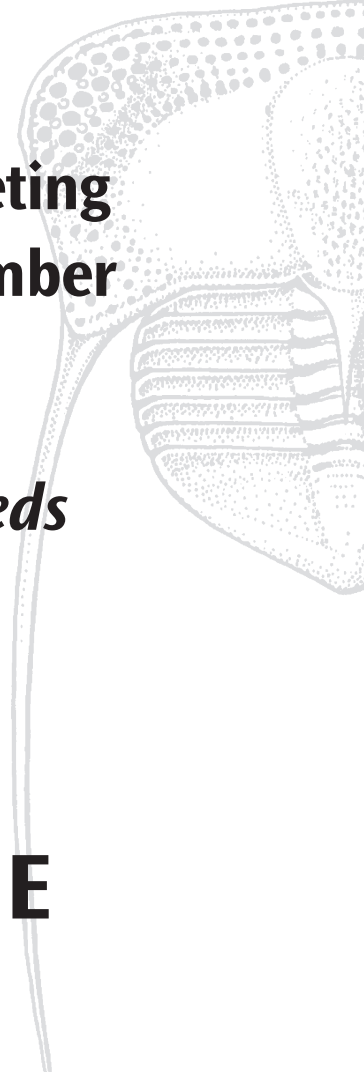


**The
Palaeontological
Association**

**58th Annual Meeting
16th–19th December
2014**

University of Leeds

PROGRAMME
abstracts
and AGM papers





Walk it
Leeds City Centre Map

Information

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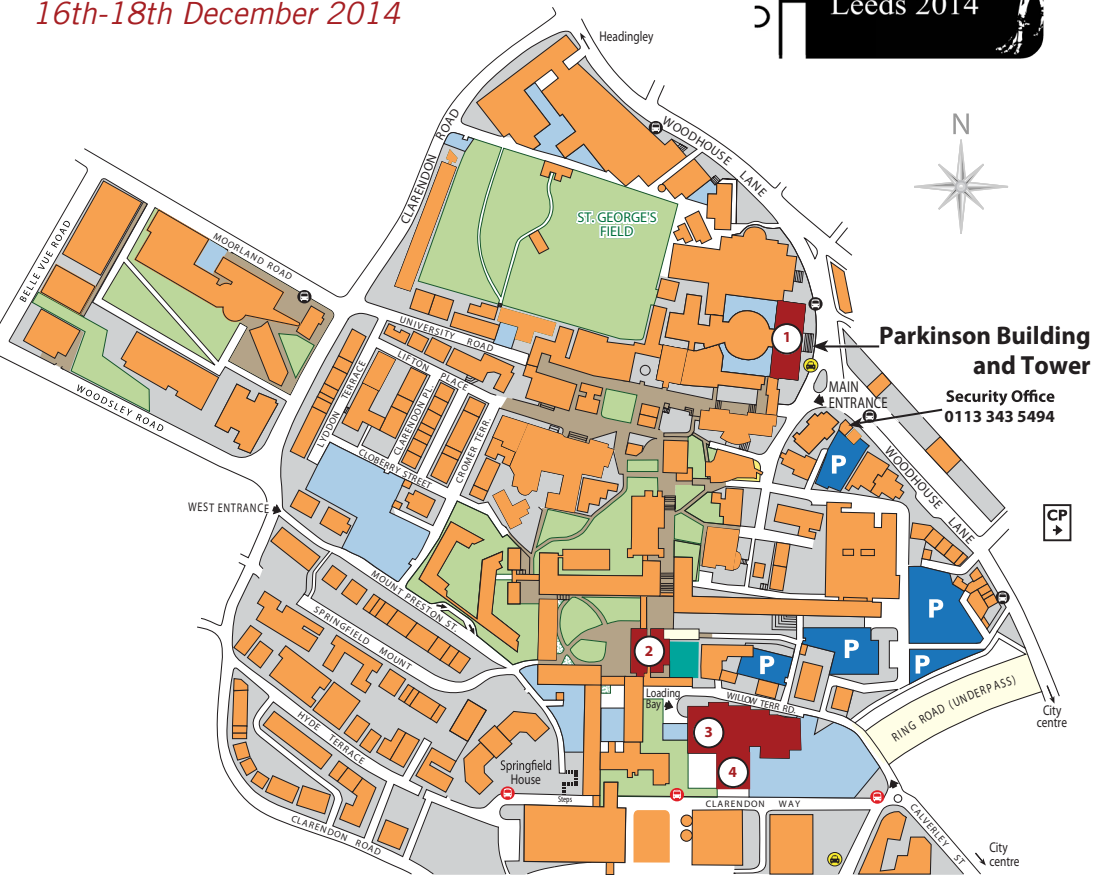
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PalAss Conference

16th-18th December 2014



Parkinson Building and Tower

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Key

Venue

- Parkinson Court 1
- Roger Stevens Building 2
- Sports Hall 2 3
- Conference Auditorium 2 4

Car parks

- University visitors' car parks (limited access) P
- Other university car parks P
- Public multi-storey car park CP

Other useful information

- CityBus Stop Bus Stop
- Taxi Rank
- Pedestrian Only Area
- Lawns



The Palaeontological Association

58th Annual Meeting

16th–19th December 2014

University of Leeds

The programme for the 58th Annual Meeting of the Palaeontological Association is provided after the following summary of the meeting.

Registration and booking

Registration, abstract submission and booking (including payment by credit card) commences on **Monday 14th July 2014**. Abstract submission closes at midnight on **Friday 19th September 2014**; abstracts submitted after this date will not be considered. Registration after **Friday 3rd October 2014** will incur an additional administration charge of £25.00. The final deadline for registration is **Friday 14th November 2014**. Registrations and bookings will be taken on a strictly first-come-first-served basis. No refunds will be available after the final deadline.

Registration, abstract submission, booking and payment (by credit card) will be through online forms available on the Palaeontological Association website (<<http://www.palass.org/>>). Please note that all these transactions will be in sterling (£:GBP). Accommodation must be booked separately (see below). The cost of registration is the same as last year. Early registration is **£90.00** for ordinary and retired members; **£60.00** for students; and **£120.00** for non-members. Registration costs include sandwich lunches on Wednesday and Thursday, the icebreaker reception on Wednesday evening, full registration package and tea/coffee from Tuesday through to Thursday.

The Annual Dinner event costs **£45.00**. It will be held at the **Leeds City Museum**, which is five minutes' walk downtown from the University. The evening's festivities will include a drinks reception followed by a three-course meal including carvery and vegetarian option. Due to the size of the venue numbers are limited to 250.

Oral presentations

All speakers (apart from the symposium speakers) will be allocated 15 minutes. You should therefore prepare a 12 minute talk to allow time for questions and switching between presenters. On the second day of the meeting we are using a number of parallel sessions in adjacent theatres so timing will be especially important. All the lecture theatres will have a single A/V projector linked to a large screen (e.g. <http://www.teachingspace.leeds.ac.uk/room_details.asp?ID=1-01-086-2486-GM-GM01>, and <http://www.teachingspace.leeds.ac.uk/room_details.asp?ID=1-01-086-2810-10M-22>). All presentations should be submitted and checked the day before they are scheduled. The University of Leeds is PC-based, so Mac-based presentations may cause problems,



particularly if animations are included. If you are using a Mac please make sure your presentation is PC compatible before you leave your institution.

Poster presentations

Poster boards will accommodate an A0-sized poster presented in **portrait** format. The boards will not be suitable for posters of this size in landscape format. Materials to fix the poster to the boards will be available at the meeting.

Venue and travel

The conference will take place in the campus of the University of Leeds, which is located just to the North of Leeds city centre. The venues for talks, posters, icebreaker reception, and Annual Dinner are all very close together. Campus maps are available online at <www.leeds.ac.uk/info/20014/about/157/how_to_find_us>; hard copies will be included in the welcome pack.

Getting to Leeds

Car

There is limited parking around the University, and almost none on campus, so driving is not the best option. The closest large car park (which is expensive) is Woodhouse Lane Car Park (LS2 3AX).

Bus

Intercity buses arrive at the main bus station at the South side of Leeds city centre, about 30 minutes' walk from the University. Buses are usually cheaper than trains. See National Express Coaches (<www.nationalexpress.com>) and Megabus (<www.uk.megabus.com>). There are a number of buses that go from the bus station past the University (see <www.wymetro.com>).

Train

Leeds is on the main inter-city train network, so is easily accessible from anywhere in the UK and this is probably the best travel option. Booking early will get the best ticket prices, particularly if travelling from London on East Coast Trains (<www.eastcoast.co.uk>). From Leeds train station the University is a 20 minute walk uphill to the North (see link above).

Plane

Leeds is served by Leeds-Bradford Airport (LBA), which has connections to many other European cities (<www.leedsbradfordairport.co.uk>). The airport is about 30 minutes' drive to the North of the city, depending on traffic. There are buses into Leeds bus station, or a taxi booking service. Alternatively, the much bigger Manchester Airport (MAN – <www.manchesterairport.co.uk>) is 1.5 hours away by train (<www.tpexpress.co.uk>) from Leeds. Another option is to fly into London airports and get the intercity trains to Leeds from London Kings Cross station (<www.eastcoast.co.uk>). These run every 30 minutes or so, and the journey takes about 2.5 hours.

Taxis

Leeds city taxis are black and white, and there are a good number of designated stops around the city, including outside the train station and at the Parkinson Building of the University. There also lots of local hire taxis that have to be booked. One is Amber Cabs (0113 231 1366).



Accommodation

This needs to be booked separately. Leeds has a wide variety of hotels, hostels and guest-houses at a range of prices that can be booked through the usual online resources. The following list of hotels (that is by no means exhaustive) are all within 20 minutes' walking distance of the University. Booking in plenty of time will ensure the best prices.

Budget (around £50/night): Ibis.

Mid range (£50–£100/night): Radison Blu, Park Plaza, The Met, Premier Inn Leeds City Centre (Leeds Arena).

Expensive (£100 plus): Leeds Marriott, Hilton Leeds City, Queens Hotel.

Travel grants to student members

The Palaeontological Association runs a programme of travel grants to assist student members (doctoral and earlier) to attend the Annual Meeting in order to present a talk or poster. For the Leeds 2014 meeting, grants of less than £100 (or the € equivalent) will be available to student presenters who are travelling from outside the British Isles (UK and Ireland). The actual amount available will depend on the number of applicants and the distance travelled. Payment of these awards is given as a disbursement at the Meeting, not as an advance payment. Students interested in applying for a PalAss travel grant should contact the Executive Officer, Dr Tim Palmer (e-mail <palass@palass.org>) once the organisers have confirmed that their presentation is accepted, and before 1st December 2014. Entitle the e-mail "Travel Grant Request". No awards can be made to those who have not followed this procedure.

Leeds and Yorkshire

Leeds and the famous Yorkshire Dales to the North featured internationally in July when the Tour de France started off in the city (<letour.yorkshire.com>). Why not visit some of the areas the tour visited? The Dales in particular are fantastic for walking, and have many picturesque towns and villages, many of them accessible from Leeds by train and bus (<www.yorkshire.com>). Alternatively, spend time exploring the Victorian industrial heritage of Leeds (<www.leeds.gov.uk/museumsandgalleries/Pages/Visit.aspx>), or go by train to nearby York, to see its medieval architecture (<www.visitork.org>).

We look forward to seeing you in Leeds in December.

**Tuesday 16th: Symposium and icebreaker reception**

The meeting will begin on Tuesday at noon with the Symposium in **Conference Auditorium 2**, followed by the icebreaker reception in the **Parkinson Building**. Registration and tea/coffee will be available in **Sports Hall 2**.

The Symposium title is 'The photosynthesis revolution: how plants and photosynthetic micro-organisms have bioengineered the planet'.

Wednesday 17th to Thursday 18th: Conference and Association AGM

The conference will commence on Wednesday 17th December with a full day of talks in **Conference Auditorium 2**. The Association AGM will take place in the afternoon. In the evening there will be the Annual Dinner at the **Leeds City Museum**. Thursday 18th December will be a full day of posters and talks in parallel sessions in **Roger Stevens Lecture Theatres 22 and 25**. Posters will be displayed throughout the meeting in **Sports Hall 2**, the same place as registration, refreshments, buffet lunch and advertisers' stands.

Friday 19th: Tropical Yorkshire: field-trip to the North York Moors

Price: **£30**, including transport and barbecue lunch. Starts at 08:00 from the **Parkinson Building** steps; returns 18:00 to Leeds Train Station and then *ca.* 18:20 at the Parkinson Building. The number of participants is limited to 45.

The field-trip will visit three inactive quarries in the North York Moors, to the East of Leeds, to look at various facies of the Oxfordian (Upper Jurassic) Corallian sediments in the area. We will start at Betton Farm Quarry, a Site of Special Scientific Interest that has recently been cleared. Here there are metre-scale reef structures formed by the corals *Isastraea* and *Thamnasteria*, together with very fossiliferous inter-reef facies containing molluscs, echinoids and other fauna. Also in the quarry are examples of the surrounding oolitic facies of the Malton Oolite Member (Coralline Oolite Formation). After a BBQ lunch at the quarry we will move to Ravenswyke Quarry to look at tall quarry faces displaying weathered surfaces of the Malton Oolite, some beds of which are packed by gastropods, and the overlying Coral Rag Member, which contains in-situ *Rhabdophyllia phillipsi* corals and the characteristic echinoid spines of *Paracidaris florigemma*. We will then walk and/or drive a short way to Spaunton Quarry to look again at the Coral Rag, which here contains patch reefs and various inter-reef facies, and is overlain by the sandy sediments of the Newbridge and Spaunton Sandstone Members of the Upper Calcareous Grit Formation, from which ammonites can sometimes be collected. We will then return to Leeds. Please dress warmly as we will be exposed to the elements during the day. Stout footwear will be useful, although there will not be a lot of walking on the day. Hard hats will be provided.



Schedule of events and timetable of presentations

Tuesday 16th December

Thematic Symposium

“The photosynthesis revolution: how plants and photosynthetic micro-organisms have bioengineered the planet”

Conference Auditorium 2 (tea/coffee break in Sports Hall 2).

- 12:00–12:15 **Welcome and introductory remarks**
- 12:15–12:45 **Environmental instability following the rise of oxygenic photosynthesis**
Professor Simon Poulton
- 12:45–13:15 **Cyanobacteria and the Great Oxidation Event: Evidence from genes and fossils**
Dr Bettina E. Schirromeister
- 13:15–13:45 **Evidence for terrestrial photosynthetic organisms in the Proterozoic: the land becomes vegetated**
Professor Charles H. Wellman
- 13:45–14:15 **Photosynthesis in Proterozoic oceans: evolutionary and ecological innovations**
Dr Nick J. Butterfield
- 14:15–14:45 **Cryptogamic covers and Lilliputian plants in the mid-Palaeozoic: aspects of early photosynthesising ecosystems on land**
Professor Dianne Edwards and Professor John A. Raven
- 14:45–15:15 **Tea/coffee break** – Sports Hall 2
- 15:15–15:45 **Trees and forests as geo-engineers of past and future global climates**
Professor David Beerling
- 15:45–16:15 **Distinctive characteristics of flowering plants and their importance**
Professor Margaret Collinson
- 16:15–16:45 **The evolutionary history of marine phytoplankton**
Dr James B. Riding

Annual Address

Conference Auditorium 2.

- 16:45–17:45 **Annual Address: Understanding ancient Earth climates and environments using models and data**
Alan M. Haywood

Reception

Parkinson Building, University of Leeds.

- 18:00–20:00 **Icebreaker reception, with drinks and regional food buffet.**
This event is kindly sponsored by Wiley.



Wednesday 17th December

* Candidates for the President's Prize are marked with an asterisk.

Underlined author denotes designated speaker.

Conference, Association AGM, and Annual Dinner

Conference Auditorium 2

- 08:45–09:00 **Opening of the Annual Meeting by the Vice-Chancellor of the University of Leeds, Sir Alan Langlands; followed by logistical information.**
- 09:00–09:15 **Life and death at high latitudes: a reassessment of the Cretaceous–Paleogene (K–Pg) mass extinction event in Antarctica**
*James D. Witts, Paul B. Wignall, Jane E. Francis, Robert J. Newton, J. Alistair Crame, Vanessa C. Bowman and Rowan J. Whittle
- 09:15–09:30 **Implications for the foraminifera over the Toarcian (Early Jurassic) Oceanic Anoxic Event (TOAE), following development of the freeze-thaw extraction technique**
*Alice E. Kennedy and Angela L. Coe
- 09:30–09:45 **Decoupling of the terrestrial and marine record during the Eocene–Oligocene transition**
*Matthew J. Pound and Ulrich Salzmann
- 09:45–10:00 **The role of microbial anaerobic respiration in the end-Permian mass extinction**
*Martin Schobben, Alan Stebbins, Abbas Ghaderi, Harald Strauss, Dieter Korn, Robyn Hannigan and Christoph Korte
- 10:00–10:15 **Palaeoecology of benthic marine communities in the wake of the Late Permian mass extinction event**
*William J. Foster, Richard J. Twitchett and Silvia Danise
- 10:15–10:30 **Post-Chicxulub radiation and dispersal of Worm Lizards (Amphisbaenia)**
*Nicholas R. Longrich, Jakob Vinther, Alexander Pyron, Davide Pisani and Jacques Gauthier
- 10:30–11:00 **Tea/coffee break and posters** – Sports Hall 2
- 11:00–11:15 **A quantitative comparison of dispersed spores/pollen and plant megafossil assemblages from a Middle Jurassic plant bed from Yorkshire, UK**
*Sam M. Slater and Charles H. Wellman
- 11:15–11:30 **Dark and disturbed or just disturbed? Modelling thermal tolerance to determine habitat preferences in early angiosperms**
*Alexandra P. Lee



- 11:30–11:45 **Global Dinoflagellate Diversity and Temperature Preference Compared to Neogene Climate Development**
*[Jamie L. Boyd](#), Matthew J. Pound, Jim B. Riding, Alan M. Haywood and Ruza F. Ivanovic
- 11:45–12:00 **An exceptional three-dimensionally preserved *Pararaucaria* (Cheirolepidiaceae) ovuliferous cone from the Late Jurassic of Southern England: non-destructive recovery of full anatomical and histological detail using Diamond Light Source synchrotron**
*[Alan R. T. Spencer](#), Paul Kenrick, Dave C. Steart, Russell J. Garwood, Jason Hilton, Martin Munt and John Needham
- 12:00–12:15 **Paleocene forests and climates of Antarctica: signals from fossil wood**
*[Laura Tilley](#), Jane E. Francis, Vanessa Bowman and J. Alistair Crame
- 12:15–12:30 **Fungal and fungal-like interactions with plants in early terrestrial ecosystems: state of the art and future direction**
*[Christine Strullu-Derrien](#) and Paul Kenrick
- 12:30–13:30 **Lunch and posters** – Sports Hall 2
- 13:30–13:45 **Extratropical peaks in Cretaceous terrestrial vertebrate diversity: the influence of primary producers on vertebrate species distribution**
*[Mark A. Bell](#), Paul Upchurch, Philip D. Mannion, Roger B. J. Benson and Anjali Goswami
- 13:45–14:00 **A Morphological Analysis of the Pectoral Girdle Skeleton of Soaring Birds**
*[Megan E. Williams](#)
- 14:00–14:15 **Craniodental biomechanical character evolution within the Sauropodomorpha, and the influence of dietary evolution on gigantism**
*[David J. Button](#)
- 14:15–14:30 **A 3D approach: investigating dietary evolution in Archaeocete whales (Cetacea: Archaeoceti) using tooth microtextures**
*[Robert H. Goodall](#), Mark A. Purnell, Julia M. Fahlke and Katharina A. Bastl
- 14:30–14:45 **Eccentric conodonts from extreme environments: specialized biota of late Wenlock (Silurian) sabkhas**
*[Emilia Jarochovska](#) and Axel Munnecke
- 14:45–15:00 **Turtle diversity in the Mesozoic**
*[David B. Nicholson](#), Roger B. J. Benson, Patricia A. Holroyd, Matthew T. Carrano and Paul M. Barrett
- 15:00–15:30 **Tea/coffee break and posters** – Sports Hall 2
- 15:30–15:45 **The curious case of chaetae in brachiopods from the Middle Cambrian Burgess Shale**
*[Timothy P. Topper](#), Lars E. Holmer, Luke Strotz, Noel Tait, Zhifei Zhang and Jean-Bernard Caron



- 15:45–16:00 **Deciphering brachiopod origins: The Cambrian Explosion, small shelly fossils and early evolutionary history of Lophotrochozoa**
*Aodhán D. Butler, Michael Streng, Zhifei Zhang, Russell Garwood and Lars E. Holmer
- 16:00–16:15 **Minerals in the gut: Scoping a Cambrian digestive system**
*Katie M. Strang, David A. T. Harper and Howard A. Armstrong
- 16:15–16:30 **Puckered, Woven and Grooved: the Importance of Substrate for Ediacara Paleocology, Paleoenvironment and Taphonomy**
*Lidya G. Tarhan, Mary L. Droser and James G. Gehling
- 16:30–17:45 **Poster session with refreshments** – Sports Hall 2
- 17:45–18:15 **Annual General Meeting (AGM)** – Conference Auditorium 2
- 18:30–late **ANNUAL DINNER** – Leeds City Museum

Thursday 18th December

Conference (Parallel Sessions)

A: Roger Stevens Lecture Theatre 22 (RSLT22)

- 09:00–09:15 **An agglutinated Early Cambrian actinotroch-like phoronid from the Chengjiang Lagerstätten and its implications**
Zhifei Zhang and Lars E. Holmer
- 09:15–09:30 **Loriciferan SCFs from the Cambrian of Canada: the origins of a meiofaunal phylum**
Thomas H. P. Harvey and Nicholas J. Butterfield
- 09:30–09:45 **Burgess Shale-type preservation of ‘shelly’ metazoans**
Mónica Martí Mus
- 09:45–10:00 **A new problematic colonial organism from the Cambrian of Morocco**
Christian Skovsted and Sebastián Clausen
- 10:00–10:15 ***Thaumaptilon walcottii* and the early evolution of the Cnidaria**
Jonathan B. Antcliffe
- 10:15–10:30 **High-resolution of the Changhsingian succession in Iran and correlation with China**
Dieter Korn, Abbas Ghaderi, Lucyna Leda and Martin Schobben
- 10:30–11:00 **Tea/coffee break and posters** – Sports Hall 2
- 11:00–11:15 **Sediment permeability and exceptional preservation within concretions**
*Victoria E. McCoy, Robert T. Young and Derek E. G. Briggs



- 11:15–11:30 **The Winneshiek Lagerstätte (Middle Ordovician, Darrivilian) of Iowa yields the oldest known eurypterids**
*[James C. Lamsdell](#), Derek E. G. Briggs and Huaibao P. Liu
- 11:30–11:45 **Systematic excavation in the Lower Ordovician Fezouata Lagerstätte (Zagora area, Morocco)**
*[Emmanuel L. O. Martin](#), Ninon Allaire, Abdelfattah Azizi, Khadija El Hariri, Khaoula Kouraiss, Juan Carlos Gutiérrez-Marco, Bertrand Lefebvre, Rudy Lerosey-Aubril, Ahmid Hafid, Moussa Masrour, Elise Nardin, Bernard Pittet, Abel Prieur, Emmanuel Robert, Peter Van Roy, Jean Vannier, Romain Vaucher, Muriel Vidal and Daniel Vizcaino
- 11:45–12:00 **Solving Darwin's Dilemma? Differential taphonomy reveals tissue biochemistry dependence of mould/cast exceptional fossil preservation**
*[Breandán Anraoi MacGabhann](#), James D. Schiffbauer, James W. Hagadorn, Peter Van Roy, Edward P. Lynch, Liam Morrison and John Murray
- 12:00–12:15 **Favourable Impressions: Ammonoid Taxonomy and Biostratigraphy in the Carboniferous Shannon Basin, Western Ireland**
*[Anthea Lacchia](#)
- 12:15–12:30 **Modelling Functional Morphology and Extinction selectivity in Ammonites**
*[Timothy Astrop](#), Matthew Wills, Qilong Ren, Michael Carley, Sylvain Gerber and Stefan Angioni
- 12:30–13:30 **Lunch and posters** – Sports Hall 2
- 13:30–13:45 **Recognising the reproductive mode of *Fractofusus* through spatial analysis**
*[Emily G. Mitchell](#), Alexander G. Liu, Charlotte G. Kenchington and Nicholas J. Butterfield
- 13:45–14:00 **Oxygen, age and facies controls on the appearance of Ediacaran and Cryogenian macroscopic fossils in the Mackenzie Mountains, Northwest Territories, Canada**
*[Erik A. Sperling](#), Calla Carbone, David T. Johnston, Guy M. Narbonne and Francis A. Macdonald
- 14:00–14:15 **A diverse Late Ediacaran skeletal fossil assemblage from central Spain**
*[Iván Cortijo Sánchez](#), Mónica Martí Mus, Sören Jensen and Teodoro Palacios
- 14:15–14:30 ***Hallucigenia's* head and the Cycloneuralian ancestry of Panarthropoda**
*[Martin R. Smith](#) and Jean-Bernard Caron
- 14:30–14:45 **Non-actualistic Ediacaran conditions drove the formation of Salter's (1856) Longmyndian discoidal fossils**
*[Latha R. Menon](#), Duncan McIlroy, Alexander G. Liu and Martin D. Brasier
- 14:45–15:00 **Using growth models to test the vendobiont hypothesis for the Ediacara Biota**
*[Renee S. Hoekzema](#) and Martin Brasier
- 15:00–15:30 **Tea/coffee break and posters** – Sports Hall 2



- 15:30–15:45 **The Middle Permian Mass Extinction in High Latitudes**
Paul B. Wignall and David P. G. Bond
- 15:45–16:00 **‘Death Metal’ in the Early Palaeozoic**
Thijs R. A. Vandenbroucke, Poul Emsbo and Axel Munnecke
- 16:00–16:15 **Evolving phytoplankton stoichiometry in response to marine-terrestrial interactions: the Late Palaeozoic “phytoplankton blackout”**
Ronald E. Martin, Thomas Servais and Alexander Nützel
- 16:15–16:30 **The cause of late Cenozoic mass extinction in the western Atlantic: insights from sclerochronology**
Andrew L. A. Johnson, Annemarie Valentine, Melanie J. Leng, Donna Surge and Mark Williams
- 16:30–16:45 **Aragonite / Calcite seas and the evolution of biomineralization**
Uwe B. Balthasar
- 16:45–17:00 **Disparity trends in the shell shape of non-heteromorph ammonoids (Cephalopoda)**
Matthew E. Clapham
- 17:00–17:30 **Presentation of President’s Awards** to oral and poster presenters; followed by closing remarks for the Leeds Annual Meeting.

