil skull and associated maxillae at Gunnamatta Beach, Nepean Peninsula, Victoria, is one of several recent discoveries along this stretch of coastline from Gunnamatta, west to Diamond Bay. The Gunnamatta fossil has been identified as *Simosthenurus occidentalis* (Family Macropodidae) and constitutes the first reported occurrence of this species from the Point Nepean area.

The *S. occidentalis* fossil was embedded in the rock platform of the intertidal zone. Initial stratigraphic analysis of

the lithofacies indicates a calcareous arenite, dominated by foraminifers and bryozoans, with evidence for both tabular and trough cross-bedding. Locally, the section is composed of dune-sized (>4 m) aeolianites displaying cross-bed sets interbedded with palaeosols and prominent horizons of rhizocretions and calcrete. The lithofacies composition is considered an equivalent unit to the extensive Bridgewater Formation, which occurs along the coast of southeastern Australia, extending from the Otway Ranges in Victoria through to the Coorong Coastal Plain in South Australia.

Optically Stimulated Luminescence (OSL) will provide a defined age constraint for the stratigraphic unit (age pending). The absolute date, combined with a detailed stratigraphic interpretation, will place the Gunnamatta fossil site within a temporal context for the region.

Additionally, correlation of the stratigraphy and sediments from this site, with two other coastal vertebrate fossil sites in the region, will contribute to the palaeohistory of the area.

Determining the incidence of oral necrobacillosis ('lumpy jaw') in an extinct Pleistocene macropod (kangaroo) *Macropus giganteus titan* Owen 1838

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Palaeopathology is the study of disease in the fossil record. It is playing an increasing role in the field of palaeoecology. Knowledge of modern diseases can be used to extrapolate information about factors contributing to disease in the past.

To date, there are few Pleistocene marsupial palaeopathological studies compared to investigations into humans, domestic animals and dinosaurs. This project aims to determine the extent of oral necrobacillosis (lumpy jaw) on the fossil jaw bones of the extinct Pleistocene macropod species, *Macropus giganteus titan* Owen 1838, in Museum Victoria's vertebrate palaeontology collection. *Macropus giganteus titan* belonged to the Pleistocene 'megafauna' (animals > 44 kg) that became extinct between 50,000–30,000 yrs BP.

Oral necrobacillosis is one of the most common diseases in modern kangaroos. In the wild, the modern form of the disease is correlated with the incidence of drought, high population density and high concentrations of faecal matter on pasture. The main cause remains unclear, although an anaerobic bacterium, *Fusobacterium necrophorum,* has been identified as an important factor in several studies. Other factors such as inappropriate diet, stress and physical weakness have been identified as potential contributors.

This project compares healthy modern, diseased modern and fossil jaw bones to determine possible factors influencing macropod health and lifestyles during the Late Pleistocene. Due to scarce information about the incidence of disease in the past, the authors assume that disease follows similar patterns in ancient and modern animals. Lumpy jaw in the modern Eastern Grey kangaroo *Macropus giganteus* (considered the dwarfed version of *M. g. titan*) is the focus. The project additionally provides a diagnostic reference scale for assessing lumpy jaw progression on fossil macropod jaw bones.

Exceptional three-dimensional preservation of hyoliths from mid-Cambrian sediments of the Buchava Formation (Skryje-Týřovice Basin, Barrandian area, Czech Republic)

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The mid-Cambrian fossil sites of the Skryje-Týřovice Basin (Barrandian area, Czech Republic) have been well known since the middle of the 19th century. In this basin, the Buchava locality (Buchava Formation) provides a highly diverse invertebrate skeletal fauna (mostly trilobites and hyoliths). The hyoliths are abundantly preserved in carbonate nodules. Almost all seventeen hyolith taxa known from the mid-Cambrian sedimentary rocks of this area have been recorded at Buchava and this is the type locality for several hyolith species (e.g. *Carinolithes bohemicus* Marek *in* Valent *et al*. 2011, *Circotheca smetanai* Valent *et al*. 2013, *Gracilitheca mirabilis* Valent *et al*. 2013, *Nephrotheca betula* Valent *et al*. 2013 and *Slehoferites slehoferi* Marek *in* Valent *et al*. 2011).