B: Roger Stevens Lecture Theatre 25 (RSLT25)

- 09:00–09:15 **Morphology or environment: factors affecting preservation of the Middle Triassic actinopterygian *Saurichthys***
*Susan R. Beardmore and Heinz Furrer
- 09:15–09:30 **‘Fish’ (Actinopterygii and Elasmobranchii) diversification patterns through deep time**
*Guillaume Guinot and Lionel Cavin
- 09:30–09:45 **Denticle Déjà Vu, and the Evolution of Speed**
*Tom Merrick-Fletcher, John D. Altringham, Jeff Peakall, Paul B. Wignall, Robert M. Dorrell and Gareth M. Keevil
- 09:45–10:00 **A fight for survival: Megalodon vs the Great White shark**
*Laura McLennan and Mark Purnell
- 10:00–10:15 **Patterns of morpho-functional disparity during the explosive radiation of acanthomorph fishes**
*Roger A. Close, Matt Friedman, Zerina Johansen, Hermione Beckett and Dan Delbarre
- 10:15–10:30 **Exceptionally preserved Devonian actinopterygian skull presents a new model for early ray-fin evolution**
*Sam Giles, Laurent Darras, Gaël Clément and Matt Friedman



- 10:30–11:00 **Tea/coffee break and posters** – Sports Hall 2
- 11:00–11:15 **Derived ornithopod dinosaurs: a case of evolutionary parallelism and convergence**
David B. Norman
- 11:15–11:30 **Automated generation of large phylogenies and a probabilistically time-scaled 1,000-taxon phylogenetic hypothesis for Mesozoic dinosaurs: dating the origins of flight and crown-birds**
Graeme T. Lloyd, David W. Bapst, Katie E. Davis and Matt Friedman
- 11:30–11:45 **Function and evolution of theropod jaws**
Emily J. Rayfield, Roger B. J. Benson and Philip S. L. Anderson
- 11:45–12:00 **Unlocking geological and sea level biases reveals cryptic evolutionary history of early vertebrates**
Robert Sansom, Emma Randle and Philip C. J. Donoghue
- 12:00–12:15 **Dinosaur body size maxima driven by global temperature**
Roger Benson, Nicolas Campione, Philip Mannion and David Evans
- 12:15–12:30 **Use and misuse of cladistic matrices for morphospace analyses**
Sylvain Gerber
- 12:30–13:30 **Lunch and posters** – Sports Hall 2
- 13:30–13:45 **Chondrichthyan diversity and distribution in the Early Carboniferous: new evidence from the Tournaisian of northern Britain**
Timothy R. Smithson, Kelly R. Richards, Rebecca Bennion and Jennifer A. Clack
- 13:45–14:00 **Enameloid microstructure in sharks and bony fishes: What do we really know?**
Gilles Cuny, Sébastien Enault, Guillaume Guinot and Martha Koot
- 14:00–14:15 **Long snouted lungfish and the variable dipnoan endocranium**
Tom Challands and Alexey Pakhnevich
- 14:15–14:30 **Chitons of the Permian Capitan Reef, and the nature of late Palaeozoic Polyplacophora**
Michael J. Vendrasco, Richard D. Hoare, Gordon L. Bell and Jonena M. Hearst
- 14:30–14:45 **A surfeit of sponges: unexpected Ordovician diversity in central Wales, UK**
Joseph P. Botting and Lucy A. Muir
- 14:45–15:00 **Finding food efficiently: the origin and evolution of optimal foraging strategies**
Richard J. Twitchett, Andrew M. Reynolds, Nicolas E. Humphries, Emily J. Southall, Victoria J. Wearmouth, Brett Metcalfe and David W. Sims
- 15:00–15:30 **Tea/coffee break and posters** – Sports Hall 2
- 15:30–15:45 **Cladistic analysis of the enigmatic Polychelidan lobsters**
*Denis Audo, Sylvain Charbonnier and Jean-Paul Saint Martin



- 15:45–16:00 **Epibioses of fossil crustaceans: insights on specific palaeoecology and true palaeosymbioses**
**Ninon Robin*, Sylvain Charbonnier, Barry Van Bakel, Sylvain Bernard, Jennyfer Miot and Gilles Petit
- 16:00–16:15 **A global perspective of the Trigoniida (Bivalvia: Palaeoheterodonta), with a focus on their Mesozoic and Cenozoic representatives**
**Simon Schneider* and Simon R. A. Kelly
- 16:15–16:30 **Repeat colonisation of temporary water-bodies by Early Carboniferous invertebrates**
**Carys Bennett*, Peter Brand, Sarah Davies, Tim Kearsey, Dave Millward, Tim Smithson and Mark Williams
- 16:30–16:45 **Rudist myophores: constructional constraints and phylogenetic informativeness**
Peter W. Skelton
- 16:45–17:00 **Phylogeny of the barnacles – combining molecular and morphological approaches**
Andy Gale
- 17:00 Delegates in RSLT25 move to RSLT22.

The organisers of the Annual Meeting gratefully acknowledge the support of the sponsors:

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Abstract of Annual Address

Understanding Ancient Earth Climates and Environments using Models and Data

Professor Alan M. Haywood

School of Earth & Environment, Woodhouse Lane, University of Leeds, Leeds LS2 9JT, UK.

<eamrh@leeds.ac.uk>

Geology and palaeontology have demonstrated that climate is not stable. We know that climate change occurs over a variety of timescales (*e.g.* tectonic, orbital, millennial, centennial, decadal, sub-decadal). The fossil record and advanced numerical models of climate, and increasingly the Earth system, are gradually lifting the veil on the mysteries of Earth's climatic and environmental evolution and variability. Studies have focused on understanding the drivers for changes in mean climate state as well as the causes and consequences of climatic transitions and rapid climate change. In this talk we will explore how models and data have been used successfully together to better understand three distinctly different intervals in Earth history, each presenting its own unique challenges, scientific questions and benefits.

The first case study is focused on the relative role of climate and environmental change versus human influence on the extinction of Late Quaternary megafauna. Despite decades of research, the roles of climate and humans in driving the dramatic extinctions of large-bodied mammals during the Late Quaternary Period remain contentious. Models and data have shown that climate has been a major driver of population change over the past 50,000 years. However, species respond differently to the effects of climatic shifts, habitat redistribution and human encroachment. Although climate change alone can explain the extinction of some species, such as Eurasian musk ox and woolly rhinoceros, a combination of climatic and anthropogenic effects appears to be responsible for the extinction of others.

The second case study focuses on quantifying the equilibrium response of global temperatures to an increase in atmospheric carbon dioxide concentrations, which is one of the cornerstones of climate research. Components of the Earth's climate system that vary over long timescales, such as ice sheets and vegetation, have an important effect on this temperature sensitivity, but are normally neglected. Climate models, using geological derived boundary conditions (vegetation and ice cover), have been used to simulate the climate of the mid-Pliocene warm period, and to analyse the forcing and feedbacks that contributed to the relatively warm temperatures. Estimates suggest that the response of the Earth system to elevated atmospheric carbon dioxide concentrations is 30% to 50% greater than the response based on those fast-adjusting components of the climate system that are used traditionally to estimate climate sensitivity. This suggests that targets for the long-term stabilization of atmospheric greenhouse-gas concentrations aimed at preventing a dangerous human interference with the climate system should take into account this higher sensitivity of the Earth system.

The final case study focuses on the Eocene to Oligocene transition and the shift between a greenhouse and ice house state *ca.*33 million years ago. The development of the Antarctic Circumpolar Current (ACC) has been linked to the thermal isolation and growth of the Antarctic Ice Sheet at the time, yet the development of the ACC during the Cenozoic is controversial in terms of timing and its role in major climate transitions. Climate model results show that a coherent ACC was not possible during the Oligocene due to Australasian palaeogeography, despite deep water connections through the Drake Passage and Tasman Gateway and the initiation of Antarctic glaciation. These simulations of ocean currents compare well to marine proxy records relating to the physical oceanography of the Oligocene, and provide a framework for understanding apparently contradictory dating of the initiation of the ACC.



Abstracts of symposium presentations: The photosynthesis revolution: how plants and photosynthetic micro-organisms have bioengineered the planet

Trees and forests as geoengineers of past and future global climates

David Beerling

University of Sheffield

For over two decades, it has been widely hypothesized that the origin and diversification of trees and forests accelerated continental silicate weathering, a process regulating atmospheric CO₂ over millions of years. I will introduce new evidence supporting this paradigm by illustrating early forest tree rooting systems are linked to enhanced soil weathering processes, as shown by preliminary results from our recent drilling programme in New York State, USA. This raises the question: to what extent can we artificially accelerate the process to sequester our fossil fuel CO₂ emissions? Earth system model simulations investigating this issue suggest enhanced weathering through the distribution of pulverised silicate rocks over tropical land could play a significant role in anthropogenic carbon sequestration, with additional benefits of protecting coral reefs from ocean acidification.

talks

Photosynthesis in Proterozoic oceans: evolutionary and ecological innovations

Nicholas J. Butterfield

Department of Earth Sciences, University of Cambridge

Oxygenic photosynthesis has been driving the global carbon cycle for at least the past three billion years, but the manner in which it has been packaged, and the associated geobiological feedbacks have changed radically over this time. The body-fossil record documents effectively modern cyanobacterial mat biotas in sunlit settings since at least the mid-Palaeoproterozoic, imparting a pervasive sedimentary fabric and accompanying taphonomic signatures. Eukaryotic microfossils are also known from at least the late Palaeoproterozoic, most likely representing benthic photosynthesizers. By the late Mesoproterozoic and early Neoproterozoic these have been joined by a range of unicellular and multicellular plant-protists, though sedimentological and molecular biomarker data point to the continued ecological dominance of cyanobacteria. Eukaryotes were not contributing significantly to ecosystem function until the middle Neoproterozoic, documented by the first quantitative occurrence of eukaryotic steranes. Along with the coincident appearance of testate amoebae and biomineralized scale microfossils, these biomarker data identify a major reorganization of the biological pump – with important implications for interpreting the redox geochemistry and climatic perturbations of the later Neoproterozoic. Full eukaryotic control of marine productivity was achieved during the Ediacaran and Cambrian radiations, establishing the default Phanerozoic condition. The belated shift to a eukaryote-dominated carbon cycle is best explained as a co-evolutionary by-product of early animal evolution.



Distinctive characteristics of flowering plants and their importance

Margaret Collinson

Department of Earth Sciences, Royal Holloway University of London

(This Abstract will be available online, and on paper at the Meeting.)

Cryptogamic covers and Lilliputian plants in the Mid-Palaeozoic: aspects of early photosynthesising ecosystems on land

Dianne Edwards¹ and John A. Raven²

¹*Cardiff University*

²*University of Dundee*

Cryptogamic covers, terrestrial communities that today colonise soil, rock and even plant surfaces, comprise photosynthesising organisms including cyanobacteria, algae, lichens and bryophytes, plus fungi. Until recently they have received little attention, although, despite their limited extent, it has been estimated that they account for about 7% of carbon dioxide consumed by terrestrial vegetation and, even more remarkably, are responsible for 46% of biological nitrogen fixation on land. It is hypothesised that from Mid-Ordovician times until the advent of larger tracheophytes, terrestrial cryptogamic covers contributed to global carbon and nitrogen cycles in similar ways. Fossil evidence will be reviewed including a critical evaluation of that for lichens, and the affinities of very small axial plants (cryptophytes/basal embryophytes), the ecophysiological equivalent of the extant bryophyte component, discussed. Carbon isotope signatures might provide further indirect evidence for the composition of the communities, provided carbon can be obtained from individual plants and carbon inputs from freshwater can be ruled out. These organisms could have increased weathering, producing conditions, including soils, appropriate for subsequent homoiohydric plants and animals. A more quantitative approach is far more contentious because both local and global extents of subaerial colonisation are unknown.

Environmental instability following the rise of oxygenic photosynthesis

Simon Poulton

University of Leeds

The evolution of oxygenic photosynthesis irrevocably changed the course of chemical and biological evolution on Earth. Yet, despite this significance, the timing of the evolution of oxygenic photosynthesis is extremely poorly constrained, as are the resultant dynamics and consequences of biospheric oxygenation. Over recent years a wealth of geochemical and geological data has been produced, which in general converges on an environmental signal of oxygenic photosynthesis by at least 2.7 Ga, although more speculative data suggests a much earlier origin. Thus, it appears likely that oxygenic photosynthesis evolved at least several hundred million years before the Great Oxidation Event at *c.*2.3 Ga. The evolution of oxygenic photosynthesis essentially threw the Earth into a state of turmoil, and it took more than two billion years to achieve the (more or less) stable levels of oxygenation experienced during the Phanerozoic. As well as providing a broad overview of Earth's oxygenation history, this presentation will include new data that questions both the timing of persistent atmospheric oxygenation, and the concept of an irreversible rise in oxygen after the rise of oxygenic photosynthesis.



The evolutionary history of the phytoplankton

James B. Riding

British Geological Survey, Keyworth, Nottingham NG12 5GG, UK

During the Palaeozoic, the principal phytoplankton group was the acritarchs, a polyphyletic group of unknown affinity. They had their origins during the Neoproterozoic and probably represent the resting cysts of extinct unicellular planktonic organisms similar to the dinoflagellates. The acritarchs were abundant and diverse throughout most of the Early Palaeozoic, but declined markedly during the Carboniferous. Acritarchs were extremely sparse throughout the Carboniferous, Permian and most of the Triassic. During the Triassic, body fossils of dinoflagellate cysts emerged and these diversified significantly during the remainder of the Mesozoic. They declined markedly from the Oligocene, probably in response to falling global temperatures and sea levels. The dinoflagellates underwent a significant evolutionary radiation during the latest Early Bajocian (*c.* 169 Ma), and this event is coincident with diversifications and radiations in other fossil groups. For example the closely-related calcareous nannofossils diversified, and planktonic foraminifera are observed for the first time. This Bajocian radiation of dinoflagellates is a significant watershed and represents the dawn of modern planktonic biotas. The precise reasons behind this evolutionary event are not known with certainty; it may be related to the breakup of Pangaea and related changes in global palaeoceanography, and/or the Mesozoic Marine Revolution.

Cyanobacteria and the Great Oxidation Event: Evidence from genes and fossils

Bettina E. Schirrmeister

School of Earth Sciences, University of Bristol

Cyanobacteria are among the oldest organisms on this planet and unique among prokaryotes, regarding their age, morphology and fossil record. Their ability to gain energy via oxygenic photosynthesis transformed Earth's atmosphere and redefined the evolutionary boundaries of life. More than 2.4 Ga they caused one of the most dramatic environmental changes in the history of our planet, the 'Great Oxidation Event' (GOE). Yet, the origin of cyanobacteria and their morphological disparity, as well as their causal association to the rapid accumulation of atmospheric oxygen, are not resolved. Previous phylogenetic studies I have conducted suggest that the origin of multicellular cyanobacteria might be associated with the GOE.

In the fossil record unequivocal cyanobacterial fossils are not found before 2Ga. Fossil findings from the Archean and early Proterozoic failed to provide enough taxonomic information using traditional methods. To resolve the occurrence of multicellular cyanobacteria during the early Precambrian, I have combined novel data on morphotype disparity and abundance from Synchrotron Radiation X-ray tomographic microscopy, with phylogenetic analyses of all major prokaryotic taxa. Results suggest that multicellular fossils from the Archean/early Proterozoic can only be compared to modern Cyanobacteria, Chloroflexi or Actinobacteria among the Eubacteria.



Evidence for terrestrial photosynthetic organisms in the Proterozoic: the land becomes vegetated

Charles H. Wellman

Dept. of Animal & Plant Sciences, University of Sheffield

Pre-Ordovician terrestrial deposits are rare and are difficult both to recognize and to age constrain. Nevertheless recent work on billion-year-old terrestrial deposits of the Torridonian of Scotland and the Nonesuch Shale of Michigan, USA is demonstrating the existence of diverse freshwater aquatic and terrestrial biotas. These biotas include cyanobacteria and primitive eukaryotes, with a number of basal protist groups, such as euglenids, identified. Interestingly, emerging evidence from phylogenetic analyses, molecular clock studies and ancestral state reconstruction suggests that freshwater and terrestrial environments may have been much more important than previously anticipated in the evolution and diversification of life on Earth. Cyanobacteria have been shown to be an essentially non-marine group that most likely originated in freshwater environments where they diversified. Ultimately they were integral to the origin of photosynthetic eukaryotes having given rise to the chloroplast. All of these events may have occurred in non-marine environments, away from the 'poisonous' anoxic/euxinic oceans. We often think of carbon cycling on Proterozoic Earth as being driven by the marine carbon-cycle. Also important was the terrestrial carbon-cycle, dominated by aquatic/terrestrial photosynthesis and carbon burial, combined with silicate rock weathering by microbial soil crusts during development of rudimentary soils.



Abstracts of oral presentations

* Candidates for the President's Prize are marked with an asterisk.

Underlined author denotes designated speaker.

Thaumaptilon walcottii and the early evolution of the Cnidaria

Jonathan B. Antcliffe

University of Oxford

The Cambrian Burgess Shale from British Columbia, Canada has provided generations of palaeontologists with new and wonderful puzzles concerning the early evolution of animal life. *Thaumaptilon* is one of the most intriguing of these as it links to two major problems in early animal evolution. First is the possible connection between enigmatic Ediacaran age (c.565Ma) taxa such as *Charnia* and their possible successors such as *Thaumaptilon* from the Cambrian. It has been thought that if we could understand the relationships of *Thaumaptilon* to modern animals, then by inference we could understand the relationship of the critically important Ediacaran biota. Second is that *Thaumaptilon* has been interpreted as an early soft-bodied cnidarian. The early evolution of the Cnidaria is poorly understood as Cambrian cnidarians are rare and often poorly preserved. This is particularly problematic as the bilateria appear in the fossil record at the same time, if not even before, the earliest reliable cnidarian fossils. Here new ontogenetic, anatomic, and decay data are presented that aims to resolve these major questions with implications for the earliest evolution of the Cnidaria and the battle between convergent and contingent patterns of evolution in the Cambrian Explosion.

Modelling Functional Morphology and Extinction selectivity in Ammonites

***Timothy Astrop¹, Matthew Wills¹, Qilong Ren¹, Michael Carley¹, Sylvain Gerber² and Stefan Angioni¹**

¹*University of Bath*

²*University of Cambridge*

Ammonoids famously survived three major pulses of extinction at the Devonian/Carboniferous, Permian/Triassic and Triassic/Jurassic boundaries. They radiated rapidly after each of these events via unique trajectories, but ultimately occupied the same regions of morphospace inhabited by their ancestral counterparts. They therefore offer an excellent model system for studying extinction dynamics and the subsequent processes of diversification and radiation. Although traditional Raupian measurements (and cardinal conch parameters) have been successful in identifying trends in conch geometry through ontogeny, linear measurements often miss the more complex aspects of shape associated with the functional biology of the organism. By using a novel sliding semi-landmark morphometric approach we have begun to describe detailed shape trends in the aperture ('living space') of ammonoids and by extension an aspect of their biology throughout ontogeny.

Together with high-quality 3D scanning and printing technology, this constitutes a unique set of methods for investigating how hydrodynamic parameters vary with shell growth patterns and adult morphology across the Devonian/Carboniferous extinction boundary.



By using extant analogues to produce biologically sound velocity profiles to explore likely locomotive behaviours for different ammonite morphotypes in analytical flow-tanks we begin to identify the morphological, developmental and functional parameters that determine susceptibility to extinction.

Cladistic analysis of the enigmatic Polychelidan lobsters

***Denis Audo**¹, **Sylvain Charbonnier**² and **Jean-Paul Saint Martin**²

¹*Université de Rennes 1, EA 7316 'Biodiversité et Gestion des Territoires'*

²*UMR 7207 (CR2P) MNHN/UPMC, Département Histoire de la Terre, Muséum national d'Histoire naturelle, Paris, France*

Polychelida is an unusual group of decapod crustaceans characterized by their four to five pairs of claws, a flattened body and a reduced rostrum. The systematic of this group is still poorly studied and no phylogenetic analysis focused on fossil species is available. Our study has systematically reviewed all species of fossil Polychelida. Among valid species, all species with well-preserved specimens have been considered in the phylogenetic analysis. Our study includes 37 fossil species and 4 extant species of Polychelida, and is therefore the most complete cladistic analysis to date on this group. Our preliminary results show that Palaeopentachelidae are sister taxa of Eryonidae. Coleiidae and *Coleia*, respectively the most diversified family and genus, are not monophyletic but correspond to a paraphyletic group from which Tetrachelidae and Polychelidae (the latter comprising all extant species) have been artificially excluded. These new results allow the partial reconstruction of the evolutionary history of polychelidans. For instance, we trace the origin of Polychelidae at least to the Early Jurassic (Toarcian–Aalenian). We also suggest that the well-known shallow-water plattenkalks from the Solnhofen-type localities (Germany) were colonised by groups originating from deeper water settings, such as those of Lyme Regis (England), Holzmaden (Germany) or La Voulte (France).

Aragonite / Calcite seas and the evolution of biomineralization

Uwe B. Balthasar

Plymouth University

The vast majority of marine invertebrate skeletons are composed of the CaCO₃ polymorphs aragonite and calcite, yet the influence of seawater composition on the evolution of calcareous skeletal composition is poorly understood. Conventional thinking is that a threshold in the marine Mg:Ca ratio determines CaCO₃ polymorph formation with Phanerozoic Mg:Ca oscillations resulting in periods of 'aragonite seas' or 'calcite seas': the principal environmental context in which the evolution of biogenic CaCO₃ is assessed. I present data from CaCO₃ precipitation experiments to show that the concept of a distinct threshold is misleading because Mg:Ca ratio and temperature combined result in a Phanerozoic continuum of co-existing aragonite-calcite seas with aragonite-facilitating conditions existing throughout the Phanerozoic in shallow warm-water (>20°C) environments. The comparison between Phanerozoic models of Mg:Ca (expressed as percent of non-biogenic aragonite) and the Phanerozoic occurrence of skeletal aragonite shows that the skeletal composition of reefs tracks the marine Mg:Ca ratio with a lag of tens of millions of years. This pattern cannot be explained by mass extinctions or changing skeletal mineralogy and thus points to a more complex influence of seawater composition on biocalcification than previously appreciated.



Morphology or environment: factors affecting preservation of the Middle Triassic actinopterygian *Saurichthys*

***Susan R. Beardmore¹ and Heinz Furrer²**

¹Elgin Museum, 1 High Street, Elgin, Moray IV30 1EQ

²Paläontologisches Institut und Museum der Universität Zürich, Karl Schmid-Strasse 4, CH-8006, Zürich

Excavations of Middle Triassic strata at Monte San Giorgio (Switzerland-Italy) have famously recovered a range of reptiles described extensively regarding their affinities, morphology and preservation. Less well-known, but equally diverse, is the contemporaneous fish fauna that has yet to be described as thoroughly. To address this, a comprehensive taphonomic study was undertaken using the actinopterygian *Saurichthys*, a relatively abundant taxon found in the Besano Formation (Anisian-Ladinian) and Cassina Beds of the Meride Formation (Ladinian). Specimens from each horizon were scored for articulation and completeness across ten anatomical units, the resulting datasets being used to determine a taphonomic model for each and preservational variation through time. *Saurichthys* showing moderate to high articulation and high completeness occur in both horizons but states of low articulation and moderate completeness are only present in the Besano Formation. The same feature is apparent in corresponding unit plots, suggesting environmental differences between each horizon. An investigation of body length versus articulation and, separately, completeness infers a slight increase in overall preservation with increasing length, suggesting morphology might also have had some influence. Adhesion to substrate, rolling of carcasses and rupture of the body cavity are evident in specimens from both horizons.

Extratropical peaks in Cretaceous terrestrial vertebrate diversity: the influence of primary producers on vertebrate species distribution

***Mark A. Bell¹, Paul Upchurch¹, Philip D. Mannion², Roger B. J. Benson³ and Anjali Goswami¹**

¹University College London

²Imperial College London

³University of Oxford

The Latitudinal Biodiversity Gradient (LBG), a pole-ward decline in species richness, is well-documented in the modern world, but poorly understood. This pattern has been attributed to temperature, seasonality, the geographical extent of landmasses, and other causes. Previous studies have demonstrated that palaeotemperate peaks are prevalent in greenhouse worlds. The Cretaceous, with its global greenhouse conditions and well-constrained climate history, provides an important counterpoint to the modern LBG.

We examine the evolution and causes of the Cretaceous LBG using the most comprehensive dataset of terrestrial vertebrates, comprising *c.*2,500 species. Estimates of latitudinal diversity were calculated at 10° intervals using Shareholder Quorum Subsampling. Generalized least-squared regression was used to examine the fit of variables representing the latitudinal distribution of fossil sampling, non-marine land area, temperature, and plant diversity.

Species diversity shows a palaeotemperate peak in the northern hemisphere across the entire dataset and for physiological, taxonomic and spatial subsets. Multivariate modelling supports a combination of plant diversity and sampling, with an AICc weight of 0.70, as



the best fit to subsampled vertebrate diversity. These results suggest that latitudinal climatic distribution did not directly cause the Cretaceous extratropical peak in terrestrial vertebrate diversity, but that primary producers controlled terrestrial vertebrate distributions.

Repeat colonisation of temporary water-bodies by Early Carboniferous invertebrates

***Carys Bennett¹, Peter Brand², Sarah Davies¹, Tim Kearsley², Dave Millward², Tim Smithson³ and Mark Williams¹**

¹*University of Leicester*

²*British Geological Survey*

³*University Museum of Zoology, Cambridge*

The TW:eed Project investigates the rebuilding of Carboniferous ecosystems following the end Devonian mass extinction. New fossils populate ‘Romer’s Gap’ with a diversity of tetrapods, fish (gyracanthids, lungfish, rhizodonts, actinopterygians and chondrichthyans), invertebrates (malacostracans, eurypterids, scorpions and myriapods) and plants. The fossil-bearing Ballagan Formation was deposited on an extensive low relief, coastal-alluvial, vegetated floodplain, with temporary pools and shallow lakes. Bivalves and ostracods are the most numerous invertebrates in the formation and are here described from the 502 m thick Norham West Mains Core. Present in over 150 horizons, euryhaline/non-marine *Modiolus* bivalves and Leiocopida and Podocopida ostracods dominate, with an associated fauna of fish (actinopterygians, chondrichthyans and dipnoans, which likely predated the ostracods and bivalves), and rarer eurypterids, Spinicaudata, gastropods and *Spirorbis*. The majority of these fossils occur in sedimentary deposits that overlie palaeosols or desiccation horizons, indicating the repeated occupation of temporary pools and lakes after periods of desiccation. Most of the bivalve specimens are juveniles suggesting short-lived aquatic environments. Living freshwater Unionidae bivalves attach to the gills of fish in a phoretic parasitic larval stage, as a mechanism for dispersal. We explore the links between Early Carboniferous fish, bivalves and ostracods in their radiation into these temporary environments.

Dinosaur body size maxima driven by global temperature

Roger Benson¹, Nicolas Campione², Philip Mannion³ and David Evans⁴

¹*Oxford University*

²*Uppsala University*

³*Imperial College, London*

⁴*Royal Ontario Museum*

Interactions between organismal body and physical climatic variation depend on thermal physiology. For example, mammals achieved their largest body sizes during globally cool intervals. To estimate the relationship between maximum body size and global climate in dinosaurs we used a comprehensive dataset of *ca.*500 dinosaurian body masses estimated using robust scaling relationships, and compared these to the $\delta^{18}\text{O}$ palaeotemperature proxy using time series regression approaches. Dinosaurs achieved large body masses by the Late Jurassic, exceeding 50 tonnes in sauropodomorphs, five tonnes in stegosaurian ornithischians, and three tonnes in allosauroid theropods. Subsequently, ornithischians attained their body size maximum around 15 tonnes, during globally cool intervals



in the Early Cretaceous and again in the Campanian–Maastrichtian. In contrast, sauropodomorphs attained their body size maximum, exceeding 50 tonnes, during globally warm intervals, in the Late Jurassic and early Late Cretaceous. A strong ($R^2 = 0.80$), statistically significant ($p < 0.001$) positive correlation between maximum body mass and temperature in sauropodomorphs is distinct from the negative association seen in ornithischians and modern endotherms, and suggests that physiological rates of sauropods were controlled by environmental temperatures (*i.e.* poikilothermy). Our results indicate distinct evolutionary responses to climate change among major groups of dinosaurs, and suggest that sauropodomorph physiology was distinct from that of ornithischians, and also from that of mammals.

A surfeit of sponges: unexpected Ordovician diversity in central Wales, UK

Joseph P. Botting and Lucy A. Muir

Independent

Sponges are generally considered to be minor components of Ordovician communities in siliciclastic settings, but this may be an underestimate due to their low preservation potential. The Builth Inlier (Middle and Late Ordovician) yields abundant articulated sponges, providing a unique opportunity to assess the ecological distribution of different sponge groups and to estimate their true palaeobiodiversity.

Long-term fieldwork has yielded more than 100 new sponge species from a range of sites. Clear patterns are evident in the distribution of particular groups, with more derived taxa occupying shallow water, and the more primitive reticulosans dominating offshore communities. One new fauna from intermediate depth contains a diverse protomonaxonid-dominated sponge assemblage resembling that of the Burgess Shale.

Most articulated faunas in the inlier are diverse, with little taxonomic overlap between different assemblages. This indicates higher α - and β -diversity than any other co-occurring group, and/or very low sampling saturation. These factors imply that, despite being the most diverse group known in these deposits, all aspects of their diversity are underestimated. If the Builth Inlier is typical of Ordovician ecosystems in general, then palaeontologists are missing an unexpectedly large component of biodiversity during the Great Ordovician Biodiversification Event.

Global Dinoflagellate Diversity and Temperature Preference Compared to Neogene Climate Development

***Jamie L. Boyd¹, Matthew J. Pound², Jim B. Riding³, Alan M. Haywood¹ and Ruza F. Ivanovic¹**

¹*The University of Leeds*

²*Northumbria University*

³*The British Geological Survey*

The Neogene (23.03–2.59 Ma) is a period of progressive global cooling, interrupted by the Middle Miocene Climatic Optimum, that led to the glacial-interglacial cycles of the Pleistocene. We have tested the role of Neogene climate change on the evolution, diversity and biogeography of dinoflagellates. Using the Tertiary Oceanic Parameters Information System (TOPIS) database, 500 globally distributed sites and 28,100 dinoflagellate occurrences from the Neogene have been synthesised. We found that during the Neogene the number of Warm-Water Species (WWS) reduces in the higher latitudes, but the global diversity of both WWS and Cold-Water Species (CWS) increases. These results suggest that



dinoflagellate evolution, diversity and biogeography is, in part, controlled by climate. The WWS migrated away from the poles due to the cooling climate and narrowing warm water zone, but because more species are thought to originate in the tropics than the poles, we still see a rise in the diversity in the WWS, even as their habitat decreases. This suggests that some of the CWS of today may have originated in tropical regions and then expanded into the higher latitudes.

Deciphering brachiopod origins: The Cambrian Explosion, small shelly fossils and early evolutionary history of Lophotrochozoa.

***Aodhán D. Butler¹, Michael Streng¹, Zhifei Zhang², Russell Garwood³ and Lars E. Holmer¹**

¹*Uppsala University*

²*Northwest University, ELI*

³*University of Manchester*

The fossil record of life on Earth is strongly biased towards organisms composed of hard parts – biomineralised tissues such as shells or skeletons. The Cambrian explosion, once considered as the initial appearance of life, in fact partially results from the evolution of hard parts and their seemingly sudden appearance in the fossil record. This event is predated by the appearance of a group of problematic microfossils known as the small shelly fauna (SSF). A consensus has emerged that many of the taxa comprising the SSF are stem-group representatives of extant phyla that emerged during the Cambrian, although this is not without controversy. We provide a review of the current synthesis of tommotiid research including novel data retrieved using SEM and CT scanning techniques that strengthen the purported link of a tommotiid sub-group, the tannuoliniids, with stem-group brachiopods such as *Mickwitzia* and the acrotretids. Generation of a comparative dataset based on broad high-resolution CT sampling of these enigmatic animals has also allowed investigation of patterns of growth and development in these early Cambrian organisms. Determining suites of homologous characters through such a comparative approach allows us to unravel the pattern of tommotiid inter-relationships and their affinities to extant Lophotrochozoa.

Craniodental biomechanical character evolution within the Sauropodomorpha, and the influence of dietary evolution on gigantism

***David J. Button^{1,2}**

¹*University of Bristol*

²*Natural History Museum*

The Sauropodomorpha included the largest known terrestrial vertebrates and were the first dinosaur group to achieve a global distribution. This success is associated with the early adoption of herbivory by the group; in particular sauropod gigantism has been hypothesized to be related to specialization towards bulk-feeding and obligate high-fibre herbivory. A combination of biomechanical character analysis, osteological and myological reconstruction, finite-element modelling and comparative phylogenetic methods was employed in order to investigate the evolution of herbivory in this clade.

Results identify a functional shift towards increased cranial robustness, increased bite force and the onset of tooth occlusion at the base of the Sauropoda, consistent with a shift towards bulk-feeding. Convergent trends towards more specialized foraging apparatuses are observed in the Diplodocoidea and Titanosauriformes, potentially relating to ecological expansion of the latter following Diplodocoid extinction.



Modelling of craniodental character and body mass evolution demonstrates that these functional shifts are not correlated with shifts in evolutionary rate; evidence for coincident rate shifts in body mass and craniodental evolution is weak. Instead, the significant correlation of body mass and characters related to bite force and cranial robustness suggest a correlated-progression evolutionary mode, with positive-feedback loops between mass and dietary specializations fuelling sauropod gigantism.

Long-snouted lungfish and the variable dipnoan endocranium

Tom Challands¹ and Alexey Pakhnevich²

¹University of Edinburgh

²Russian Academy of Sciences · Paleontological Institute, Moscow

In 1963 Erik Stensiö suggested that the dipnoan brain ‘type’ had developed by the beginning of the Devonian and has not undergone any significant changes since that time. Here we present new data from the endocast of a long-snouted Upper Devonian lungfish, *Orlovichthys limnatis* from the Orel region of central Russia. This endocast demonstrates, along with other recently described Devonian dipnoan endocasts and endocasts of extant lungfish, that the dipnoan brain cavity is not and has not been held in evolutionary stasis since the beginning of the Devonian. This supports recent interpretations that dipnoan rates of morphological evolution persisted well beyond the Devonian as far as the split between the Neoceratodid–Lepidosirenid lineages. Furthermore, the new data from *Orlovichthys* presents the most exceptionally preserved hypophysial recess region of any fossil dipnoan, shedding light onto the function and homology of this structure in fossil Dipnoi.

Disparity trends in the shell shape of non-heteromorph ammonoids (Cephalopoda)

Matthew E. Clapham

University of California, Santa Cruz

The shape of non-heteromorph ammonoid shells can be described by simple geometric parameters, enabling quantification of conch shape and assessment of trends in disparity during successive replacements of dominant taxonomic groups, across mass extinctions, and with changes in prey, competitors, or predators. I collated measurements of shell diameter, whorl width and height, and umbilical diameter from published papers, totalling more than 8,200 Emsian–Maastrichtian specimens from over 2,500 species. I performed principal components analysis on dimensions normalised to shell diameter and quantified the disparity of shell shapes by the sum of variances. Shell-shape disparity peaked in the Early and Middle Permian, dropping precipitously with the shift to ceratite-dominated faunas in the Late Permian. Despite the high diversity of Mesozoic ammonoids, disparity never recovered to Paleozoic values. High Permian disparity partly resulted from the coexistence of prolecanitid and goniatite lineages, which had different shell shapes. However, goniatites alone had much more disparate shell shapes than ceratites or ammonites. Non-heteromorph ammonites rarely re-occupied morphospace characterized by high width:diameter ratio shells, previously occupied by goniatites, perhaps because that ecological niche was instead filled by heteromorph ammonites, by non-ammonoid competitors, or was unfeasible at the larger body sizes typical of ammonites.



Patterns of morpho-functional disparity during the explosive radiation of acanthomorph fishes

***Roger A. Close¹, Matt Friedman¹, Zerina Johansen², Hermione Beckett¹ and Dan Delbarre¹**

¹University of Oxford

²Natural History Museum

Three-dimensional fossil fishes from the Late Cretaceous (Cenomanian–Campanian) English Chalk and Eocene (Ypresian) London Clay have been known and collected for nearly two centuries. Despite excellent preservation, fishes from these exceptional localities have received little attention outside of monographs that are all now over 50 years old. The application of computed tomography (CT) has permitted us to efficiently extract considerable new morphological and functional information from large numbers of fossil fishes from the English Chalk and the London Clay. In addition to providing a wealth of anatomical information on early representatives of many major eurypterygian lineages, CT scanning 3D fish crania permits the acquisition of: 1) data on morphological shape variation that is lost in compression fossils; 2) functional and ecomorphological measurements previously only accessible from neontological datasets. Harnessing the mature framework for quantifying feeding ecomorphology in fish allows us to critically test previous hypotheses relating to changes in functional diversity between the Mesozoic and Cenozoic in acanthomorph (spiny-finned) teleosts, one of the most successful radiations of modern vertebrates. Using ground-truthed measures of biomechanical performance, we show a substantial increase in acanthomorph cranial functional diversity between the Late Cretaceous and Eocene, corroborating inferences drawn from sparse cranial landmark constellations applied to taphonomically flattened material from other localities.

A diverse late Ediacaran skeletal fossil assemblage from central Spain

***Iván Cortijo Sánchez, Mónica Martí Mus, Sören Jensen and Teodoro Palacios**

Universidad de Extremadura, Badajoz

Knowledge of late Ediacaran (*ca.*551–541 Ma) skeletal fossils is critical to unravel the earliest evolution of animals, including the acquisition of biomineralised hard parts. However, fossils of this age are scarce and their diversity remains poorly known. Late Ediacaran platform carbonates from the Ibor Group in the area of Villarta de los Montes, central Spain, have recently yielded a diverse skeletal fossil assemblage. Fossils occur as moulds in siliciclastic levels and mineralised (preserving a carbonatic composition or secondarily pyritised or phosphatised) in carbonate beds. The assemblage is dominated by *Cloudina*, a millimetric tubular fossil consisting of stacked funnel-shaped elements. Two species, *C. bartmannae* and *C. carinata*, that differ both in funnel morphology and imbrication pattern, are present. Particularly well-preserved *C. carinata* have also been found in related olistostromic levels within the Valdelacasa anticline. The Villarta de los Montes assemblage also includes the first *Simotubulites baimatuoensis* specimens from north-west Gondwana. *Simotubulites* is a millimetric fossil with a tube-in-tube construction and a folded, irregular ornamentation in the outermost layers. Small, winding tubular fossils and flask-shaped fossils similar to *Protolagena* have been also observed. Such relatively high diversity in a late Ediacaran assemblage has been previously described only from South China.



Enameloid microstructure in sharks and bony fishes: What do we really know?

Gilles Cuny¹, Sébastien Enault², Guillaume Guinot³ and Martha Koot⁴

¹UMR CNRS 5276, University Claude Bernard 1, France

²UMR CNRS 5554, University Montpellier 2, France

³Department of Geology and Palaeontology, Natural History Museum, Geneva, Switzerland

⁴25 Honicknowle Lane, Plymouth PL2 3QS, UK

Since the German palaeontologist Wolf-Ernst Reif's studies in the seventies, enameloid microstructure has been widely used to differentiate between teeth belonging to hybodont and neoselachian sharks despite a limited taxonomic scope. The recent discovery in cladodontomorph sharks of a Parallel Bundled Enameloid (PBE), a microstructural feature long supposed to be specific to neoselachian sharks, has blurred the use of this kind of structure for taxonomic purposes. To this, one should add a number of other recent observations that make the understanding of the evolution of this tissue even more complicated: a typical 'triple-layered' enameloid is absent in batomorphs, so that this structure is diagnostic of the Selachimorpha only, and not of the Neoselachii as a whole; the discovery of enameloid microstructures more complex than the usual Single Crystallite Enameloid (SCE) in hybodont sharks; a wide diversity of microstructures among ctenacanth sharks, going from very simple SCE to the presence of PBE; the strong resemblance between the enameloid microstructure of selachimorphs and the acrodine of some actinopterygian fishes. It is thus time to re-assess our understanding of the evolution of this hypermineralized tissue among fishes and to establish whether the current terminology really fits the variations observed.

Palaeoecology of benthic marine communities in the wake of the Late Permian mass extinction event

***William J. Foster¹, Richard J. Twitchett² and Silvia Danise³**

¹School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA. UK; Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD. UK

²Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD. UK

³School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA. UK

The Late Permian extinction event was the largest biotic crisis of the Phanerozoic and is associated with an extreme climate warming event. Here, we use multivariate analyses to investigate the temporal and environmental distribution of fossil benthic invertebrates from the Lower Triassic succession of the Aggtelek Karst, Hungary, which was deposited in a mixed siliciclastic-carbonate ramp setting on the northwestern margin of the Palaeotethys Ocean. There were no significant changes in α diversity or community structure through the Induan of the study site, and only minor differences with the Smithian. The Spathian communities, however, show significant increases in α diversity and the re-establishment of deep infaunal and erect tiers. Furthermore, the Spathian biofacies show a strict environmental control: siliciclastic inner ramp settings are characterised by low diversity assemblages whereas mixed carbonate-siliciclastic shoal to outer ramp settings show the greatest α diversity. Ecologically most of the Early Triassic assemblages were dominated by infaunal suspension feeders, apart from the mid-ramp setting during the Spathian which is characterised by slow-moving grazers. Our data, therefore, demonstrate the importance of



the depositional environment in the restructuring of benthic communities following the late Permian mass extinction event.

Phylogeny of the barnacles – combining molecular and morphological approaches

Andy Gale

University of Portsmouth

Models of barnacle evolution have been based largely on evidence from the ontogeny of living forms ('ontogeny recapitulates phylogeny') weakly supported by the sparse early fossil record of the group. New molecular phylogenies provide evidence of a very different evolutionary history, in which secondary character loss occurred a number of times, contradicting morphological hypotheses. The molecular approach works very well for this group which has undergone iterative parallel evolution.

However, much of early barnacle evolution is known only from fossil material and there is therefore a need to combine molecular and morphological datasets in order to reconstruct phylogeny. The first step to this approach has been to develop morphological trees which are congruent with the molecular ones; fossils can then be slotted into the morphological trees.

Using this methodology, it has proved possible to reconstruct major events in thoracican history, most notably the origin and early evolution of the sessilian barnacles (verrucomorphs and balanomorphs). The stalked scalpellomorphs are more problematical, as there is extensive paraphyly, and many taxa have no extant relatives. However, the broad evolutionary history of the group is becoming better known, and major events can be identified.

Use and misuse of cladistic matrices for morphospace analyses

Sylvain Gerber

University of Cambridge

Morphospaces have become standard tools in palaeobiology to analyse patterns of morphological evolution. Despite their common purpose, morphospaces gather a heterogeneous set of mathematical objects with unequal potential for biological inferences. Here, I focus on morphospaces constructed from discrete character data. These spaces have become increasingly popular in recent years. This trend mostly results from the exaptation of cladistic matrices as input data for carrying out disparity analyses. Cladistic matrices provide morphological descriptions of taxa as combinations of character states and thus appear (if not conceptually, at least mathematically) comparable to discrete character spaces found in numerical taxonomy. Hence, cladistic datasets seem to constitute an abundant source of data readily available for morphospace analyses. Discrete character spaces have been generally described as more flexible than morphospaces capturing continuous shape variation. The discrete coding of morphology allows morphospaces to accommodate more disparate morphologies, and the ability of discrete character frameworks to handle missing data is also often emphasized. This flexibility comes at a cost, however. Discrete character spaces have weaker geometric structures than their reduced-space ordinations suggest, and meaningful uses of distance-based approaches are not guaranteed. In this talk, I highlight some pitfalls and suggest possible ways to avoid them.