Those hyoliths preserved in carbonate nodules are usually preserved three-dimensionally with minimal signs of compression. In rare cases, the hyolith conchs are preserved with their operculum and even their helens *in situ*. The exceptional preservation of conchs and opercula provides detail of fine surface sculpture as well as the internal and external morphological elements of the opercula (e.g. clavicles, cardinal processes, muscle scars, etc.). The preservation is so fine that it is possible to count every growth line on some opercula and conchs (e.g. in *Quasimolites quasimodo* Valent *et al*. 2015 there are 18-22 growth lines per mm visible on the outer surface of the operculum).

This exceptional three-dimensional preservation makes possible a more detailed understanding of hyolith functional morphology but, unfortunately, no soft parts are preserved.

New observations on the most mineralised brachiopod *Diandongia* from the Chengjiang Lagerstätte (Cambrian, Stage 3) of eastern Yunnan, China

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Diandongia Rong 1974 is the most thick-shelled and strongly mineralised of all the brachiopods that have been recorded from the base to the topmost Yu'anshan Formation. The well preserved and abundant material of *Diandongia* from Chengjiang includes preserved pedicles and mantle canals. Detailed internal and external shell morphologies of the type species *Diandongia pista* Rong 1974 are described for the first time based on BSEM and SEM observations. A neotype is selected among the specimens of *D. pista* from the type locality in eastern Yunnan. The shell shape, pseudointerareas and pustulose ornamentation of *Diandongia* are most similar to that of the Botsfordiidae. In particular, many species of *Botsfordia* are provided with a *Diandongia*-like rhombic pattern of pustules in the juvenile apical region only. The dorsal visceral field forms a narrow, elevated, three-lobed platform, which is similar to that of *Edreja* Koneva from the Cambrian (Stage 5) of Kazakhstan. However, the notion that *Diandongia* is a junior synonym of *Edreja* can be rejected, as the species from Kazakhstan clearly lacks pustulose ornamentation. Moreover, *Diandongia* differs from the Botsfordiidae in the apparent lack of apical tubercles in the ventral and dorsal valves. The most unusual aspect of *Diandongia* is that the terminal branches of the mantle canals are directed peripherally only. This type of vascular pattern was previously known only from craniiform and rhynchonelliform brachiopods, indicating that the earliest brachiopods that appeared during the Cambrian Explosion interval have a previously unsuspected wide range of unusual morphological features.

Ordovician conodont biozonation and biostratigraphy of North China

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The Ordovician conodont zonation of North China established more than 30 years ago by the late Professor An Taixiang and his co-authors is thoroughly revised based on comprehensive later studies, particularly our recent work in this classical region. Using widely distributed and taxonomically well established species whenever possible as the index of each biozone, the Ordovician of North China is now to be subdivided into 22 conodont biozones. This biozone succession includes, in ascending order, the Tremadocian *Iapetognathus jilinensis-Cordylodus lindstroemi*, *Cordylodus angulatus*, *Chosonodina herfurthi*, *Rossodus manitouensis*, *Glyptoconus quadraplicatus* and *Scalpellodus tersus-Triangulodus* sp. aff. *T. bifidus* biozones; the Floian *Serratognathus bilobatus*, *S. extensus*, *Paraserratognathus obesus* and *Jumudontus gananda* biozones; the Darriwilian *Histiodella holodentata-Tangshanodus tangshanensis*, *Eoplacognathus suecicus-Histiodella kristinae*, *Pygodus anitae* and *P. serra* biozones; the Sandbian *Pygodus anserinus*, *Plectodina aculeata*, *Erismodus quadridactylus*, *Belodina compressa* and *Phragmodus undatus* biozones; and the Katian *Belodina confluens*, *Yaoxianognathus neimengguensis* and *Y. yaoxianensis* biozones. The biozones defined and described herein can be correlated regionally and internationally with those in successions in South China, Tarim, northern Europe, North America, Argentina and Australia. In North China, the base of the *Iapetognathus jilinensis-Cordylodus lindstroemi* Biozone marks the base of the global Tremadocian Stage, and the FAD (First Appearance Datum) of *Serratognathus bilobatus* is taken as the base of the Floian Stage. However, the bases of the global Sandbian and Katian stages are less precisely defined in the conodont biostratigraphy, but are within the *Pygodus anserinus* and *Phragmodus undatus* biozones respectively. Having a much improved biostratigraphic precision and better regional correlation, this new biozone framework provides a better reference basis for the understanding of the age of tectonostratigraphic events (such as the Huaiyuan Epeirogeny) and the depositional history of North China during the Ordovician.