Exceptionally preserved Devonian actinopterygian skull presents a new model for early ray-fin evolution

***Sam Giles¹, Laurent Darras², Gaël Clément³ and Matt Friedman¹**

¹University of Oxford

²University of Leicester

³Muséum National d'Histoire Naturelle

Actinopterygians (ray-finned fishes) today account for over half of living vertebrate diversity, but their early evolution, particularly during the Devonian 'Age of Fishes', is poorly resolved. Despite recent advances in our understanding of the relationships and evolution of gnathostomes and sarcopterygians, comprehension of actinopterygian origins has changed little since detailed descriptions of *Mimipiscis* and *Moythomasia* were published three decades ago. Here we present an exceptionally preserved ray fin from the Late Devonian (Frasnian) of Northern France. This new taxon is represented by a single articulated specimen preserving a near-complete dermal cranium, braincase and articulated mandibular, hyoid and gill arches. The new actinopterygian displays many primitive ray fin characters, such as a notched jugal, short aortic canal bearing a prominent midline notch, long lateral dorsal aortae, an open spiracular canal, and poorly developed ascending processes of the parasphenoid. When combined with endoskeletal data from the braincase of *Cheirolepis*, the new taxon helps to paint a new picture of primitive ray fin cranial anatomy. Our results suggest that many anatomical aspects of *Mimipiscis*, which is often used as a model of a primitive actinopterygian, are specialized rather than generalities of the earliest ray-finned fishes.

A 3D approach: investigating dietary evolution in Archaeocete whales (Cetacea: Archaeoceti) using tooth microtextures

***Robert H. Goodall¹, Mark A. Purnell¹, Julia M. Fahlke² and Katharina A. Bastl³**

¹University of Leicester, Department of Geology, Leicester, UK

²Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany

³HNO-Klinik der Medizinischen Universität Wien, Forschungsgruppe Aerobiologie und Polleninformation, Vienna, Austria

The major dietary transition in whale evolution was from terrestrial omnivory/herbivory to aquatic piscivory/carnivory. This occurred between the evolution of the earliest Pakicetidae (early Eocene *ca.*52.5 Ma) and the emergence of crown group whales near the Eocene/Oligocene boundary (*ca.*33.7 Ma). Morphological analysis suggests an extensive mid-late Eocene semi-aquatic stem lineage, preceding obligate aquatic lifestyles in later stem clades. Isotope data suggest a rapid transition to the marine realm. Neither morphological nor isotope data reveal direct evidence of trophic ecology. Recent analysis of low magnification 2D tooth microwear suggests a subtle dietary shift to mixed semi-aquatic diets, similar to modern pinnipeds, in the cetacean stem lineage (early-mid Eocene), but quantitative 3D-microtextural analysis of tooth wear has the potential to reveal more details of ecological transitions in whale evolution. This approach is well established for dietary analysis in terrestrial mammals, but has not been applied to aquatic mammals. Statistical comparison and multivariate analysis of microtextures in extant pinnipeds and odontocete whales (including different dietary ecotypes of killer whale) combined with analysis of early fossil whales shows that microtextures of tooth wear vary with diet in aquatic mammals, allowing us to shed new light on the terrestrial-marine transition in whale evolution.



'Fish' (Actinopterygii and Elasmobranchii) diversification patterns through deep time

***Guillaume Guinot and Lionel Cavin**

Department of Geology and Palaeontology, Natural History Museum of Geneva, Switzerland

Direct reading of raw palaeobiodiversity curves is hampered by various biases affecting the fossil record quality. Hence, analytical approaches are needed to correct observed diversity patterns in order to achieve more realistic pictures of palaeobiodiversity variations. Because phylogenetic trees and stratigraphic ranges of corresponding terminal taxa provide two independent sets of data, comparing both datasets represents a unique way of testing the historical pattern of evolution. Although 'fish' groups represent the major component of marine and freshwater vertebrates since the Palaeozoic, patterns of the 'fish' evolutionary history remain largely unknown. This talk presents an assessment of various phylogenetic hypotheses for two major 'fish' groups: actinopterygians and elasmobranchs. Disparities and resemblances in the fossil record quality of both groups as well as within different ray-finned fish groups are discussed. Corrected family and genus-level palaeobiodiversity patterns are presented, critically reviewed and quantitatively assessed for both marine and freshwater taxa. Possible main drivers of observed major palaeodiversity events over the Meso-Cenozoic are proposed and discussed.

Loriciferan SCFs from the Cambrian of Canada: the origins of a meiofaunal phylum

Thomas H. P. Harvey¹ and Nicholas J. Butterfield²

¹*Department of Geology, University of Leicester*

²*Department of Earth Sciences, University of Cambridge*

Miniature animals that inhabit interstitial spaces in sediments (the meiofauna) are scarcely represented in the fossil record, and are often under-sampled in molecular phylogenetic analyses. Therefore, there are few constraints on the timings or mechanisms of their evolution. Here, we report miniature scalidophoran worms, with particular characters of the phylum Loricifera, from the Middle/Upper Cambrian Deadwood Formation of Saskatchewan, Canada. The specimens ($n = 72$) occur as small carbonaceous fossils (SCFs) extracted using hydrofluoric acid from mudrock. Most specimens consist of an empty cuticular lorica, but a few contain remnants of the introvert appendages (scalids), and one specimen preserves an intact introvert with several hundred scalids. Despite the adult morphology of the introvert, the total body length does not exceed $c.300 \mu\text{m}$, suggesting a meiofaunal ecology, as in modern loriciferans. At the same time, the fossils share some characters with extant larval priapulids and extinct 'macro-loricated' worms, consistent with loriciferans being miniaturized priapulids. We discuss the implications for ecdysozoan phylogeny and the evolution of the meiofauna.

Using growth models to test the vendobiont hypothesis for the Ediacara Biota

***Renee S. Hoekzema and Martin Brasier**

Department of Earth Sciences, University of Oxford

Although macrofossils from the Ediacara biota (575–542 Ma) have often been interpreted as containing the ancestors of various different metazoan clades, many were united by



Seilacher (1989) into a single clade he called the Vendozoa, on the basis of a shared, 'quilted pneu' manner of construction. We here test this 'vendobiont' hypothesis by comparing the growth mechanisms of macroscopic branches within three iconic and distinct Ediacaran fossil taxa: *Dickinsonia costata*, *Charnia masoni* and *Charniodiscus* spp. These have often been regarded as representatives of distinct clades. We find, however, that these three seemingly disparate forms share very similar modes of growth, involving not only apical insertion of branches either side of a growth axis but also branches that grew in two distinct stages. For every branch in each of these taxa, we can distinguish a juvenile phase of fast growth and a mature phase of slower inflationary growth, for which the ratio remains similar throughout ontogeny. Our evidence strengthens the view that many macro-organisms of the Ediacara biota should be re-considered as members of a single vendobiont clade, as yet lacking clear relationships with modern metazoan groups.

Eccentric conodonts from extreme environments: specialized biota of late Wenlock (Silurian) sabkhas

***Emilia Jarochowska and Axel Munnecke**

GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Conodonts are one of the key groups in Palaeozoic biostratigraphy and fossil-based geochemistry. Although biofacies models are well established for late Palaeozoic conodonts, they are nearly lacking for Silurian conodont faunas, resulting in sea-level and facies control over local conodont diversity being under-appreciated. We show an example from the latest Wenlock – the conodont record of this time is dominated by taxa representing highly specialized biofacies, characteristic for restricted, upcratonic settings.

The Ustya Formation, in Podolia, Ukraine, and Rootsiküla Formation in Estonia represent hypersaline, tidal carbonate settings dominated by dolomite-precipitating microbial mats. These evaporitic, periodically-emerged environments were hostile to most skeletal organisms except for rare eurypterids and ostracods. The only organisms to thrive in these conditions were stromatoporoids, porostromate problematica, and calcifying cyanobacteria. These extreme environments are associated with a distinct conodont fauna dominated by diverse species of *Ctenognathodus* characterized by large and robust elements.

Conodont diversity estimates for the late Wenlock indicate a major drop in the taxonomic richness and shift towards low-diversity assemblages, followed by slow recovery at the Wenlock/Ludlow boundary. These estimates appear to be biased by the coincident eustatic sea-level fall resulting in a wider spread of shallow-water depauperate conodont biofacies and, in extreme cases, monospecific *Ctenognathodus* faunas.



The cause of late Cenozoic mass extinction in the western Atlantic: insights from sclerochronology

Andrew L. A. Johnson¹, Annemarie Valentine¹, Melanie J. Leng², Donna Surge³ and Mark Williams⁴

¹*Department of Natural Sciences, University of Derby, Derby DE22 1GB, UK*

²*NERC Isotope Geosciences Laboratory, Keyworth, Nottingham NG12 5GG, UK*

³*Department of Geological Sciences, University of North Carolina, Chapel Hill, NC 27599-3315, USA*

⁴*Department of Geology, University of Leicester, Leicester LE1 7RH, UK*

Heavy late Cenozoic extinction amongst marine molluscs in the western Atlantic has traditionally been interpreted as a consequence of climatic deterioration. However, the pattern of extinction was not the same in the eastern Atlantic, where conditions also became colder. A fall in primary productivity, suggested by a decline in phosphate deposition, may be the real explanation for western Atlantic extinctions. Evidence in support comes from isotopic- and increment-based (sclerochronological) indications of growth rate in Pliocene scallops. A western Atlantic genus that has survived to the present (*Placopecten*) had the same moderate growth rate in the Pliocene as now, while two genera that became extinct (*Carolinapecten* and *Chesapeakepecten*) had growth rates as fast as any known amongst living scallops. Such rapid growth implies abundant food. Selective extinction of a fast-growing species has also been documented amongst Pliocene oysters in the Caribbean region and attributed to a decline in primary productivity. The likely cause of this is the development of the Central American Isthmus and the consequent reorganization of oceanic circulation in the Gulf of Mexico and wider North Atlantic.

Implications for the foraminifera over the Toarcian (Early Jurassic) Oceanic Anoxic Event (TOAE), following development of the freeze-thaw extraction technique

***Alice E. Kennedy and Angela L. Coe**

The Open University

The Toarcian Oceanic Anoxic Event (TOAE) is marked by the widespread deposition of organic-rich mudrocks and pronounced changes in palaeoenvironmental conditions. The interval between the Pliensbachian/Toarcian boundary and the TOAE is associated with a mass extinction. Microfossils, including foraminifera, are highly sensitive to the environment around them and therefore suitable as a proxy for examining the impacts of palaeoenvironmental change. This study has investigated a range of processing techniques for the extraction of foraminifera from organic-rich mudrocks, using samples from the TOAE on the North Yorkshire coast. These included the widely-used hydrogen peroxide (H₂O₂) and a modification of the freeze-thaw technique. Those processed with H₂O₂ contained fewer foraminifera, lower diversity and damaged tests (Kennedy and Coe, 2014). In this presentation we will show the results from our modified freeze-thaw technique (Kennedy and Coe, 2014) which call into question the previously observed changes in foraminifera: including size decrease, lower diversity and barren interval associated with the TOAE that may be an artefact of sampling and processing. Our study highlights the importance of high resolution sampling and careful extraction techniques, and has implications for other microfossil groups when they are in low abundance.



High-resolution of the Changhsingian succession in Iran and correlation with China

Dieter Korn¹, Abbas Ghaderi², Lucyna Leda¹ and Martin Schobben¹

¹Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany

²Department of Geology, Faculty of Sciences, Ferdowsi University of Mashhad, Mashhad-Iran

We investigated the Changhsingian Stage in six sections in the area of Julfa (Aras Valley) for their lithology (petrography and carbonate facies), geochemistry (stable isotopes), conodonts and ammonoids. Revision of the biostratigraphy led to the separation of ten Changhsingian conodont zones and eight ammonoid zones. This refined scheme serves as a basis for studies on the proximate causes of the end-Permian mass extinction. The detailed subdivision of the Changhsingian by means of ammonoids has some potential for the correlation of sections within the Tethyan realm. However, ammonoids have only rarely been used for the correlation of the Transcaucasian/Iranian with the Chinese sections, but nevertheless they played a role in discussions about the completeness or incompleteness of the central Tethyan sections. This resulted in the statement that the Iranian assemblages represent only the lower part of the Changhsingian. Correlation of the Late Permian ammonoid successions in Iran and China reveals major problems, which are rooted in the significant differences of the assemblages on the family level. The morphological differences demonstrate that, in terms of sutural development (notching of individual lobes), the Tethyan forms are even more advanced than the Chinese forms.

Favourable impressions: ammonoid taxonomy and biostratigraphy in the Carboniferous Shannon Basin, Western Ireland

***Anthea Lacchia**

Trinity College Dublin

In the Carboniferous Shannon Basin, Western Ireland, ammonoids are largely preserved as 2D moulds. Taxonomy of 2D ammonoids relies on knowledge of shell ornament which varies with ontogeny. A detailed study of ontogenetic changes, based on the systematic description of 3D shells, is needed in order to provide robust taxonomic identifications but is not yet available for many ammonoids in the basin, whose fill spans part of the Alportian and Kinderscoutian substages.

Ammonoids are present throughout the succession, but are concentrated in thin dark shales, which are thought to represent intervals of sediment starvation and are referred to as condensed sections or ‘ammonoid bands’.

The make-up of the ammonoid assemblages in these bands shows that, while some bands are distinctive and useful in both intrabasinal and extrabasinal correlation, the faunas of others are far more diverse than previously thought. This puts into question the idea of a series of discrete, widespread ammonoid bands in the regional Namurian Stage, each with a diagnostic assemblage.



The Winneshiek Lagerstätte (Middle Ordovician, Darriwilian) of Iowa yields the oldest known eurypterids

***James C. Lamsdell**¹, **Derek E. G. Briggs**^{1,2} and **Huaibao P. Liu**³

¹*Department of Geology and Geophysics, Yale University, New Haven, CT, USA*

²*Yale Peabody Museum of Natural History, New Haven, CT, USA*

³*Iowa Geological Survey, University of Iowa, Iowa City, IA, USA*

The Winneshiek Lagerstätte, which occurs in the Decorah meteorite impact crater in northeast Iowa, has yielded a diverse fauna including conodont assemblages, early vertebrates, brachiopods, phyllocarids, and large eurypterids. The eurypterids are preserved as carbonaceous cuticle and probably represent exuviae. They are the oldest recorded members of the group, predating the previously known earliest occurrence by about eight million years. Preliminary study of approximately 300 specimens has revealed the presence of at least two species. The ornamentation of the large body segments of the more common species and the nature of fragments of cercal blades indicate an affinity with *Megalograptus*. The prosomal doublure and posterior appendages, however, more closely resemble those of Carcinomatidae, suggesting that the species is a basal megalograptid or intermediate between the two groups. The second species appears related to *Orcanopterus*, another Ordovician predatory form known from Canada. These taxa are relatively derived within eurypterid phylogeny, and their presence in the Middle Ordovician hints at an explosive radiation earlier in the Ordovician or a cryptic Cambrian radiation. Early North American eurypterids appear to be limited to members of two clades and may represent successful immigrants from less well-sampled palaeobiogeographic regions.

Dark and disturbed or just disturbed? Modelling thermal tolerance to determine habitat preferences in early angiosperms

***Alexandra P. Lee**

The University of Nottingham

Despite more than a century of research, some key aspects of habitat preference and ecology of the early angiosperms remain poorly constrained. Proposed ecology has varied widely from opportunistic weedy species growing in full sun to slow-growing species limited to the shaded understory of gymnosperm forests. Evidence suggests that the earliest angiosperms possessed low transpiration rates – the gas exchange rates for extant basal angiosperms are low, as are the reconstructed gas exchange rates for the oldest known angiosperm leaf fossils. Leaves with low transpirational capacity are vulnerable to overheating in full sun, favouring the hypothesis that early angiosperms were limited to the shaded understory. Here, modelled leaf temperatures are used to examine the thermal tolerance of some of the earliest angiosperms. Our results indicate that small leaf size could have mitigated low transpirational cooling capacity of many early angiosperms, enabling many species to survive in full sun. We propose that during the earliest phases of angiosperm evolution, angiosperms were not limited to the understory and that some species were able to compete with ferns and gymnosperms in both shaded and sunny habitats, especially in the absence of competition from more rapidly growing and transpiring advanced lineages of angiosperms.



Automated generation of large phylogenies and a probabilistically time-scaled 1,000-taxon phylogenetic hypothesis for Mesozoic dinosaurs: dating the origins of flight and crown-birds

Graeme T. Lloyd¹, David W. Bapst², Katie E. Davis³ and Matt Friedman⁴

¹*Macquarie University*

²*South Dakota School of Mines and Technology and University of California Davis*

³*University of Bath*

⁴*University of Oxford*

Generating phylogenies that sample large numbers of fossil taxa remain challenging for palaeontology. Here we outline a novel approach that implements several methodological improvements over previous 'supertree' approaches, including: 1) increased automation; 2) increased input tree information; 3) inclusion of greater taxonomic data; 4) weighting of non-independent data sets; 5) up-weighting of more recent studies, and 6) safe taxonomic reduction. We apply these new techniques to 663 cladistic analyses of Mesozoic dinosaurs to produce a phylogenetic hypothesis containing over 1,000 taxa.

The resulting tree was used to compare two different phylogenetic dating techniques (cal3 and a novel method that uses successive outgroup ages) to ask: 1) What is the probability that dinosaurs emerged prior to the end-Permian mass extinction?; 2) When did avian flight first evolve?; 3) When did crown birds originate?

In both cases a pre-Mesozoic origin for dinosaurs cannot be rejected at an alpha of 0.05. Other estimates agree closely, with avian flight estimated at 152.39–172.69 Ma or 156.6–167.9 Ma, and crown-birds estimated at 70.12–107.52 Ma or 70.7–97.8 Ma (95% CIs). This last set of dates is younger than typical molecular clock estimates and suggests elevated rates of molecular evolution at the base of the extant dinosaur radiation.

Post-Chicxulub radiation and dispersal of Worm Lizards (*Amphisbaenia*)

***Nicholas R. Longrich¹, Jakob Vinther², Alexander Pyron³, Davide Pisani² and Jacques Gauthier⁴**

¹*University of Bath*

²*University of Bristol*

³*George Washington University*

⁴*Yale University*

Amphisbaenians, or worm-lizards, are burrowing squamates that are highly specialized for life as subterranean predators. Their underground existence would seem to limit dispersal, and yet worm lizards are widespread throughout Europe, North America, Africa, South America, and the Caribbean. This pattern was traditionally explained by continental drift, with modern distributions resulting from Mesozoic fragmentation of Pangaea. However, molecular data and fossils suggest a Paleogene radiation. Phylogenetic analysis, combining molecular and morphological data, including fossils from Europe, Africa and North America, shows that worm lizards originated in North America, then radiated in the Paleocene in the wake of the K-Pg mass extinction. This scenario requires three trans-Atlantic dispersals: one from North America to Europe, one from North America to Africa, and one from Africa to South America and the Caribbean. Rafting in tree root-balls or in rafts of vegetation is the most likely mechanism of dispersal. The amphisbaenians provide



a striking case study in biogeography, and suggest that the role of continental drift in biogeography is overstated. Instead, the patterns seen here support Darwin and Wallace's hypothesis that the geographic ranges of modern clades result from dispersal, including trans-oceanic rafting. Mass extinctions may facilitate dispersal events by eliminating competitors and predators that would otherwise prevent dispersing populations from becoming established.

Solving Darwin's Dilemma? Differential taphonomy reveals tissue biochemistry dependence of mould/cast exceptional fossil preservation

***Breandán Anraoi MacGabhann^{1,2,3}, James D. Schiffbauer⁴, James W. Hagadorn⁵, Peter Van Roy⁶, Edward P. Lynch^{3,7}, Liam Morrison³ and John Murray³**

¹*Department of Geography, Edge Hill University*

²*School of GeoSciences, The University of Edinburgh*

³*Earth and Ocean Sciences, National University of Ireland, Galway*

⁴*Department of Geological Sciences, University of Missouri*

⁵*Department of Earth Sciences, Denver Museum of Nature & Science*

⁶*Department of Geology and Geophysics, Yale University*

⁷*Geological Survey of Sweden*

Molecular palaeontology suggests that animals emerged nearly 800 million years ago – perplexingly, over 200 million years before the oldest known megascopic fossils. The enigmatic cast-and-mould siliciclastic preservation of these first fossils is widespread in Neoproterozoic deposits, suggesting a predominance of taphonomic conditions unlike those on the present-day Earth.

However, by examining and comparing fossil eldonids preserved as moulds and casts in the Ordovician Tafilalt Lagerstätte in Morocco, and as compressions in the Burgess Shale, we have shown the former taphonomic mode to depend on the formation of aluminosilicate and/or iron sulphide moulds on specific organic surfaces. This occurs via adsorption of reduced iron ions onto tissues composed primarily of high molecular weight biopolymers which require enzymatic degradation prior to decay, and nucleation of sulphides or aluminosilicates around adsorbed ions. Animals lacking tissues primarily composed of such high molecular weight biopolymers, which must have included the first animals to evolve, thus could not have been fossilized in this style. Understanding the origin and earliest evolution of metazoans will therefore require a focus on alternative modes of fossilization.

Burgess Shale-type preservation of 'shelly' metazoans

Mónica Martí Mus

Universidad de Extremadura, Badajoz

Most studies of Burgess Shale-type preservation have understandably focused on soft-bodied organisms, but 'shelly' metazoans are also preserved as carbonaceous films. Common examples include brachiopods, trilobites, spiculate sponges and hyolithids. In such cases, the carbonaceous films are usually interpreted as coherent organic layers that were originally present in the mineralised elements, mostly external sheaths or periostacal layers. Using the example of hyolithids it is shown that these films do not represent original cuticular 'layers'. Instead, they are a composite carbonaceous compression resulting from



the coalescence of all the preservable organic matter originally present in the skeletal element. The diagenetic processes that led to Burgess Shale-type preservation (which involve the polymerisation of organic matter and the loss of original internal structure and chemical integrity of the original tissues) are compatible with, and can account for, the characteristics observed in the fossil films of hyolithid skeletal elements. These observations have general implications for the interpretation of other mineralised organisms, such as the diverse and often problematic Cambrian sponges. The observations summarised in this work suggest that all sponge spicules, regardless of their original mineralogy or precise phylogenetic affinities, could be preserved as carbonaceous films.

Systematic excavation in the Lower Ordovician Fezouata Lagerstätte (Zagora area, Morocco)

***Emmanuel L. O. Martin**¹, **Ninon Allaire**², **Abdelfattah Azizi**³, **Khadija El Hariri**³, **Khaoula Kouraiss**³, **Juan Carlos Gutiérrez-Marco**⁴, **Bertrand Lefebvre**¹, **Rudy Lerosey-Aubril**¹, **Ahmid Hafid**³, **Moussa Masrouf**⁵, **Elise Nardin**⁶, **Bernard Pittet**¹, **Abel Prieur**¹, **Emmanuel Robert**¹, **Peter Van Roy**⁷, **Jean Vannier**¹, **Romain Vaucher**¹, **Muriel Vidal**⁸ and **Daniel Vizcaino**⁹

¹*Laboratoire de Géologie de Lyon: Terre, Planètes, Environnement (UMR 5276, CNRS), Université Claude Bernard Lyon 1, Villeurbanne, France*

²*Laboratoire Géosystèmes (UMR 5217, CNRS), Université Lille 1, Villeneuve d'Ascq, France*

³*Faculté des Sciences et Techniques, Université Cadi Ayyad, Marrakech, Morocco*

⁴*Instituto de Geociencias (CSIC, UCM), 28040 Madrid, Spain*

⁵*Faculté des Sciences, Université Ibn Zohr, Agadir, Morocco*

⁶*Géosciences Environnement Toulouse, Observatoire Midi-Pyrénées, Toulouse, France*

⁷*Department of Geology and Geophysics, Yale University, New Haven, CT 06511, USA*

⁸*Département des Sciences de la Terre, Université de Bretagne Occidentale, Brest, France*

⁹*Maquens, Carcassonne, France*

The Lower Fezouata Formation (Lower Ordovician, Morocco) has yielded a remarkably diverse exceptionally-preserved biota, which provides unique insights into the transition between the Cambrian and Palaeozoic Evolutionary Faunas. Until recently, fossils from these deposits were collected from small isolated excavations, the stratigraphic positions of which relative to one another were poorly constrained. These collections were also biased by a greater interest for non-biomineralized fossils. This approach has been fruitful for documenting the diversity of the biota, but it does not permit exploration of the spatial and stratigraphic evolution of fossil assemblages. To address this question, we initiated a long-term systematic excavation at Bou Izargane, a locality exposing an 18 m-thick section within one of the two stratigraphic intervals with exceptional preservation recently identified within the Lower Fezouata Formation. Our first campaign has shown that exceptional preservation occurs in three discrete horizons within the section, each preserving an abundant but weakly diverse fauna. These characteristics are suggestive of episodes of environmental stress, as are the presence of abnormally small trilobites or the abundance of stylophorans. Ongoing sedimentological and geochemical studies will provide new data on the environmental context that facilitated soft-tissue preservation in these deposits.



Sediment permeability and exceptional preservation within concretions

***Victoria E. McCoy¹, Robert T. Young² and Derek E. G. Briggs¹**

¹*Yale University*

²*Clark Energy Group*

Concretions are an important source of soft-bodied fossils. In order to determine the controls on exceptional fossilization within concretions, we scored 88 concretion-bearing sites for different states of 11 variables, and analyzed their effects on the presence/absence of soft-tissue preservation using qualitative logistic regression. Fine-grained host lithology correlates with the presence of soft-tissue preservation, suggesting that low permeability sediments promote soft tissue fossilization within concretions by: 1) inhibiting decay and 2) promoting the precipitation of authigenic minerals. We tested these two effects with decay experiments on fish tissue in glass beads of three different sizes and therefore of different permeability. We measured decay using infrared gas analysis and mineral precipitation using micro CT scanning. The results showed that decay is inhibited and mineral precipitation enhanced in lower permeability sediments. Thus a process of positive feedback promotes exceptional preservation during concretion formation where decay is inhibited and early cementation results in a rapid decrease in permeability.

A fight for survival: Megalodon vs the Great White shark

***Laura McLennan and Mark A. Purnell**

Department of Geology, University of Leicester, Leicester, UK

The Great White Shark (*Carcharodon carcharias*) and the extinct Megalodon (*Carcharocles megalodon*) have iconic status as oceanic apex predators. Recent research suggests that Megalodon was driven to extinction through dietary competition with Great Whites during the early Pliocene. This hypothesis is controversial, not least because evidence of competitive replacement in the fossil record is extremely rare. Current consensus, based on tooth morphology, is that both species consumed large marine mammals. Tooth morphology alone, however, cannot provide enough evidence for dietary competition between these species. Here we test the hypothesis of dietary competition using newly developed 3D-microtextural analyses of teeth.

Microtextural analysis has never been applied to sharks, but our analysis of extant Lamniform sharks reveals that 3D-microtextures vary with diet. Application of the same methods to Megalodon and Great White shark teeth, from the same sedimentary horizons, allows us to test the hypothesis that their diets were the same, thus addressing the question of dietary competition between the two. This study provides the first non-morphological evidence of diet in Megalodon and Great Whites, and the first 3D-microtextural analysis of fossil shark teeth. This approach opens the gateway for further analysis of dietary influence on evolutionary patterns in fossil sharks.



Non-actualistic Ediacaran conditions drove the formation of Salter's (1856) Longmyndian discoidal fossils

***Latha R. Menon¹, Duncan McIlroy², Alexander G. Liu³ and Martin D. Brasier^{1,2}**

¹*Department of Earth Sciences, University of Oxford, South Parks Road, Oxford OX1 3AN, UK*

²*Department of Earth Sciences, Memorial University of Newfoundland, St John's, NL, A1B 3X5, Canada*

³*School of Earth Sciences, University of Bristol, Life Sciences Building, 24 Tyndall Avenue, Bristol BS8 1TQ, UK*

Discoidal impressions are often presented as evidence of complex life deep in the Neoproterozoic. This study demonstrates the wide dynamic effect of microbial mats on Ediacaran sediments, and the importance of allowing for non-actualistic processes when interpreting ancient discoidal impressions. The discoidal impressions in late Precambrian rocks of the Long Mynd, Shropshire, UK, were first described in the mid 19th century by John Salter as evidence of the activity of metazoans. Darwin mentions these 'traces of life' below the Cambrian in *The Origin*. Although their biogenicity has subsequently been debated, they have recently been regarded as showing affinities with the Ediacaran taxa *Medusinites*, *Beltanelliformis* and *Intrites*. We here present a reassessment of several discoidal forms observed in the c.560 Ma, marine upper Burway Formation of the Longmyndian Supergroup at Ashes Hollow. We show that all these discs can be explained as surface expressions of a fluid escape regime operating at millimetre scales – far smaller than most injection features – and driven by the sealing effect of microbial mat layers. The mats also influence the shapes of the discoidal impressions, now recognized as pseudofossils. Ornaments such as radial grooves, central bosses, and lobes are insufficient in themselves to demonstrate biogenicity.

Denticle Déjà Vu, and the Evolution of Speed

***Tom Merrick-Fletcher¹, John D. Altringham², Jeff Peakall¹, Paul B. Wignall¹, Robert M. Dorrell¹ and Gareth M. Keevil¹**

¹*School of Earth and Environment, University of Leeds*

²*School of Biology, University of Leeds*

Thelodont and acanthodian scales exhibit remarkable convergence with those of modern sharks, whose functions include drag reduction, abrasion defence, parasite resistance, and luminescence. Of these, drag-reduction has been a focus in biomechanical and engineering investigations, particularly the riblets that ornament the dermal denticles of pelagic sharks. These structures are known to reduce skin friction by up to 10%, improving the efficiency and speed of movement. Modern shark scales have significantly narrower riblet spacing in faster-moving species, implying a functional optimum for higher speeds. Furthermore there is no significant difference between the riblet spacing of fast modern sharks, thelodonts, and acanthodians.

More broadly, scales along the flank may be inducing turbulent flow on purpose to delay boundary layer separation (stall), and reduce wake. To test this, and the efficacy of riblets in fossil taxa, flume studies were performed on plates of rapid prototyped Palaeozoic fish scales. Laser Doppler anemometry revealed that the majority of morphologies did not reduce flow velocity relative to the smooth control plate. This suggests that even without riblets ornamenting the crowns, having a rougher scale surface helps reduce drag. Our results demonstrate that novel and sophisticated drag-reduction adaptations existed at a remarkably early stage of vertebrate evolution.



Recognising the reproductive mode of *Fractofusus* through spatial analysis

***Emily G. Mitchell, Alexander G. Liu, Charlotte G. Kenchington and Nicholas J. Butterfield**

University of Cambridge

Fractofusus is one of the most distinctive members of the Rangeomorpha, a clade of fractally branching Ediacaran macroscopic fossils that has defied palaeobiological resolution. *Fractofusus* positions were mapped out on three bedding planes ('D' and 'E' Surfaces, Mistaken Point and H14 surface, Bonavista Peninsula) in Newfoundland, Canada (565–570 Ma), allowing spatial distributions to be analysed and shedding light on their reproductive biology. For each bedding plane, the spatial patterns of fossils were described using pair correlation functions and the patterns were compared with different types of clustering models. All three of the *Fractofusus* populations were found to exhibit recurrent, species-specific spatial clustering indicative of reproductive processes. On 'E' and H14 we identified three generations of *Fractofusus*, but only two on 'D'. Where body-size was recorded (H14), *Fractofusus* specimens in the smallest size class preferentially cluster around those in the medium size class, which preferentially cluster around those in the largest size class. Comparison of pair correlation functions, cluster directionality and mean cluster radius suggest that *Fractofusus* grew via a process of stolon-like reproduction, similar to that seen in plants that propagate via asexual runners. The identification of this reproduction strategy represents a fundamental new level of palaeobiological understanding of rangeomorphs.

Turtle diversity in the Mesozoic

***David B. Nicholson¹, Roger B. J. Benson², Patricia A. Holroyd³, Matthew T. Carrano⁴ and Paul M. Barrett¹**

¹*The Natural History Museum, London, UK*

²*University of Oxford, UK*

³*University of California, Berkeley, USA*

⁴*National Museum of Natural History, Smithsonian Institution, Washington DC, USA*

Turtles have successfully endured for over 220 million years through several major environmental perturbations. Inhabiting marine, freshwater and terrestrial environments, abundant as fossils, with a well-established taxonomy and well-understood habitat preferences, turtles are a model system for studying the responses of ectothermic vertebrates to long-term environmental change. However, few studies have documented long-term trends in richness in the context of sampling biases, biotic events, or environmental change. Mesozoic chelonian occurrences downloaded from the Paleobiology Database (PBDB) (comprising 1,706 genus-level occurrences in 1,012 PBDB collections) were analysed to remove sampling biases, providing fair estimates of changes in Mesozoic turtle diversity, using Shareholder Quorum Subsampling (SQS). Uncorrected data show a general increase in diversity through the Mesozoic, however the Jurassic and earlier Cretaceous mainly comprises data from Asia and Europe whereas North American records dominate the latest Cretaceous. SQS analyses of continental records indicate that turtle diversity in Early Cretaceous Europe was comparable to the North American latest Cretaceous, suggesting that apparent exponential increase in turtle global diversity through the Cretaceous is an artefact of sampling biases. The sharp increase in North American diversity towards the K-Pg boundary is genuine and matched by a similar increase in Asia.



Derived ornithopod dinosaurs: a case of evolutionary parallelism and convergence

David B. Norman

University of Cambridge

Derived ornithopod dinosaurs were abundant and widespread geographically during the latter half of the Mesozoic Era. Recent discoveries and new research on iguanodontians from the Wealden of southern England have led to alterations to the systematics and implied phylogeny of these dinosaurs. As a consequence it is now necessary to revise current understanding of the taxonomic content of the clade Iguanodontia, and to recognise a distinct higher-order clade of clypeodonts that are divisible into the Hypsilophodontia and Iguanodontia. Hypsilophodontia is a clade that includes ornithopods such as the eponymous *Hypsilophodon*, as well as rhabdodontids, *Muttaborrasaurus* and *Tenontosaurus*. In marked contrast, the clade Iguanodontia includes *Iguanodon*, dryosaurids, camptosaurus and a wide range of styracosternan ornithopods, culminating in the abundant and diverse euhadrosaurids of the Late Cretaceous. Both hypsilophodontians and iguanodontians diversified and produced animals of medium-to-large body size independently; as a consequence these animals display a tendency to converge anatomically because their bodies were subjected to similar biomechanical regimes.

Teasing apart anatomical convergence from the phylogenetic signal is instructive because it offers insights into the processes of biological evolution and diversification within clades of animals that were dominant in the terrestrial environment during the Mesozoic.

Decoupling of the terrestrial and marine record during the Eocene–Oligocene transition

***Matthew J. Pound and Ulrich Salzmann**

Northumbria University

The Eocene–Oligocene transition is a key step from the greenhouse to the icehouse world. Geochemical marine records show both surface and bottom water cooling, associated with the expansion of Antarctic glaciers. However, the global response of the terrestrial biosphere is less well understood. We present new global vegetation and climate reconstructions of the Priabonian (late Eocene; 38–33.9 Ma) and Rupelian (early Oligocene; 33.9–28.45 Ma) to explore the terrestrial response.

By synthesising 215 pollen and spore localities into an ArcGIS-Microsoft Access database it has been possible to investigate global vegetation changes in response to the Eocene–Oligocene transition. Using presence/absence data of pollen and spores with multivariate statistics has allowed the reconstruction of vegetation groups without relying on modern analogues, such as biomes. The reconstructed vegetation groups show no geographic change from the Priabonian to the Rupelian. Reconstructions of mean annual temperature show no statistically significant difference between the Priabonian and the Rupelian. Our new reconstructions differ from previous global syntheses and our terrestrial-based climate reconstructions are in stark contrast to marine-based climate estimates. Our results raise new questions on the nature and extent of global climate change at the Eocene–Oligocene transition.



Function and evolution of theropod jaws

Emily J. Rayfield¹, Roger B. J. Benson² and Philip S. L. Anderson³

¹University of Bristol

²University of Oxford

³Duke University

Ecomorphological variation can be used as a proxy for variation in feeding ecology in extinct animals, where behaviour cannot be directly observed. Whether inferences from ecomorphology are congruent with inferences of feeding behaviour from biomechanical analysis within clades is unclear. Here we use Geometric Morphometrics (GMM) and finite element (FE) modelling to discern the variation in mandibular shape and function in non-avian theropod dinosaur taxa. Six two-dimensional landmarks and 50 semilandmarks were used to capture the variation in jaw shape from 103 taxa. Principal Component Analysis (PCA) demonstrates that the largest proportion of variation is explained by changes in jaw robustness (mandibular length and depth), with a change in the relative size of coronoid process playing a key role. Oviraptorids are morphologically and biomechanically distinct to all other taxa in the analysis (NPMANOVA, $p < 0.05$). There is some partitioning of taxa based on feeding ecology, with supposed omnivorous and herbivorous taxa occupying statistically distinct regions of morphospace from carnivorous taxa (NPMANOVA, $p < 0.05$). We find that jaw strength is tied to morphological variance, and demonstrate how changes in morphology influence the feeding capabilities of the theropod jaw.

Epibioses of fossil crustaceans: insights on specific palaeoecology and true palaeosymbioses

***Ninon Robin¹, Sylvain Charbonnier², Barry Van Bakel³, Sylvain Bernard⁴, Jennyfer Miot⁴ and Gilles Petit¹**

¹Muséum national d'Histoire naturelle, Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements CNRS-MNHN-UPMC, 8, rue Buffon, 75005 Paris

²Muséum national d'Histoire naturelle, Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements CNRS-MNHN-UPMC, 8, rue Buffon, 75005 Paris

³Oertijdmuseum De Groene Poort, Bosscheweg 80, NL-5283 WB Boxtel

⁴Université Pierre et Marie Curie, UMR 7202, CNRS-MNHN-UPMC-IRD, Institut de minéralogie, de physique des matériaux et de cosmochimie, 4 place Jussieu, 75005 Paris

Because their study may reveal possible palaeosymbioses, organisms fossilized in direct association deserve a true consideration. However, their *syn-vivo* or *post-mortem* nature is not always obvious. Focusing on decapod crustaceans as hosts, we report here two studied kind of epibioses: a case of *post-mortem* meeting which brings insights on the palaeoecology of associated organisms, and a true palaeosymbiosis. The first epibiosis involves one of the earliest brachyuran crabs of the world and two bryozoan colonies fixed on its dorsal side. We described this precious Bathonian crab (Sarthe, France) and placed it within the Homolodromioidea. Systematic, sizes and structures of the bryozoan colonies demonstrate their *post-mortem* settlement on the crab, enabling us to conclude on a probable higher thickness of the carapace of Homolodromioidea in the past than today. A cohabitation of hermit crabs in the palaeoenvironment of this crab may also be presumed. The second epibiosis, described in both fossil (La Voulte Lagerstätte, France) and extant record, involves calcifying bacterial colonies living on Penaeoidea shrimps. This association



has been identified as a *syn-vivo* one, and shows even parasitic features. These studies show the ability of punctual fossil epibioses to reveal aspects of both palaeoenvironments and life habit of associated organisms.

Unlocking geological and sea-level biases reveals cryptic evolutionary history of early vertebrates

Robert Sansom¹, Emma Randle¹ and Philip C. J. Donoghue²

¹*University of Manchester*

²*University of Bristol*

The fossil record of early vertebrates has been influential in elucidating the evolutionary assembly of the gnathostome bodyplan. Understanding of the timing and tempo of vertebrate innovations remains, however, mired in a literal reading of the fossil record. Early jawless vertebrates (ostracoderms) exhibit restriction to shallow-water environments. The distribution of their stratigraphic occurrences therefore reflects not only flux in diversity, but also secular variation in facies representation of the rock record. Using stratigraphic, phylogenetic and palaeoenvironmental data, we assessed the veracity of the fossil records of the jawless relatives of jawed vertebrates (Osteostraci, Galeaspida, Thelodonti, Heterostaci). Non-random models of fossil recovery potential using Palaeozoic sea-level changes were used to calculate confidence intervals of clade origins. These intervals extend the timescale for possible origins into the Upper Ordovician; these estimates ameliorate the long ghost lineages inferred for Osteostraci, Galeaspida, and Heterostraci, given their known stratigraphic occurrences and stem-gnathostome phylogeny. Diversity changes through the Silurian and Devonian were found to lie within the expected limits predicted from estimates of fossil record quality, indicating that it is geological, rather than biological, factors that are responsible for shifts in diversity. Environmental restriction also appears to belie ostracoderm extinction and demise rather than competition with jawed vertebrates.

A global perspective of the Trigoniida (Bivalvia: Palaeoheterodonta), with a focus on their Mesozoic and Cenozoic representatives

***Simon Schneider and Simon R. Kelly**

Cambridge Arctic Shelf Project (CASP)

The Trigoniida Dall, 1889 are a globally important group of dominantly marine Bivalvia, which had their acme during the Mesozoic, when they played an influential role in shallow marine communities. The anticipated revision of the bivalve volumes of the ‘*Treatise*’ has fostered the authors’ attempt on a global genus-level systematic arrangement for the Mesozoic and Cenozoic Trigoniida. Currently, classification is not based on rigid phylogenetic analysis, but on qualitatively defined apomorphies. Nevertheless, it allows for identification of several palaeogeographically and stratigraphically well-constrained clades. Other clades, in particular the Myophorellidae and Pterotrigoniidae, are considerably less resolved and their subdivision is controversially discussed, mainly due to conflicting genus-level concepts. A circum-Pacific origin seems obvious for most of the Triassic clades of the Trigoniida. Subsequently, the break-up of Pangaea and later Gondwana created space for global expansion across shelf seas. At the same time, isolation forced more localized radiations of several groups. We present chronostratigraphic range charts for the genera currently recognized as valid, supplemented by palaeogeographic distribution maps for selected taxa.



We further exemplarily discuss difficulties of generic assignment in the Myophorellidae. Finally, we propose a revised classification for the Trigoniida that is put up for discussion.

The role of microbial anaerobic respiration in the end-Permian mass extinction

***Martin Schobben¹, Alan Stebbins², Abbas Ghaderi³, Harald Strauss⁴, Dieter Korn¹,**

Robyn Hannigan² and Christoph Korte⁵

¹*Museum für Naturkunde, Leibniz Institut für Evolutions- und Biodiversitätsforschung, Invalidenstr 43, D-10115 Berlin, Germany*

²*School for the Environment, University of Massachusetts Boston, 100 Morrissey Blvd, Boston, MA 02125, USA*

³*Department of Geology, Faculty of Sciences, Ferdowsi University of Mashhad, Azadi Square, 9177948974 Mashhad, Iran*

⁴*Institut für Geologie und Paläontologie, Westfälische Wilhelms Universität Münster, Corrensstraße 24, 48149 Münster, Germany*

⁵*Department of Geosciences and Natural Resource Management, University of Copenhagen, ØsterVoldgade 10, DK-1350, Copenhagen, Denmark*

Changes in plankton productivity have been connected with the end-Permian mass extinction. A box-model – proxy data comparison suggests that an increase of microbial sulfate reduction (MSR) can explain excursions in $\delta^{34}\text{S}_{\text{CAS}}$ and $\delta^{18}\text{O}_{\text{CAS}}$. These fluctuations are contemporaneous with the biodiversity crisis and are probably related to enhanced availability of organic substrates. This caused MSR to increase proportionally and induce the observed positive $\delta^{18}\text{O}_{\text{CAS}}$ excursion. The scenario would only require an increase in the oceans organic carbon inventory – a suggestion that can be linked to the climate warming and elevated continental weathering at that time. These physical processes are linked to the short-term carbon cycle, as ocean fertilization by nutrient input stimulated primary productivity.

Enhanced microbial activity can be regarded as the killing agent because of increased oxygen consumption (aerobic respiration) and H_2S (MSR) production. This caused a rapid global expansion of euxinic water and resulted in iron limitation in the ocean water. This, together with decreased iron supply due to a change in fluvial regimes, reduced pyrite burial, explaining a negative $\delta^{34}\text{S}_{\text{CAS}}$ excursion. This suggests that the latest Permian ocean was not dead ('Strangelove Ocean') but rather alive, and that microbial life can create adverse conditions for eukaryotic organisms.

Rudist myophores: constructional constraints and phylogenetic informativeness

Peter W. Skelton

The Open University

Molluscan muscle/shell attachment is mediated by adhesive epithelium, which secretes a collagenous 'tendon sheath' bonded to the shell by embedded fibres. Serial detachment and re-attachment of muscle fibres allows growth migration of the muscles across the epithelium. But tendon sheath adhesion to the shell constrains normal growth of the latter. Hence, for the adductors to maintain their relative positions in the shell during growth, the insertion surfaces must remain coplanar with their growth trajectories. In most bivalves, muscle scars thus lie flush on the inner valve surfaces, tracking the radial growth of the valve margins.



Primitive rudists maintained this pattern, albeit with the posterior adductor migrating helicospirally along myophoral ledges that limited the muscle's length. With further muscle shortening the myophores became flat extensions of the hinge plates. But with the onset of uncoiled valve growth accompanying ligamentary invagination, the adductor insertions had to tilt away from the commissural plane to allow them to track the now orthogonally growing valve margins. Different clades of uncoiled rudists followed contrasting options for such myophoral tilting. Each re-arrangement proved virtually irreversible, however, so imparting a reliable phylogenetic signal, as illustrated for example by contrast between the caprinoid families Caprinidae and Caprinuloideidae.

A new problematic colonial organism from the Cambrian of Morocco

Christian Skovsted¹ and Sebastián Clausen²

¹Swedish Museum of Natural History

²UFR Sciences de la Terre, Université Lille 1

A large number of minute colonial fossils have been found in the Cambrian Brece a Micmacca Limestone at Lemdad in the High Atlas Mountains, Morocco. The fossils are formed by replacement and/or infill of iron oxides and most specimens are represented by internal moulds of the cone-shaped internal cavity of individual elements, often with triangular or quadratic cross-sections. Individual elements were closely juxtaposed and arranged in sub-parallel or radiating bundles that were attached to larger skeletal elements (e.g. trilobites or archaeocyathans). The largest composite specimens contain more than 20 individual elements.

The new fossils resemble some poorly known Cambrian colonial organisms such as *Labyrinthus* Kobluk, 1979 and *Rosellatana* Kobluk, 1984 which has been compared to corals. However, the Moroccan specimens are preserved in a fundamentally different way compared to previous accounts, allowing better resolution of important internal structures. These include potential connecting structures between individual elements and the origination of the colony as well as the addition of new elements during growth which can be studied in three dimensions. Thanks to the new data it is possible to evaluate the suggested affinity of these problematic fossils to corals and elucidate their potential role in the early evolution of the Anthozoa.