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Carbon isotopes: putting some spice into Cambrian stratigraphy of the southern Georgina Basin in central Australia

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New carbon isotope data ($\delta^{13}C_{carb}$) have been acquired in selected petroleum, stratigraphic and mineral wells drilled in the southern Georgina Basin in central Australia. Supplemented by existing carbon isotope and biostratigraphic data, carbon isotope profiles in wells are assisting in correlating the middle Cambrian succession regionally from the Dulcie Syncline in the west to the Toko Syncline in the east.

The upper Cambrian SPICE event has now been identified in seven wells and confirms that the Arthur Creek Formation to Arrinthrunga Formation interval of this succession is strongly diachronous. This succession is observed on regional seismic traverses to be progradational in overall aspect, but with internal perturbations indicative of periodic second-order base level shifts.

A second prominent positive carbon isotope excursion is recorded lower in the succession in several wells located in the Dulcie Syncline, including the originally designated type section of the Arthur Creek Formation in NTGS HUC1, but not in the nominated replacement type section in NTGS99/1, located some 140 km to the east. This potentially creates a nomenclatural issue with respect to this formation. This positive carbon isotope excursion is believed to be a correlative of the global middle Cambrian OETE event, although based on agnostide trilobites it is Templetonian in age.

A pronounced negative excursion is observed in several Dulcie Syncline wells in an organic-rich calcareous shale section, historically attributed to the basal Arthur Creek Formation, that has been dated by trilobites as late Ordian to early Templetonian. Whether this excursion correlates with the global ROECE event remains contentious as its occurrence may be more a function of high organic carbon content, and hence a local, not global phenomenon.

A second major negative excursion has been recorded in an interbedded dolostone/redbed sequence immediately overlying the Red Heart Dolostone, perhaps unconformably, in the well NTGS HUC1. The Red Heart Dolostone is a regionally correlatable unit dated as early Cambrian by archaeocyaths. As this excursion has only been recorded in one well, despite attempts to replicate it in seemingly correlative lithofacies in nearby wells, it may be spurious.

A preliminary study of microscopic skeletal fossils from the Cambrian Jiumenchong Formation at Guizhou, China

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Sponge spicules and brachiopods were collected from limestones of the Jiumenchong Formation at the Yangtiao section, Majiang County, Guizhou Province. These fossils were extracted from limestones with 3% acetic acid, and examined under SEM after being coated with gold. Sponge spicules consist of orthohexactines, clinohexactines and stubby hexactines. The brachiopods belong to *Eohadrotreta zhenbaensis* with subcircular to transversely oval outline, finely ornamented with concentric growth lines, lacking well defined apical pits, apical process slight uplifted, dorsal median buttress and median groove well developed. In the past, *E. zhenbaensis* was mainly found in the Cambrian Stage 2 of southern Shaanxi and western Hubei. This is the first record of *E. zhenbaensis* in eastern Guizhou Province. This study has enriched our understanding of the faunal composition of the Jiumenchong Formation, but also provided information allowing a more detailed comparison of the lithostratigraphic units with those in the Yangtze and Transitional regions. The diversity and abundance of microscopic skeletal fossils in the Jiumenchong Formation at Majiang County are significantly less than those of the Shuijingtuo Formation in southern Shaanxi and western Hubei. It seems that faunal composition of these assemblages are controlled by water depth, and this provides a better understanding of the differences in community structure in different facies.