A quantitative comparison of dispersed spores/pollen and plant megafossil assemblages from a Middle Jurassic plant bed from Yorkshire, UK

***Sam M. Slater and Charles H. Wellman**

Department of Animal and Plant Sciences, University of Sheffield, UK

Detailed quantitative data have previously been collected from palaeobotanical plant megafossil assemblages from a Middle Jurassic (Aalenian) plant bed from Hasty Bank, North Yorkshire, UK. We conducted a similar analysis of palynological dispersed sporomorph (spores and pollen) assemblages collected from the same section using the same sampling regime. Both dispersed sporomorph and plant megafossil assemblages display consistent changes in composition, diversity and abundance through time. However, the dispersed sporomorph and plant megafossil datasets provide conflicting evidence for the nature of the parent vegetation. Multivariate analysis of sporomorph occurrence/abundance and palynofacies data suggests that temporal variation in sporomorph/plant



megafossil assemblages is the result of depositional change between claystone, siltstone and grey clay lithologies, which reflect discrete depositional environments and different vegetation types. The reproductive strategies of parent plants are considered to be a principal factor in shaping many of the major abundance and diversity irregularities between dispersed sporomorph and plant megafossil data sets that seemingly reflects different parent vegetation. Preferential occurrence/preservation of sporomorphs and equivalent parent plants is a consequence of a complex array of biological, ecological, geographical, taphonomic and depositional factors that act inconsistently between and within fossil assemblages, which results in significant discrepancies between data sets.

Hallucigenia's head and the Cycloneuralian ancestry of Panarthropoda

***Martin R. Smith¹** and **Jean-Bernard Caron²**

¹*University of Cambridge*

²*Royal Ontario Museum and University of Toronto*

Hallucigenia is the most stubbornly problematic of the Cambrian's palaeontological enigmas. Although its affinity has recently been resolved – its claws place it in the onychophoran stem group – fundamental problems remain, not least the question of which end represents its head.

This question is at last resolved by our detailed analysis of all available material from the Burgess Shale, including dozens of new specimens collected by the Royal Ontario Museum. A pair of simple eyes demonstrate that *Hallucigenia* boasted visual capabilities similar to modern onychophorans'; they imply an independent origin of vision in each panarthropod phylum. A differentiated foregut occupies an elongate neck, with a ventrally oriented terminal mouth. The animal's mouthparts comprised circumoral spines and pharyngeal teeth; the arrangement of these scalids recalls the foregut armature of cycloneuralian worms (Priapulida + Nematoida). In light of *Hallucigenia's* phylogenetic position, this suggests that the panarthropod pharynx is a derived homologue of the cycloneuralian introvert. This interpretation provides palaeontological support for a molecular hypothesis which interprets cycloneuralians as paraphyletic with respect to panarthropods.

Chondrichthyan diversity and distribution in the Early Carboniferous: new evidence from the Tournaisian of northern Britain

Timothy R. Smithson, Kelly R. Richards, Rebecca Bennion and Jennifer A. Clack

University of Cambridge

The end-Devonian extinction event marked a profound change in the diversity of fishes. The dominant Devonian taxa, the acanthodians, placoderms and sarcopterygians, were suddenly replaced by minor components of the fauna, the actinopterygians and chondrichthyans. This replacement began in the Early Carboniferous but the evidence for it is poor. Until recently, the earliest Carboniferous chondrichthyans were known mainly from teeth from localities in China, Russia and North America. In the UK, the entire Tournaisian chondrichthyan fauna was represented by two teeth. Collecting at two new sites in the Scottish Borders has uncovered an extraordinarily diverse fauna of chondrichthyans. Represented by well-preserved cladodont, xenacanth and bradyodont teeth, most of the taxa are new and undescribed. The bradyodont teeth have been found in large numbers and exhibit a broad range of shapes and sizes. This is adding to growing evidence that, in the UK, immediately after the end-Devonian extinction, a durophagous



feeding habit was common. The UK Tournaisian bradyodonts were much larger than their younger relatives from the later Carboniferous. In contrast, the cladodont and xenacanth sharks were relatively smaller. All known Tournaisian chondrichthyan sites are in tropical palaeolatitudes, suggesting that sharks may have had a restricted distribution following the extinction event.

An exceptional three-dimensionally preserved *Pararaucaria* (Cheirolepidiaceae) ovuliferous cone from the late Jurassic of Southern England: non-destructive recovery of full anatomical and histological detail using Diamond Light Source synchrotron

***Alan R. T. Spencer¹, Paul Kenrick², Dave C. Steart², Russell J. Garwood³, Jason Hilton⁴, Martin Munt² and John Needham⁵**

¹Imperial College London, London, UK

²Natural History Museum London, London, UK

³The University of Manchester, Manchester, UK

⁴University of Birmingham, Birmingham, UK

⁵[Non-Institutional], Tisbury, Wiltshire, UK

The Cheirolepidiaceae are an extinct group of conifers with an extensive Mesozoic fossil record well-documented by foliage, wood, pollen and reproductive organs. Three-dimensionally preserved Cheirolepidiaceae ovuliferous cones are rare, with few known species. Here we use X-Ray computed micro-tomography at the Diamond Light Source Synchrotron (Oxfordshire, UK) to non-destructively image the internal anatomy of a recently discovered petrified ovuliferous cone from a Jurassic (Tithonian *c.*145 Ma) forest in southern England. The cone is derived from a suite of silicified plant materials, most of which were permineralised *in situ* in a hyper saline lagoonal setting during a shallow transgressive phase.

Tomographic datasets were used to fully describe the histology of the cone and produce three-dimensional models of the gross morphology. These images revealed a remarkable degree of information on the internal tissues of the cone by resolving cellular level details. The results demonstrate that the cone belongs to the extinct genus *Pararaucaria* (Cheirolepidiaceae) that has only previously been reported from South and North America, and forms only the fourth species to be systematically described. This new species extends the known geographic range of *Pararaucaria* to Europe and emphasises the wide distribution of Pararaucarian conifers during the Jurassic.

Oxygen, age and facies controls on the appearance of Ediacaran and Cryogenian macroscopic fossils in the Mackenzie Mountains, Northwest Territories, Canada

***Erik A Sperling¹, Calla Carbone², David T. Johnston¹, Guy M. Narbonne² and Francis A. Macdonald¹**

¹Harvard University

²Queens University

The causes behind the appearance of abundant macroscopic fossils at the end of the Neoproterozoic remain debated. Iron geochemical analysis of fossiliferous Ediacaran successions in Newfoundland suggested that first appearances there were correlated with



an oxygenation event. A similar relationship was claimed to exist in the Mackenzie Mountains, Canada, although recent stratigraphic studies indicate the sections analyzed for geochemistry were incorrectly correlated with those hosting the fossils. To directly connect fossils with geochemistry, we conducted a multi-proxy iron, carbon, sulfur, and trace element geochemical analysis of the sections hosting the Cryogenian 'Twitya discs' at Bluefish Creek and Ediacaran fossils at Sekwi Brook. There is no oxygenation event correlated with the appearance of macroscopic body fossils in either section, or simple bilaterian burrows in the Blueflower Formation, although partial oxygenation appears correlated with increasing burrow width higher in the Blueflower. Data from Sekwi Brook suggest that these organisms were periodically colonizing a predominantly anoxic basin, requiring assumptions of differing timescales between redox proxy data and ecological responses in order to reconcile fossil and geochemical data. Thus, hypotheses directly connecting ocean oxygenation with the appearance of macrofossils may be too simplistic or not apply to all areas of a heterogeneous Ediacaran ocean.

Minerals in the gut: scoping a Cambrian digestive system

***Katie M. Strang, David A. T. Harper and Howard A. Armstrong**

University of Durham

The Sirius Passet Lagerstätte of North Greenland contains exceptionally-preserved fossils, including an abundance of iconic arthropod and other gut tracks. Understanding the taphonomy leading to this preservation is key to accurately reconstructing these past ecosystems. High-resolution photography, Scanning Electron Microscopy, EDAX and elemental mapping have been carried out on a variety of gut specimens from this Cambrian locality to determine the exact mode of preservation. Preliminary results show a high concentration of $\text{Ca}_3(\text{PO}_4)_2$ and SiO_2 present in the mid gut glands and surrounding appendages. It is postulated that the precipitation of calcium phosphate is a result of an initially high organic content in the organisms' digestive tracts. Further analysis is revealing more information regarding the distribution of elements relating to the gut morphology, allowing a clear taphonomic pathway to be developed and providing an insight into the trophic relationships of this Early Cambrian Lagerstätte.

Fungal and fungal-like interactions with plants in early terrestrial ecosystems : state of the art and future direction

***Christine Strullu-Derrien and Paul Kenrick**

Department of Earth Sciences, The Natural History Museum, London, UK

Fungi were of key importance to the early evolution of life on land, yet direct fossil evidence of plant fungal interactions is still limited. Fossil evidence of fungal-like microorganisms (oomycetes) is rarer still. We are investigating the evolution of these relationships through re-examination of historic slide collections and through the analysis of new materials, focusing on the Devonian and Carboniferous Periods. Our general approach is to compare and contrast the nature of the interactions in pre- and post-arborescence ecosystems. We are using a suite of methods, including Confocal Laser Scanning Microscopy. Results show that historic slide collections harbour a hidden diversity of plant-associated microorganisms. Recently, we have documented a new form of mycorrhizal relationship in the Rhynie Chert involving Mucoromycotina, overturning the paradigm that early symbioses involved exclusively Glomeromycota. Our analysis of Carboniferous seed ferns provides the earliest



evidence of parasitism in oomycetes. A new putative oomycete from the Rhynie chert will be presented showing the difficulties encountered in discriminating oomycetes from fungi. Generating new data on fossil fungi and fungal-like microorganisms provides much needed direct evidence for the calibration of molecular clocks and is crucial to developing our knowledge of the impact and diversity of interactions in ancient ecosystems.

Puckered, Woven and Grooved: the importance of substrate for Ediacara Paleocology, Paleoenvironment and Taphonomy

***Lidya G. Tarhan¹, Mary L. Droser² and James G. Gehling³**

¹*Yale University*

²*University of California, Riverside*

³*South Australian Museum*

The Ediacara Biota, Earth's earliest complex, macroscopic, multicellular ecosystem, is preserved in terminal Ediacaran strata worldwide. In the Ediacara Member of South Australia, Ediacara fossil assemblages occur in intimate association with iterated or patterned macroscopic organosedimentary structures, known as 'textured organic surfaces' (TOS). These widespread surfaces encompass considerable variability in size and complexity and likely included densely packed eukaryotic as well as prokaryotic benthic communities.

We documented considerable heterogeneity in the composition and facies of Ediacara fossil assemblages through systematic sedimentary and palaeoecological analysis of 27 fossiliferous beds (>300 m²). Particular TOS commonly occur in association with distinct fossiliferous facies. For instance, the TOS 'weave,' which consists of iterated rectilinear elements branching at acute angles, occurs only along amalgamated, sandy, storm-deposited event beds. Conversely, 'micropucker,' which consists of discrete patches of closely-packed dimples, occurs only along silty, planar-laminated and tool-marked sandstone beds deposited below storm wave base.

Intimate spatial and facies associations of TOS and body fossils suggest that TOS communities strongly influenced the benthic ecology of Ediacara macrofaunal ecosystems. TOS stabilized the substrate, fostered the development of unique benthic life modes, and significantly shaped the biostratigraphic and early diagenetic pathways responsible for the preservation of Ediacara communities.

Paleocene forests and climates of Antarctica: signals from fossil wood

***Laura Tilley¹, Jane Francis², Vanessa Bowman² and J. Alistair Crame²**

¹*University of Leeds*

²*British Antarctic Survey*

During the greenhouse world of the Paleocene the Antarctica Peninsula was covered in forests. Fossil wood has been systematically collected from Paleocene marine sequences of Seymour Island and has been studied in order to reconstruct the forest composition and evolution of the vegetation throughout the Paleocene. Trees that lived in the forests included *Nothofagus*, Myrtaceae, *Weinmannia*, *Araucaria*, *Phyllocladus* and podocarp conifers. These tree types can be found in cool temperate forests in Chile and New Zealand today. Mean growth ring analysis shows a trend towards narrow growth rings in the



early-mid Paleocene, which suggests cooler climates. Mean sensitivity calculated from tree ring width generally shows growth under an equable climate. Vulnerability Index (VI) and Mesomorphy Index (MI) have been calculated using angiosperm vessels as an indicator of water availability, and more precise MI values indicate sufficient water availability. Specific gravity has been linked to a plant's adaption to water availability in its environment as well as growth strategy. Most of the fossil wood types show medium specific gravity (0.40 – 0.75) values, which is expected for temperate forests. Investigating these factors is essential for understanding how sensitive vegetation is to climate change.

The curious case of chaetae in brachiopods from the middle Cambrian Burgess Shale

***Timothy P. Topper**¹, **Lars E. Holmer**¹, **Luke Strotz**², **Noel Tait**², **Zhifei Zhang**³ and **Jean-Bernard Caron**^{4,5}

¹Department of Earth Sciences, Palaeobiology, Uppsala University, Villavägen 16, SE - 752 36 Uppsala, Sweden

²Department of Biological Sciences, Macquarie University, Sydney, NSW, 2109, Australia

³Early Life Institute and Department of Geology, State Key Laboratory for Continental Dynamics, Northwest University, Xian 710069, China

⁴Department of Natural History (Palaeobiology Section), Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, M5S2C6

⁵Department of Ecology and Evolutionary Biology, University of Toronto, 25 Willcocks Street, Toronto, Ontario M5S3B2, Canada

The Burgess Shale Lagerstätte has over the years given us a range of extraordinary creatures, exquisitely preserved in the dark shales of the Canadian Rockies. In a community dominated by arthropods, brachiopods are the forgotten phylum in the Lagerstätte deposit, yet as the second most abundant benthic filter feeder, brachiopods were undoubtedly an essential component of the Burgess Shale community. One of the more remarkably preserved brachiopods from the Cambrian Stage 5, Burgess Shale is *Micromitra burgessensis*. *Micromitra* is exceptionally preserved, exhibiting elongate chaetae that fringe the mantle and extend far beyond the margin of the biomineralized shell. Chaetae of extant brachiopods have been interpreted as potentially performing a range of defensive and sensory functions in addition to assisting in feeding, burrowing and actively warding off encroaching organisms. The shape, size and frequency of the chaetae possessed by *M. burgessensis* are unique amongst Recent and fossil brachiopod taxa and here we explore the potential function/s of these distinctive chaetae. Chaetae have now been documented from a variety of extant and fossil brachiopod groups and the wide morphological variation observed across families indicates that chaetae may be a potentially significant tool for taxonomic, phylogenetic and palaeoecological studies of the phylum.



Finding food efficiently: the origin and evolution of optimal foraging strategies

**Richard J. Twitchett¹, Andrew M. Reynolds², Nicolas E. Humphries³, Emily J. Southall³,
Victoria J. Wearmouth³, Brett Metcalfe⁴ and David W. Sims^{3,5}**

¹Natural History Museum, London SW7 5BD, UK

²Rothamstead Research, Harpenden AL5 2JQ, UK

³Marine Biological Association, Plymouth PL1 2PB, UK

⁴VU University Amsterdam, 1081 HV, Amsterdam, The Netherlands

⁵University of Southampton, Southampton SO17 1BJ, UK

How best to search for sparse food resources in heterogeneous landscapes is a universal problem facing mobile organisms. Living animals use a theoretically optimal scale-free random search known as a Lévy walk, composed of many small-move steps interspersed by rarer long steps, but little is known of the origins and evolution of foraging behaviour and the search strategies of extinct animals. Computer simulations show that patterns that are consistent with Lévy walks may emerge from very simple behaviours, such as random strophotaxis (*i.e.* U-turns), and thus may have an ancient origin. To test this, we used a novel path-analysis technique to analyse Eocene examples of *Cosmorhappe*, *Helminthorhappe* and *Scolicia*, and found the first evidence of Lévy-like search strategies in the fossil record. Specimens of *Cosmorhappe* and *Helminthorhappe* are quantitatively similar to the simple Brownian random walks that approximate short-range, localized foraging movements of extant animals, implying homogeneously distributed food. In contrast, those of *Scolicia* exhibited more complex behaviours analogous to Lévy walks, indicating that the echinoid trace-makers were optimally searching for patchily distributed food resources in their deep-sea habitats. Thus, Lévy-like behaviour has been used by foragers since at least the Eocene, but likely has a deeper origin.

‘Death Metal’ in the Early Palaeozoic

Thijs R. A. Vandenbroucke¹, Poul Emsbo² and Axel Munnecke³

¹UMR 8217 du CNRS: Géosystèmes, Lille1 University, Avenue Paul Langevin - bâtiment 5N5, 59655 Villeneuve d'Ascq, France

²USGS, CMERSC, Denver Federal Center, Denver, CO 80225, USA

³Universität Erlangen-Nürnberg, GeoZentrum Nordbayern, Fachgruppe Paläoumwelt, Loewenichstr. 28, D-91054, Erlangen, Germany.

Some, if not most, of the major Ordovician–Silurian extinction events coincided with glacial episodes. However, it has become increasingly clear that cooling, itself, is not a viable kill-mechanism to explain these extinctions. Interestingly, these events are announced by the appearance of malformed organic-walled fossil zoo- and phytoplankton. New geochemical analyses (using ToF-SIMS and LA-ICP-MS) of these teratological microfossils and their host rocks, through a mid-Pridoli event, show a correlation between teratology and a dramatic increase in redox-sensitive metals. By analogy with metal-induced teratology in modern marine environments, our results suggest that these *in vivo* teratological reactions result from the pollution of the Silurian marine environment by toxic metals. These new data appear to link the initiation of the mass extinctions with the cycling of harmful redox-sensitive metals likely related to Ocean Anoxic Events (OAEs), rather than with climate change. Our work introduces metal-induced teratology as a potential and independent proxy for the monitoring of palaeo-ocean geochemistry in deep time.



Chitons of the Permian Capitan Reef, and the nature of late Palaeozoic Polyplacophora

Michael J. Vendrasco¹, Richard D. Hoare², Gordon L. Bell³ and Jonena M. Hearst³

¹*University of Granada, Spain*

²*Bowling Green State University, Ohio, USA*

³*Guadalupe Mountains National Park, Texas, USA*

A diverse assemblage of exceptionally preserved chiton shell plates has been extracted from the Permian Bell Canyon Formation in the Guadalupe Mountains of west Texas, USA. The chitons were found in thin debrites shed from the massive Capitan Reef. These fossils show fine details of tegmental sculpture and configuration of aesthete canals, and they add to the already high diversity of chitons known from the Permian of Texas. A rarefaction analysis of these assemblages indicates that diversity of late Palaeozoic chitons was probably much higher than recorded. The fossils show high variability in overall shape, tegmental coverage and sculpture, as well as shape and extent of incisions in insertion plates. Mesozoic chitons, in contrast, are sparse and morphologically uniform. Thus it seems many chiton lineages died out during the end Permian mass extinction and along with diversity went disparity. The Capitan fossils confirm convergent evolution in the Polyplacophora of both tegmentum reduction as well as incisions in the articulamentum. Otherwise the presence of such slits in insertion plates might provide an upper bound for the origin of the chiton crown group. In either case the crown group Polyplacophora probably originated during the late Palaeozoic, by which time some chitons had shell plate morphology very similar to modern forms.

The Middle Permian Mass Extinction in high latitudes

Paul B. Wignall¹ and David P. G. Bond²

¹*School of Earth and Environment, University of Leeds*

²*Department of Geography, Environment and Earth Sciences, University of Hull*

The mass extinction at the end of the Permian is one of the best-known crises of the Phanerozoic. However, it was preceded by a little known extinction around ten million years earlier. This Capitanian crisis was first identified 20 years ago and affected taxa from shallow-water tropical sites such as fusulinids, rugose corals and brachiopods. However, the impact of the crisis on higher latitude communities has not been addressed. The Kapp Starostin Formation is a mixed carbonate – spiculite ramp unit that accumulated at mid-high Boreal latitudes. It contains an abundant benthic fauna of brachiopods, bryozoans, corals, sponges and bivalves but mostly lacks stratigraphically useful fossils such as conodonts and ammonoids. Chemostratigraphic evidence (from strontium and carbon isotope variations) suggests the Middle/Late Permian boundary is *c.*80m from the top of the Formation. Range charts in the Kapp Starostin reveal that there is a major and abrupt extinction event in the latest Middle Permian. The Capitanian mass extinction is thus developed in both low and mid latitudes. The benthic communities in the Kapp Starostin Formation subsequently recover and consist of a diverse brachiopod/bivalve/ bryozoan/ sponge assemblage.



A morphological analysis of the pectoral girdle skeleton of soaring birds

***Megan E. Williams**

University of Cambridge

Soaring flight conserves energy by gaining lift from environmental air movements rather than flapping the wings. Its habitual use in the form of static (energy from thermals) and dynamic (energy from windshear) soaring has evolved convergently within neoavians. Previous research has found associations of aspects of skeletal morphology with soaring flight.

This study uses traditional and geometric morphometric techniques to investigate the morphology of the bones of the pectoral girdle associated with dynamic and static soaring relative to non-soaring species.

All bones of the pectoral girdle were found to be diagnostic of flight style, with the strongest associations found in the coracoid, and the weakest associations found in the geometric morphometric analysis of the furcula. Diagnostic accuracy was reduced but not removed when the effects of allometry were taken into account, suggesting that, while body size is associated with flight style, there are further associated morphological features unrelated to body size.

This work in characterising the skeletal morphology associated with soaring flight allows further research into the origins of soaring flight and the flight styles of extinct avian taxa. There is potential for this study to also identify key osteological features in the initial evolution of powered flight.

Life and death at high latitudes: a reassessment of the Cretaceous–Paleogene (K–Pg) mass extinction event in Antarctica

***James D. Witts¹, Paul B. Wignall¹, Jane E. Francis², Robert J. Newton¹, J. Alistair Crame², Vanessa C. Bowman² and Rowan J. Whittle²**

¹*School of Earth and Environment, University of Leeds, Woodhouse Lane, Leeds LS2 9JT, UK*

²*British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK*

The Cretaceous–Paleogene (K–Pg) extinction of 66 Ma is a key event in Earth history, with extinction of many previously dominant terrestrial and marine groups providing a foundation for the subsequent evolution and expansion of the modern fauna during the Cenozoic. The highest southern latitude site for studying this interval is Seymour Island, Antarctica (65°S today, and during the Late Cretaceous). Here, a thick and abundantly fossiliferous Maastrichtian–Danian (*c.*70–65 Ma) section is preserved within a sedimentary sequence deposited in a back-arc basin to the East of the Antarctic Peninsula.

We have produced stratigraphic range data for major macrofossil groups as well as stable isotope records (carbon and sulfur isotopes) based on new sedimentary sections and a taxonomic reassessment of the fauna from the *c.*1100 m thick López de Bertodano Formation exposed on Seymour Island. Our results show a stable Maastrichtian community, with fluctuations in the diversity of the fauna up-section probably related to sea-level and other latest Cretaceous environmental changes, before a single pulse of extinction coincident with the K–Pg boundary. These new data do not support claims for a double extinction pulse in Antarctica, and allow us to examine latitudinal and taxonomic selectivity of this major mass extinction event.



An agglutinated early Cambrian actinotroch-like phoronid from the Chengjiang Lagerstätten and its implications

Zhifei Zhang¹ and Lars E. Holmer²

¹Early Life Institute, State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, 710069, China

²Uppsala University, Department of Earth Sciences, Palaeobiology, Villavägen 16, SE-752 36, Uppsala, Sweden

The lophophorates are united by the presence of a fan of ciliated tentacles surrounding the mouth. Although considerable advances have recently been made in unveiling the Cambrian morphology and diversity of brachiopods, and other lophophorate animals, the most conspicuous phylogenetic gap in the Cambrian fossil record is for the Phoronida. *Iotuba* (= *Eophoronis* Chen) was proposed as a phoronid candidate, but it has more recently been considered as a sipunculid.

New, abundant, well-preserved material of *Archisaccophyllia kunningensis* Hou *et al.*, from the Cambrian (Series 2) Chengjiang deposits, is here reinterpreted 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 distal holdfast. The soft anatomy includes a U-shaped gut with a mouth surrounded by a fan of flexible tentacles. *Archisaccophyllia kunningensis* differs from extant phoronid actinotroch larvae in being much larger with a sessile lifestyle, as well as in having the calyx covered by agglutinated quartz grains that is reminiscent of agglutination that is known in both extant adult phoronid and the stem-group brachiopod *Yuganotheca* recently reported from the Chengjiang fauna.



Abstracts of poster presentations

* indicates a poster eligible for the Council Poster Prize.

Underlined author denotes designated presenter.

Fossil Fruits of the London Clay: a new insight from X-Ray analysis

*Neil F. Adams^{1,2}, Mary J. Andrew¹, Margaret E. Collinson^{1,3}, Steven R. Manchester⁴, Gregory W. Stull⁴, Fabiany Herrera^{4,5}, Paul Kenrick³ and Dan Sykes⁶

¹*Department of Earth Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK*

²*Department of Geography, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK*

³*Department of Earth Sciences, Natural History Museum, London SW7 5BD, UK*

⁴*Florida Museum of Natural History and Department of Biology, University of Florida, Gainesville, Florida 32611, USA*

⁵*Chicago Botanic Garden, 1000 Lake Cook Road, Glencoe, Illinois 60022, USA*

⁶*Imaging and Analysis Centre, Natural History Museum, London SW7 5BD, UK*

The diverse fossil flora of the London Clay Formation in South East England has been interpreted as a paratropical rainforest fringed by coastal mangroves, which grew during the Early Eocene Climatic Optimum (EECO) between 52 and 49Ma.

The London Clay collection at the Natural History Museum contains pyritized fruits and seeds of flowering plants that were first described using light microscopy nearly 200 years ago and are now stored in silicone oil to prevent further pyrite decomposition. Physical sectioning is inappropriate for their holotypes. Non-destructive, X-ray micro-computed tomography (micro-CT) was applied to specimens in silicone oil to obtain hitherto inaccessible internal information with minimal risk.

Holotypes from twenty-one species of Icacinaceae (mainly lianas) and four species of Anacardiaceae (the cashew family) were scanned. A taxonomic re-evaluation of these historic specimens, using previously unseen characters, has, in almost every case, confirmed and resolved their affinities with modern relatives and confirmed the London Clay's diversity of tropical taxa. Digital visualisation of otherwise hidden pyrite infills has enabled fossil internal casts to be linked to external fruit morphology. Even badly cracked holotypes have yielded taxonomically useful information and have highlighted the potential of micro-CT in monitoring vulnerable fossils.



The Taxonomy, Taphonomy and Tomography of Miocene *Cissus* from Kenya: the first record of Vitaceae in Africa

*Neil F. Adams^{1,2}, Margaret E. Collinson^{1,3}, Selena Y. Smith⁴, Marion K. Bamford⁵ and Federica Marone⁶

¹Department of Earth Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK

²Department of Geography, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK

³Department of Earth Sciences, Natural History Museum, London SW7 5BD, UK

⁴Museum of Paleontology and Department of Earth & Environmental Sciences, University of Michigan, Ann Arbor, Michigan 48109, USA

⁵Evolutionary Studies Institute and School of Geosciences, University of the Witwatersrand, P. Bag 3, Wits 2050, Johannesburg, South Africa

⁶Swiss Light Source, Paul Scherrer Institute, CH-5232 Villigen, Switzerland

Surface ornamentation on mineralized fossil seeds from the Kenyan Miocene Hiwégi Formation is closely comparable to that on seeds of modern African *Cissus*. These fossils are the first record of *Cissus* and the Vitaceae (grape vine family) in Africa. Previously the seeds had been assigned to the Menispermaceae – a completely different plant group. We aim to confirm our new identification, understand the previous taxonomic error, and determine the clades of *Cissus* to which the fossils belong.

Forty-two modern *Cissus* fruits were scanned using synchrotron radiation X-ray tomographic microscopy (SRXTM). The high-resolution images revealed complex layering of different tissue types and thicknesses in the fruit walls and seed coats, parts of which are very thin and delicate. All these layers would respond in different ways to decomposition and fossilization processes. Furthermore, all the seeds are characterized by deep ventral infolds, which could easily become infilled and hence obscured by minerals during fossilization. We conclude that taphonomic factors led to the previous incorrect identification and obscured the fossils' true affinity. 'Virtual taphonomy' [the digital removal or infill of structures to mimic fossilization processes] is currently being applied to the modern *Cissus* to produce digital fossils for direct comparison with actual fossils.

Phosphatization in the Ediacaran: a taphonomic model for the Biskopås Formation of southern Norway

*Peter W. Adamson

University of Cambridge

Detailed taphonomic analysis is now recognized as a prerequisite for any palaeobiological analysis, particularly in the case of problematic fossils. Reinvestigation of phosphorite pebbles from the early Ediacaran Biskopås Formation in southern Norway reveals a previously unrecorded diversity of large acanthomorphic acritarchs from two distinct taphonomic windows; most significant being apatite permineralization. Co-occurring with these apatite permineralized specimens are pyritized sphaeromorphic and filamentous microfossils and a second occurrence of Doushantuo-type preservation – early precipitation of isopachous and botryoidal apatite. Petrographic analysis of the Biskopås phosphorites suggests the microfossils were deposited into a primary phosphatic sediment, rather than a secondarily phosphatized carbonate sediment. A mould of the external morphology



was created during very early hardground formation, encasing the microfossil, which was rapidly followed by permineralization of the cell lumen. This is revealed by several examples where the cell wall has shrunk inwards from the external mould prior to permineralization. Fe-rich clay occasionally precipitates within the microfossil instead of apatite, often preventing permineralization of the wall. This model indicates that Biskopås microfossils are preserved within their primary depositional environment and enables new palaeoenvironmental and taphonomic comparisons with the Doushantuo that may shine new light on this enigmatic microbiota.

New eukaryotic microfossils from the Mesoproterozoic Ruyang Group, China

***Heda Agic¹, Malgorzata Moczydlowska¹ and Leiming Yin²**

¹*Department of Earth Sciences, Palaeobiology, Uppsala University, Sweden*

²*Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, China*

Siliciclastics of the Ruyang Group in the Shanxi Province, North China Craton, encompassing the latest Paleoproterozoic and Mesoproterozoic, have yielded a diverse assemblage of eukaryotic and prokaryotic organic-walled microfossils.

Samples from several beds in the lower Bedajian Formation (Ruyang) were macerated in HF acid, and the extracted fossils were studied with light and scanning electron microscopy. Specimens include bacterial sheaths, and acritarchs with elaborate wall structure:

Dictyosphaera macroreticulata, *Shuiyousphaeridium macroreticulatum* and *Tappania plana* morphotypes, as well as several new, unnamed taxa including both spheromorphs and acanthomorphs.

Recently, the age of deposition of the Ruyang Group and the overlying Luoyou Group has been constrained to 1750 to 1400 Ma, older than previously thought. This pushes back the age constraint on the first appearance of complex eukaryotic morphologies in the fossil record.

Novel cell morphologies in the Ruyang biota include vesicles with velutinous outer membrane, thin hirsute processes and membranous tube-like extensions, as well as internal bodies.

While the subgroup biological affinity of the new Ruyang microfossils is unclear, the sum of evidence from size and morphology to co-occurrence with members of diverged eukaryotic lineages like *Shuiyousphaeridium* (Chloroplastida), positions them within the crown group Eukarya.

Revisiting the King collection: palaeogeographical significance of the Permian brachiopods from England

***B. Allen, David A. T. Harper and Howard A. Armstrong**

Durham University

William King's classic description and analysis of the Permian Fossils of England (*Palaeontographical Society Monographs*, 1850) contains detailed descriptions and beautiful illustrations of the Brachiopoda, forming the basis for much further research on these faunas from elsewhere in the World. Despite a substantial, unpublished thesis (A. Logan, Durham University, 1962) and a field guide to Permian fossils of the region (N.T.J. Hollingworth and T.H. Pettigrew, Palaeontological Association, *Field Guides to*



Fossils, 1988) this key fossil group has received little subsequent attention. Re-evaluation and re-illustration of King's brachiopod type and figured material in the National University of Ireland, Galway has helped establish a database for the distribution of the fauna within the North of England and elsewhere in the Zechstein province. Comparisons with coeval faunas from the Arctic and Tethyan Province have confirmed the unique characteristics of the Zechstein Brachiopoda and, regionally, helped understand the palaeoecology of these brachiopod-dominated assemblages in the Northeast of England prior to major environmental changes in the Zechstein Basin.

Testing the evidence for gill slits in an Ordovician echinoderm

***Nidia Alvarez Armada**¹, **Imran A. Rahman**² and **Christopher B. Cameron**³

¹*School of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, Bristol BS8 1RJ, UK; Current address: School of Biological, Earth and Environmental Science, University College Cork, North Mall, Cork, Ireland*

²*School of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, Bristol BS8 1RJ, UK*

³*Département de sciences biologiques, Université de Montréal, C.P. 6128, Succ. Centre-ville, Montréal, Quebec H3C 3J7, Canada*

Phylogenetic bracketing of the living deuterostome clades suggests that their latest common ancestor was a bilaterally symmetrical animal with pharyngeal gill slits. If this hypothesis is accurate, we might expect to see these characters in early fossil representatives of the phyla. Here, we evaluate the evidence for gill slits in the Ordovician echinoderm *Lagynocystis pyramidalis*. X-ray micro-tomography was used to characterise the internal anatomy of *Lagynocystis* and extant deuterostomes (two hemichordates and one cephalochordate). In addition, we imaged the internal respiratory structures (hydrospires) of two Devonian blastoids using phase-contrast synchrotron radiation X-ray tomographic microscopy. Finally, we utilised computational fluid dynamics to simulate functional performance in *Lagynocystis* and the modern deuterostomes. Tomographic imaging confirms the presence of a complex of internal bars in *Lagynocystis*, which is similar in both form and size to the gill bars of the modern deuterostomes; however, individual folds in the hydrospires of blastoids are also similar to these bars. Computer modelling of fluid flow suggests that gill bars in modern deuterostomes affect water flow rather differently to the internal bars of *Lagynocystis*, implying an alternative function. Based on this, we find no support for the long-standing hypothesis that the fossil echinoderm *Lagynocystis* possessed internal pharyngeal bars.



Apparent diversity drop after the Cryogenian (Sturtian) ice age in southwestern Mongolia – a product of extinction or taphonomy?

***Ross P. Anderson¹**, **Francis A. Macdonald²**, **Nicholas J. Tosca³**, **Tanja Bosak⁴**, **Uyanga Bold²** and **Derek E. G. Briggs¹**

¹*Department of Geology and Geophysics, Yale University, 210 Whitney Avenue, New Haven, CT, 06511, USA*

²*Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, MA, 02138, USA*

³*Department of Earth Sciences, University of Oxford, South Park Road, Oxford OX1 3AN, UK*

⁴*Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139, USA*

Few fossils have been described from sequences between the Sturtian (*c.*720–660 Ma) and Marinoan (*c.*640–635 Ma) ‘Snowball Earth’ ice ages despite palaeontologists documenting a Neoproterozoic radiation of the crown-group eukaryotes in the *c.*150 Myr prior to this interval. The paucity of fossils in rocks of this age has been interpreted as the result of an extinction associated with the proliferation of biologically unfavourable environments. Recent fossil discoveries in the Zavkhan basin of southwestern Mongolia have begun to populate the fossil record of the nonglacial interlude. Here we explore the contribution of taphonomy to diversity patterns during the Neoproterozoic, in particular the role of clay minerals in the preservation of the Mongolian fossils. We report preliminary stratigraphic records from the Taishir Formation (Tsagaan–Olom Group, Mongolia) of fossil abundance based on petrographic thin-sections and rock macerations, in addition to bulk-rock clay mineralogy analysed by X-ray diffraction. Clay mineral assemblages vary from berthierine (lowest *c.*150 m) through to talc (middle *c.*25 m) and kaolinite (highest *c.*225 m) coincident with shifts in fossil abundance. Future work will use samples from shale and chert horizons to explore facies bias, and will address any metamorphic effects on clay mineral assemblages.

Cretaceous polychelidan lobster larva: evolutionary implications

***Denis Audo¹**, **Joachim T. Haug²**, **Carolin Haug²**, **Pierre Abi Saad³**, **Gilles Petit⁴**, **Jean-Paul Saint Martin⁴** and **Sylvain Charbonnier⁴**

¹*Université de Rennes 1, EA 7316 ‘Biodiversité et Gestion des Territoires’*

²*University of Munich (LMU) Department of Biology II, Functional Morphology group*

³*Memory of Time*

⁴*UMR 7207 (CR2P) MNHN/UPMC, Département Histoire de la Terre, Muséum national d’Histoire naturelle, Paris, France*

The ontogeny of some extant crustacean groups can be characterized by an abrupt metamorphosis at the transition between the planktonic larva and the benthic adult. Such metamorphoses are for instance well-documented for mantis shrimps (Stomatopoda), slipper and spiny lobsters (Palinurida) and polychelid lobsters (Polychelidae). In this latter group, the zoea and megalopa instars, called eryoneicus larvae, are characterized by an inflated, balloon-like carapace covered by abundant spines. Such larvae have never been discovered in the fossil record. Examination of small individuals of fossil Polychelida (the group containing Polychelidae) suggests that the ontogeny of many fossil species did not include eryoneicus larvae nor metamorphosis. Recently, two small fossil



decapod crustaceans were discovered in the famous Lagerstätte of Hadjoula (Lebanon, Cenomanian). These specimens are clearly juvenile Polychelida. Both possess a carapace spinier and less flattened than other juvenile fossil polychelidans. They also preserve a developed rostrum usually occurring in earliest eryoneicus stages. These characters suggest they represent an early form of eryoneicus larva. They nevertheless differ from eryoneicus larva by the shape of their carapace, less inflated than extant eryoneicus. Their unique combination of characters therefore suggests eryoneicus larvae evolved gradually from a juvenile more similar in morphology to the adult.

Development of the Elgin Museum Recognised Collection for education and scientific use

***Susan R. Beardmore**

Elgin Museum, 1 High Street, Elgin, Moray IV30 1EQ

The Elgin Museum houses a Scottish Government ‘Recognised’ Collection of Devonian, Permian and Triassic vertebrate fossils, sourced in Moray during the early-mid 19th Century. In the past the collection has been associated with Murchison, Sedgewick, Miller, Buckland, Agassiz, Lyell and Huxley among others, who visited the area and/or figured specimens in literature still relevant today. The fossils have also contributed to discussions on tetrapod evolution, dicynodont phylogeny and the radiation of early dinosaurs. The importance of the collection is further raised by the fact that many of the quarries sourcing these unique fossils are now closed or inaccessible, meaning new examples are not likely to be recovered. The Recognised Collection has therefore undergone extensive development to allow better access to the fossils, and use as an education and scientific resource. The identification and condition of specimens has been checked, storage re-organised systematically (age; location) and documentation thoroughly revised. The work has brought to light many interesting and well-preserved fish and reptile specimens of considerable historical significance for use in subsequent displays. The success, and difficulties, of the development are described so that other museums undergoing similar changes, now or in the future, can benefit from our experience.

Rats, platypuses and evolutionary dead-ends: how observed tree imbalance implies reduced rates of diversification for the evolutionary distinct

***Dominic J. Bennett^{1,2}, Mark Sutton¹ and Sam Turvey²**

¹*Imperial College London*

²*Zoological Society of London*

It has been argued that evolutionary distinct species – the ‘platypuses’ – have a higher probability of diversifying in the future. With greater time for independent evolution relative to other members of the community, they are more likely to possess adaptations unique to the environment allowing them to respond differently to change. An alternative view is that evolutionary *indistinct* species – the ‘rats’ – are in the midst of a radiation, and are hence more likely to continue to diversify. Here we provide the first quantitative test of these competing arguments by running a series of tree growth models with different diversification rate biases based on species’ evolutionary distinctiveness; we term these ‘Evolutionary Distinctiveness Biased Markov-Models’ (EDBMM). It has long been noted that the tree of life is too imbalanced to be produced by equal rates of diversification



across all tips. Comparisons between our simulated trees and real trees demonstrate that a bias of diversification towards the evolutionary indistinct recreates the typical tree imbalance observed in nature. This provides indirect evidence that the history of species does influence their future performance, in the form of a higher diversification potential in species that are part of ongoing adaptive radiations.

Cenozoic hydrocarbon seep molluscs from the Caribbean region

***Jordan Bestwick¹, Crispin T. S. Little², Fiona L. Gill² and Steffen Kiel³**

¹*School of Biology, University of Leeds, Leeds, UK*

²*School of Earth and Environment, University of Leeds, Leeds, UK*

³*Georg-August Universität Göttingen, GZG, Geobiology Group, Goldschmidtstr. 3, 37077 Göttingen, Germany*

Hydrocarbon seeps are sites along deep continental margins where hydrocarbon-rich fluids flow onto the seafloor. Modern seeps are numerically dominated by fauna with symbiotic chemoautotrophic bacteria, including bivalves and vestimentiferan tubeworms, and also by grazing gastropods. Fossil seeps date back to the Devonian and there have been substantial changes in faunal assemblages through the Phanerozoic. Eocene–Miocene seep assemblages from Barbados and Trinidad were originally described in earlier preliminary papers. Since additional specimens are now available, and knowledge of Mesozoic and early Cenozoic seep faunas has increased, reinvestigation of Caribbean seep fossils offers new insights into their evolutionary history. Over 450 specimens were described, comprising at least 20 bivalve and 18 gastropod species, including five and 11 new species respectively. Most of the described species show either a distinctive Caribbean character or affinities to coeval Pacific seep molluscs, and seem to have disappeared after the Miocene. Surprisingly few modern seep molluscs in the Caribbean/Gulf of Mexico have a pre-Pliocene fossil record in this region. It is thus tempting to speculate that the closure of the Isthmus of Panama played a role in shaping the modern seep fauna in the Caribbean.

Jurassic Halloween: Discovery of exocysts on echinoid spines from the Callovian of Israel

***Tomasz Borszcz¹, Mark A. Wilson² and Marcin Binkowski³**

¹*Department of Marine Ecology, Institute of Oceanology, Polish Academy of Sciences, Powstańców Warszawy 55, 81-712 Sopot, Poland*

²*Department of Geology, The College of Wooster, Wooster, Ohio 44691, USA*

³*X-ray Microtomography Lab, Institute of Computer Science, University of Silesia, 75 Pułku Piechoty 1, 41-500 Chorzów, Poland*

Calcified cysts provide direct evidence of parasitic interactions in ancient communities, thus offering unique insights into the evolution of biotic interactions. Until now parasites were found only on echinoid tests (coronae) and as internal infestations of spines. We discovered the first exocysts on echinoid spines from the Matmor Formation (Callovian of Israel). They represent the oldest infestation of spines. These “pumpkin masks” are located close to the spine base and their morphology (number of orifices, size, shape and spatial distribution) differs from all known echinoid infestations, including those reported on other Jurassic cidaroid hosts as well as on the irregular echinoid Collyrites. This new find demonstrates that: (i) the location of the cysts on echinoids is not linked with parasite



feeding preferences (settlement is random); (ii) parasitism was facilitated by epidermis-free spines, which is a common feature of cidaroids; (iii) parasitism intensity on echinoids was extremely low at that time, even in tropical settings; (iv) neither cyst abundance, geographic occurrence nor other ecological parameters followed a latitudinal gradient; (v) cyst size and abundance has not changed over geologic time; (vi) in contrast to modern distributions, cyst-dwelling parasites proliferated in shallow water, mid-Mesozoic calcite seas.

Variations in seasonality of productivity over the last 20 kyr in the bathyal NE Atlantic using foraminifera

***Curtis Bracher**

University of Plymouth

Benthic foraminifera (shelled protists) (> 63 μm) from the last 20 kyr were analysed from Ocean Drilling Program (ODP) Hole 980B (55°29.094'N, 14°42.137'W, 2168 m water depth), NE Atlantic Ocean. During the last 20 kyr, changes occurred in their accumulation rates, species composition and diversity. It has been shown that in the area today seasonal inputs of phytodetritus (phytoplankton detritus) to the ocean floor following the spring bloom in surface water primary productivity exert a strong influence on benthic foraminifera and other organisms. Benthic foraminifera respond rapidly to the presence of phytodetritus arriving on the sea floor by quickly colonising and feeding on the detritus, reproducing rapidly and building up large populations. In the area of ODP Hole 980B, the main 'phytodetritus species' are *Eponides pusillus*, *Nonionella iridea* and *Cassidulina obtusa*. These 'phytodetritus species' are abundant in ODP Hole 980B during the last 20 kyr and variations in their abundance are interpreted as resulting from changes in the seasonality of productivity.

Periwinkles graze holes in Pacific oyster shells

Gerhard C. Cadée

R. Neth. Inst. Sea Research (NIOZ)

The taphonomic explanation of holes in shells is not always easy. They may be produced by predators (boring gastropods, smashing stomatopods), abrasion during tumbling in the surf zone, transport over a sandy bottom and sandblasting. Can microboring organisms, living in shells of epibenthic mollusks and empty shells on the sea bottom, also cause holes in shells as sometimes suggested? I observed that the help of grazing herbivores is needed. In the Wadden Sea, gastropods *Littorina littorea* feeding on microborers make holes in the upper valves of intertidal Pacific oysters *Crassostrea gigas*. Endolithic lichens *Pyrenocollema halodytes* heavily infest these oysters. During life, oysters will add new shell material on the inside, but this stops after death. When the oysters remain attached, *Littorina* continues grazing the still living lichens. This results in holes and, finally, total destruction of the oyster shells.



Don't hold your breath: new constraints on atmospheric ρO_2 during Romer's Gap

***David Carpenter**¹, **John Marshall**¹, **David Beerling**² and **Charles Wellman**²

¹*University of Southampton*

²*University of Sheffield*

Following the End Devonian Mass Extinction tetrapods disappear almost completely from the fossil record for some 15 million years – a phenomenon known as Romer's Gap. Latest Devonian tetrapods were aquatic and equipped with a variable number of digits, front and back; following their reappearance they were fully terrestrialised and five-fingered. This apparent gap therefore covers a major turning point in vertebrate evolution, but the cause of the hiatus remains unclear. One common hypothesis, in part based on Palaeozoic atmospheric models, is that atmospheric oxygen levels were low during Romer's Gap and this drove tetrapod evolution. However, such models are highly complex and incorporate a number of assumptions which are difficult to test; disagreement over how to incorporate these in a realistic way has led to widely diverging outputs that are difficult to reconcile.

A high-resolution Famennian–Viséan record of wildfire frequency, based on the abundance of microscopic charcoal (inertinite) as dispersed organic matter in sedimentary rocks, is providing new insights into biosphere flammability, and hence an independent constraint on ρO_2 during this critical interval. Results thus far indicate no significant suppression of wildfire activity, suggesting that reduced atmospheric ρO_2 is not a viable explanation for Romer's Gap.