Spatial variation in diversity and composition of Cambrian Burgess Shale-type faunas in South China

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Strata hosting Cambrian Burgess Shale-type (BST) Lagerstätten occur throughout South China, and potentially provide the necessary detail to assess community ecology during the Cambrian Explosion. The widespread occurrences of BST Lagerstätten in South China are reviewed, with 17 such deposits having been reported. The majority appear to be confined to Cambrian Series 2, particularly the Qiongzhusian-Canglangpuan stages, although three are known in the Longwangmiaoan Stage, and only the Kaili biota (Cambrian Series 3, Stage 5) is known to be younger than Cambrian Series 2. This reduction could be an artefact of sedimentary facies change, based on the fact that vast areas of siliciclastic facies during most of Cambrian Series 2 (Qiongzhushian-Canglangpuan) were subsequently replaced by carbonate facies during the Longwangmiaoan. Fossil deposits with soft-bodied preservation are contained within the very fine-grained sedimentary rocks that constitute the siliciclastic platform facies and slope basin facies. The rapid deposition in the finest claystones and the presence of bottom-water anoxia in the slope basin facies could be important factors in soft-bodied preservation from shallow to deeper water sedimentary settings. These Lagerstätten show variation in taxonomic diversity, faunal composition and fossil preservation – fossiliferous strata with high-quality exceptional soft-tissue preservation mostly occur in the Yunnan region, which might be controlled by basin geometry, depositional environment, tectonism and other processes. Taxonomic composition of these faunas indicates that arthropods mostly dominated the shallow water facies, whereas sponges dominated the slope basin facies. Cambrian BST Lagerstätten in South China provide a good record of exceptionally preserved biotas in a chronological succession. Comparison of these Lagerstätten in a chronological framework may give us more details on the nature of evolutionary and ecological diversifications during the Cambrian Explosion.

Youngest Ordovician conodont fauna known from Australia and associated tabulate corals from the Angullong Formation of central New South Wales

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The Angullong Formation is the youngest Ordovician unit exposed in the Cliefden Caves area of central New South Wales. Its maximum age is constrained by a *Styracograptus uncinatus* graptolite Biozone fauna at the very top of the underlying Malongulli Formation, but the few fossils previously reported from higher in the Angullong Formation are either long ranging or poorly known. From allochthonous limestone clasts in the middle part of the formation we document a conodont fauna comprising *Aphelognathus grandis*, *A. solidum*, *A.* sp., *A.*? sp., *Belodina confluens*, *Drepanoistodus suberectus*, *Panderodus gracilis*, *P.* sp., *Phragmodus undatus*, *Pseudobelodina inclinata* and *P.* aff. *P.*? *obtusa*, which supports correlation with the *Aphelognathus grandis* Biozone (late Katian) of the North American Midcontinent succession. This age is consistent with the constraints of graptolites known from above and below in the succession, indicating that these limestones represent a lost carbonate unit that was either deposited contemporaneously (early Ka4) with the surrounding siltstone basinal succession, or is possibly slightly older (late Ka3). Associated corals are exclusively tabulates, dominated by agetolitids, including *Agetolites* sp. nov., *Hemiagetolites breviseptatus*, *H.* cf. *H. spinimarginatus*, *Heliolites orientalis*, *Navoites* cf. *N. circumflexa, Plasmoporella bacilliforma*, *P. marginata*, *Quepora* cf. *Q. calamus* and *Sarcinula* sp. Affinities of the coral fauna are closer to faunas from northern New South Wales and northern Queensland than to the locally recognised Fauna III of late Eastonian age in central New South Wales. We propose a subdivision of Fauna III to account for this difference, with the late Katian Fauna IIIB characterised by the incoming of agetolitid corals. This group of corals possibly originated in North China in early Katian time, and migrated to Tarim, South China and adjacent peri-Gondwanan terranes while also spreading eastward to northern Gondwana, progressively moving through eastern Australia from the Broken River region of northern Queensland to reach central New South Wales by the early Bolindian.

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