Palaeobiogeography of late Permian and Triassic temnospondyl amphibians: evidence for a provincialised stereospondyl radiation originating in western Gondwana

Daniel D. Cashmore and **Richard J. Butler**

University of Birmingham

Temnospondyls were the most speciose group of extinct amphibians. In the late Palaeozoic–early Mesozoic they inhabited the supercontinent of Pangaea during the unique environmental and biotic conditions of the end-Permian mass extinction and the subsequent Triassic recovery. They have an abundant fossil record and their worldwide distribution makes them ideal for biogeographical analysis. Geographical and phylogenetic data were collected for 143 late Permian–Triassic temnospondyls and a time-slicing protocol was implemented. By combining the most recent temnospondyl phylogenies each species was incorporated into a new informal supertree, to which a number of biogeographical methods were applied, including event-based tree-fitting, tests of palaeolatitudinal consistency and ancestral area reconstruction analyses. Results suggest that Late Permian and Early Triassic temnospondyl faunas were latitudinally provincialised as a result of climatic variation, with biogeographical processes governed by within-area speciation and minimal dispersal. By contrast, the Middle Triassic temnospondyl fauna was cosmopolitan and apparently unrestricted by any climatic or geographical barriers, whereas the Late Triassic had a latitudinally provincialised fauna governed by within-area speciation, again likely due to climatic controls. Ancestral area reconstructions also suggest that Stereospondyli originated within the Late Permian of western Gondwana.



Phylogeny of glypheidean lobsters (Crustacea, Decapoda)

Sylvain Charbonnier¹, *Denis Audo² and Véronique Barriol¹

¹UMR 7207 (CR2P) MNHN/UPMC, Département Histoire de la Terre, Muséum national d'Histoire naturelle, Paris, France

²Université de Rennes 1, EA 7316 'Biodiversité et Gestion des Territoires'

Glypheidean lobsters form a particularly specialized group of decapod crustaceans, which are highly diversified in the fossil record. They appeared in the Triassic, prospered in the Jurassic, and subsequently declined between the Cretaceous and the Eocene. They were thought to have become extinct in the Eocene until the discovery of two extant species from the Pacific. These discoveries raised questions about the phylogenetic position traditionally assigned to the glypheideans. If their position within Reptantia is still under debate, the delimitation of the whole group and the relationships with its close relatives are even more controversial. We present a phylogenetic analysis of 31 species: 27 fossil species from seven families (Glypheidae, Litogastridae, Mecochiridae, Pemphicidae, Erymidae, Clytiopsidae, Chimaerastacidae), and four extant species from three families (Glypheidae, Nephropidae, Stenopodidae). Most of the genera are coded exclusively based upon their type species and, as much as possible, based upon the type specimens. The cladistic analysis demonstrates that glypheideans form a monophyletic group including two superfamilies (Glypheoidea, Pemphicoidea). Glypheoidea includes three families (Glypheidae, Mecochiridae, Litogastridae). Litogastridae is the sister-group of the clade Glypheidae+Mecochiridae. Pemphicoidea includes a single family: Pemphicidae. A new classification is proposed and currently known genera are rearranged based upon the phylogenetic analysis.

A new Courceyan (Lower Carboniferous) eumalacostracan crustacean from the Forest of Dean

Neil D. L. Clark¹, Rollo Gillespie² and Sam F. Morris³

¹The Hunterian, Glasgow

²Kempsey, Worcestershire

³NHM, London

In 1982 the carapaces of an unknown Carboniferous crustacean were presented to the Natural History Museum. It was originally thought that these may represent a new species of *Teallicaris*. Further, better preserved, material has since been collected from the Great Doward in the Forest of Dean which allows a better comparison with other Carboniferous crustaceans. The new crustacean shows similarities with *Teallicaris* and the Scottish and Northern English crustacean *Pseudogalathea*. Although there are similarities, there are also some significant differences in the shape of the carapace and the ornamentation of the carapace and pleon. The broad, squat telson is more akin to *Pseudogalathea*, but the length of the pleon and the lack of elongated sharp postero-lateral angles to the carapace is more like that of *Teallicaris*. The lack of a scaphocerite and the lack of an enlarged third pleomere is more suggestive of affinities with *Pseudogalathea* however. PCA on 12 landmarks of the carapace indicate that this new crustacean is quite distinct from both *Teallicaris* and *Pseudogalathea* and represents a new genus and species of Lower Carboniferous eumalacostracan. Comparisons with other fossil crustaceans from around the world also suggest that this new crustacean is morphologically similar to *Chaocaris*, *Tylocaris*, *Fujianocaris*, *Pseudogalathea* and *Teallicaris*.



To what extent does depositional environment affect particle morphology in charcoal assemblages?

***Alastair J. Crawford and Claire M. Belcher**

University of Exeter

Charcoal particles, produced in wildfires and preserved in sediments, are a valuable indicator of past fire activity and environmental change. One source of this information is their morphology, which can indicate the botanical affinity of the source material, and may also affect the suitability of different methods for measuring charcoal quantity.

Previous work on this subject has focused on Late Quaternary lake sediments, which often present an optimal environment for preservation of the charcoal record. However other sedimentary archives may be studied, which may relate to different timescales and different taphonomic processes, and lead to differently preserved morphologies.

We have extracted mesocharcoal particles (> 125 µm) from a Mid-Late Holocene peat core, and from Mesozoic sedimentary rocks, and used image analysis to characterise the morphological variation in the charcoal present in these samples.

We will consider the effects of depositional environment and age on morphology, and whether these result in differential preservation of morphological information. We will assess whether such differences have implications for the quantification of charcoal particles, and thus for reconstructions of levels of fire activity, and whether they may affect the potential for broad taxonomic identification.

Testing habitat transitions in the first supertree of true crabs and hermit crabs (Brachyura and Anomura)

***Katie E. Davis, Tim Astrop and Matthew A. Wills**

University of Bath

It is generally accepted now from both morphological and molecular data that the infra-orders Anomura (hermit crabs and squat lobsters) and Brachyura (true crabs) are sister taxa, making up the clade Meiura. Relationships within these clades are however less clear. There is a wealth of phylogenetic data available for both groups, therefore supertree approaches lend themselves well to reconstructing a species-level phylogeny. Crabs are generally regarded as ocean-dwellers and although the vast majority of brachyurans are marine, there are 850 tropical and subtropical species living in freshwater, semi-terrestrial or terrestrial habitats. Similarly anomurans also occupy semi-terrestrial, freshwater and marine habitats. Historically, it was assumed that the transition from marine environments occurred just once, but there is growing evidence that within Brachyura there are two (Old and New World) or possibly more freshwater/terrestrial clades. We have built supertrees for the Brachyura and Anomura with a combined total of 2,000 taxa. We have used fossil data to calibrate our supertrees and have collated habitat data from TraitBank to optimise onto our supertrees. Our aim is to test how major events such as the Mesozoic Marine Revolution and the Cretaceous–Paleogene mass extinction affected habitat use and species diversification in these organisms.



Evidence for environmental change driving microevolution in Miocene sticklebacks (*Gasterosteus doryssus*)

***Rowan L. S. DeJardin¹**, **Melanie J. Leng^{2,3}**, **Sarah E. Metcalfe⁴**, **Michael A. Bell⁵** and **Mark A. Purnell¹**

¹*Department of Geology, University of Leicester, Leicester, UK*

²*NERC Isotope Geosciences Facilities, British Geological Survey, Nottingham, UK*

³*Centre for Environmental Geochemistry, University of Nottingham, Nottingham, UK*

⁴*School of Geography, University of Nottingham, Nottingham, UK*

⁵*Department of Ecology and Evolution, Stony Brook University, New York, USA*

Exceptionally preserved three-spine sticklebacks (*Gasterosteus doryssus*) from the Miocene diatomite of the Truckee Formation of Nevada, USA, provide a rare fossil example of finely resolved, directional microevolution through an interval of *c.*20 ka. The stickleback themselves have been subject to extensive study, but little has been done to investigate whether microevolutionary change correlates in any way with palaeoenvironmental changes in the lake where they lived. Here we test this hypothesis using microfossil data (diatom assemblages) and isotopic composition ($\delta^{13}\text{C}_{\text{bulk}}$, $\delta^{13}\text{C}_{\text{diatom}}$, and $\delta^{18}\text{O}_{\text{diatom}}$) as proxies for environmental and climatic change. Our analysis reveals that these proxies record a palaeoenvironmental trend towards increased evaporation, causing decreased lake-level and increased productivity, a trend that correlates with evolutionary changes in stickleback morphology. The hypothesis that this reflects a causal relationship is difficult to test, but a reduction in lake-level potentially drove stickleback microevolution by shifting predation pressures linked to increasingly benthic habitats in a shallower lake. Such adaptive morphological responses to changes in predation pressure are well documented in extant stickleback but this may be the first evidence for comparable adaptive responses in the fossil record.

The associated remains of a lamniform shark from the Maastrichtian (late Cretaceous) phosphates of northern Morocco

***Neil Donnelly¹**, **Charlie J. Underwood¹**, **David J. Ward²** and **Emma L. Bernard²**

¹*School of Earth Sciences, Birkbeck College, Malet Street, London WC1E 7HX, UK*

²*Department of Earth Sciences, The Natural History Museum, London SW7 5BD, UK*

The extinct lamniform shark “*Cretalamna*” *maroccana*, (Arambourg) is thought to have lived in the period between the Late Cretaceous (Maastrichtian) and the Early Paleocene (Danian). Whilst relatively common in the fossil record, “*C.* *maroccana*” has previously only been described from isolated teeth and is consequently poorly understood. In February 2014 representatives from the Department of Earth Sciences at the Natural History Museum (NHMUK), London, purchased a plaster-jacketed block of poorly consolidated phosphorite from a commercial dealer at Ouled Bouali, Morocco. This block contains an exceptionally preserved specimen of “*C.* *maroccana*” comprising 69 teeth, 59 associated vertebrae, jaw and skull material. Additionally present are 29 vertebrae in separate blocks.

Our work focuses on tooth morphology, dentition reconstruction and description of vertebrae. Sampling microvertebrate fauna in the phosphorite matrix helped confirm the specimen’s stratigraphic provenance, stated as and consistent with the vertebrate bone bed 2.65 m below the top of the Maastrichtian sediments at Sidi Chennane phosphate pit.



The genus *Cretalamna* is currently used to accommodate a number of species that share few features with the type species, *Cretalamna appendiculata* (Agassiz) and should be considered generically distinct. Reconstructing the dentition of "*C.* *maroccana*" is essential in determining its phylogenetic relationships within the lamniformes.

New crinoids from the Lynton Formation (Devonian) of the Valley of Rocks, North Devon, England

***Stephen K. Donovan**¹ and **Fiona. E. Fearnhead**²

¹*Department of Geology, Naturalis Biodiversity Center, Darwinweg 2, 2333 CR Leiden, Netherlands*

²*The Natural History Museum, Cromwell Road, London SW7 5BD, UK*

Studies of British Devonian crinoid columnals have lagged behind those of the Lower Palaeozoic and Mississippian, yet museum collections are replete with unidentified material. F. E. F. undertook a short field season collecting from the Lower–Middle Devonian of the Valley of Rocks, west of Lynton, north Devon. Specimens were collected from (mainly) the Lynton Slates Formation (Emsian to Eifelian; Lower to Upper Devonian). This site preserves rich columnal accumulations. The Lower Devonian crinoids of south-west England remain poorly known, while those of the Middle Devonian are known mainly from the Givetian limestones of south Devon.

Columnals (rarely pluricolumnals and brachials) are preserved as external moulds on slabs of fine-grained sandstone that are conducive to casting in rubber. Diversity is limited, perhaps six or so morphospecies. Some taxa are reminiscent of those described by Le Menn from coeval rocks of Portugal and the Boulonnais, northern France. The commonest columnals are from the proxistele of the monobathrid *Hexacrinites*. We conclude that studies of British Devonian crinoid columnals have the potential to provide data and insights that are not possible from the rarer thecal material found at relatively few sites.

F. E. F. acknowledges the support of an award from the Richard Owen Research Fund, Palaeontographical Society.

Quantifying diffusion periods in marine and terrestrial vertebrate fossils using rare earth elements

***Amanda E. Drewicz**¹, **David E. Grandstaff**², **Dennis O. Terry**² and **Richard D. Ash**³

¹*Boise State University*

²*Temple University*

³*University of Maryland*

Rare earth elements (REE), trace elements (TE), and uranium (U) in vertebrate fossils have been used to study taphonomy/reworking, stratigraphic correlation, palaeodiet, fossilization processes, and as proxies for palaeoenvironment reconstruction. REE and U are incorporated in fossils by diffusion during apatite recrystallization. Recrystallization periods in bone are poorly known, but may be calculated using diffusion models. This allows better refinement of temporal resolution of geochemically-based palaeoenvironmental reconstructions. Five late Eocene brontothere bones from the White River Group and three Miocene marine mammals from the U.S. Atlantic Coastal Plain were analyzed using LA-ICP-MS. Compared to terrestrial fossils, REE depth fractionation is less pronounced



in marine specimens, which may result from a greater influence of secondary diffusion pathways (Haversian systems). Diffusion periods were shorter in marine fossils (2.8 to 0.9 ka), when compared to terrestrial specimens (55 to 2.2 ka). Discrepancies in diffusion periods may result from intermittent aqueous saturation in terrestrial environments. Previous studies of soft tissue preservation in fossil bone concluded that diffusion must outpace decay for soft tissue preservation. The calculated diffusion periods suggest that biomolecule preservation in deep time would be favoured in water-saturated environments.

Analysing dinosaur biogeographic connectivity in relation to Mesozoic continental fragmentation

***Alexander M. Dunhill¹ and James Sciberras²**

¹*University of Leeds*

²*University of Bath*

Network Theory is widely used in a number of diverse fields and is a powerful framework for studying the structure of biological systems. Despite this, it has been seldom used in palaeobiological studies. Here, we use network analysis to map dinosaur connectivity across major continental landmasses through time. We also present a second set of network models illustrating Mesozoic continental fragmentation. Results show that family-level connectivity increases through the Mesozoic, despite the ongoing fragmentation of major continental landmasses and rising sea levels. However, the establishment of novel connections decreases through time and is thus positively correlated with continental connectivity. These results show that, as major landmasses underwent fragmentation from Pangaea, to Laurasia and Gondwana, through to complete separation, the potential for novel interconnectivity between continental dinosaur communities decreased significantly. This suggests that the higher taxonomic structure of dinosaur biogeography was established earlier in the Mesozoic, when all landmasses were linked via continental aggregation or sea-level-driven land-bridge formation. This biogeographic pattern was then sustained through to the end of the Cretaceous.

Taphonomic biases in Quaternary reef corals of Indonesia

***Kilian K. E. Eichenseer and Wolfgang Kiessling**

Friedrich-Alexander-Universität Erlangen-Nürnberg

Information from fossil coral reefs is increasingly used to explore the sensitivity of these ecosystems to climate change. However, a fossil reef does not represent a perfect image of the former living reef. To determine the magnitude and causes of the expected bias by taphonomic processes, we analysed living and fossil coral reefs on Sulawesi (Indonesia). We quantified the coral fauna focusing on the three dominant families (Acroporidae, Faviidae and Poritidae) and compared their relative abundance today and in three Quaternary reef terraces. These range in age from the Holocene to the Last Interglacial *c.*130 ky ago. Multiple locations were studied and ANOVA applied to separate temporal from spatial variability. All but one fossil reef are depleted in poritids and enriched in faviids relative to today, but only the depletion in poritids is likely a true taphonomic bias. Even though the fossil record of Quaternary coral faunas does not exactly mirror the former taxonomic live composition, the bias is small enough that biological signals, which may arise from climate change, can be recognized.



Palaeoecology of Cenozoic marine molluscs using stable isotopes of shell-bound organic matter (SBOM)

***Hannah C. Elms¹, Edine Pape¹, Martin Zushchin², Fiona L. Gill¹, Crispin T. S. Little¹ and Robert J. Newton¹**

¹University of Leeds

²University of Vienna

Reconstructions of feeding strategies of fossils are usually based on analogy using the diet of modern relatives, where available. However, direct evidence for such fossil feeding strategies is currently limited. Carbon, nitrogen and sulfur stable isotopic signatures in shell-bound organic matter (SBOM) of molluscs are related to those of soft tissues, which are affected by diet. This project investigates the SBOM stable isotope signature of Miocene marine molluscs interpreted to have three distinct feeding strategies. If there is a consistent relationship between feeding strategy and isotopic signature, this approach has the potential to aid understanding of the diet of fossil marine fauna and trophic structure of past marine ecosystems.

SBOM was extracted from six Miocene gastropod species and one modern species, spanning a range of assumed feeding strategies including carnivory, algal detrital grazing and filter feeding. Inter-crystalline and intra-crystalline SBOM were analysed separately, as intra-crystalline SBOM is thought to be less susceptible to diagenetic alteration.

We present isotopic data as evidence for diverse feeding strategies in Cenozoic marine fossils. This approach has previously been used to investigate chemosymbiosis in the fossil record. Here it is extended to evaluate the SBOM isotopic signatures for a wider range of nutritional strategies.

Characterization of appendage locomotion using the Radial Moment of Inertia; case study of pterosaur flight

***Cesar A. Espinoza-Campuzano**

School of Earth Sciences and Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, UK

The moment of inertia (I) has been used previously to characterize locomotion (flapping frequency and manoeuvrability) because it reflects the forces acting in a bone. If there are more than two forces acting in a bone the moment of inertia will only provide information on two axes (I_x and I_y), eliminating the possibility of establishing important patterns in the type of locomotion.

I propose to use a new parameter Radial Moment of Inertia (I_{rad}) to obtain graphs, with shapes that can be compared between organisms. These graphs of (I) will represent the stress endured around the bone because of muscular activity.

A computational implementation of the I_{rad} is currently being developed. Here I present the I_{rad} applied to proximal thin sections of the humerus of birds, bats and one pterosaur species (*Bennettazhia oregonensis*).

The patterns provided by the I_{rad} analysis distinguished two flight types in relation to the muscles involved in stroke action, the birds with resistance spikes in one axis and bats with three different axes. Pterosaur section I_{rad} was similar to the bird pattern with only one



axis of resistance, suggesting that birds are indeed the better analogue for pterosaur flight, although further analysis is needed.

Reconstructing ancestral animal feeding modes; a Bayesian inference on the origin of predation

***Cesar A. Espinoza-Campuzano¹, Jakob Vinther¹, Davide Pisani¹ and Erik Sperling²**

¹*School of Earth Sciences and Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, UK*

²*Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge MA 02138, USA*

The evolution of predation is an important transition in animal evolution. The appearance of macrophagous carnivores may have spurred the Cambrian explosion. While several carnivorous groups appear in the early Cambrian, the true origin might be more ancient. It is not clear if predation evolved convergently in several lineages or if it is ancestral to several phyla and the timing of this evolution is key claiming causality for the Cambrian explosion.

To test these linkages, we implemented an ancestral character reconstruction (ACR) using a time-calibrated phylogenetic tree of over 223 metazoan taxa. According to the best model for our database and with phylogenetic uncertainty taken into account, the first ancestor that is strongly supported as a predator was the node of Nemertea in the late Ediacaran (556 My).

This date supports an arms-race driver for the Cambrian explosion. However, in some analyses several deeper nodes were reconstructed as predators, albeit with low Bayesian support. In particular the ancestors of Ecdysozoa and Protostomia (Ediacaran and late Cryogenian, respectively), which would decouple the origins of predation from the Cambrian radiation. We further present a novel geochemical ACR that gives similar predator nodes as the qualitative one: Ecdysozoa or Nemertea + Platyhelminthes.

The Identification and Advisory Service, Natural History Museum, UK

***Fiona E. Fearnhead, S. Hine, F. Feneru, C. Fisher and F. Rumsey**

The Natural History Museum, London, UK

Natural History has been a popular pastime in the British Isles for over 200 years. That it retains its popularity is undoubtedly due to multiple influences, such as by David Attenborough's enthusiasm in authored documentaries such as *Life on Earth*, *Blue Planet* and *Natural Curiosities*. This curiosity has resulted in many people asking 'What is this?' and directing their queries to the Angela Marmont Centre at the Natural History Museum (NHM), where we try to provide informed answers. With the great interconnectivity provided by the Web, Facebook, Twitter, scientific knowledge has become accessible to a far wider public audience. Emerging media technologies on a wide range of digital platforms and devices have enabled boundaries to be crossed, supporting equality of opportunity. All these innovations have impacted on the Identification and Advisory Service of the NHM and have contributed to changes in the type of questions asked and the style of enquiries. The challenge for the Identification and Advisory Service is how to support an ever-increasing number of inquiries, providing authentic answers to more sophisticated questions, supporting inquirer learning towards a better understanding and knowledge of taxonomy.



Test abnormalities in larger benthic foraminifera from hypersaline coastal ponds of the United Arab Emirates (UAE)

Flavia Fiorini and Stephen W. Lokier

The Petroleum Institute, P.O. Box 2533, Abu Dhabi, United Arab Emirates

The benthic foraminifera assemblage from recent coastal ponds located in the inter-tidal zone of the UAE Western Region was investigated with the aim of providing modern analogues for understanding ancient near-shore environments.

The studied hypersaline coastal ponds are located between a lagoonal area and the supratidal sabkha. Detached blades of sea grass and microbial mats were present in the ponds.

The samples show an assemblage dominated by epiphytic larger benthic foraminifera as *Peneroplis pertusus* and *P. planatus*. High percentages (up to 50% of the living assemblage) of anomalous tests of the benthic foraminifera *Peneroplis*, *Spirolina* and *Sorites* were observed. The observed anomalies included dissolution, microboring and abnormality in growth. Different forms of abnormal test architecture were recorded: presence of multiple apertures with reduced size, deformation in the test shape and abnormal coiling.

The high percentage of abnormal tests reflects natural environmental stress. The unique presence of epiphytic species suggests that they may be transported into the pond together with seagrass either during high tides or in storm surge events, and continued to live in the pond. This hypothesis is supported by the fact that all the abnormal foraminifera are adult and show a normal proloculus and normal growth of the earlier chambers.

The Anthropocene Biostratigraphy of Leicestershire

***Deborah Fish**

University of Leicester

The Anthropocene reflects a large biological impact as a result of human interaction with the environment. Leicestershire, England shows evidence of this impact from the beginning of the Holocene to present day, using archaeological findings and more traditional geological techniques, such as core logging in lakes. The impact is most clearly seen in mammals, due to their uses as food sources and pets. Changes in mammal composition in the region have not been constant over the Holocene, and a wave of introductions and extinctions came with each human invasion of the UK. The most obvious change is within the past 1,000 years, as human population of the area exploded, with the spread of urban areas and the expansion of global trade. Other types of fauna analysed, specifically gastropods and ostracods, react to human influence differently to mammals, as they are not directly used for human benefit. These invertebrates likely respond more closely to changes in forest cover and temperature. The successive assemblages reflect human impact on the biology of Leicestershire, and may help constrain boundary level between the Anthropocene and the Holocene.



The microorganisms of a 430-million-year-old hydrothermal vent community

***Magdalena N. Georgieva**^{1,2}, **Crispin T. S. Little**¹, **Adrian G. Glover**² and **Alexander D. Ball**²

¹*University of Leeds*

²*Natural History Museum*

Microorganisms are the chief primary producers within present-day deep-sea hydrothermal vent ecosystems, and play a fundamental role in shaping the ecology of these unique environments. However, little is known about the microorganisms that occurred within, and structured, ancient vent communities – their evolutionary history, diversity, and the nature of their interactions with hydrothermal vent animals are largely undetermined. The oldest known hydrothermal vent community occurs in the Yaman–Kasy deposit of the Ural Mountains, Russia, which dates back to the Silurian, 430 Ma. This deposit contains two types of dwelling tube fossils attributed to the polychaete worms – the large tubes of *Yamankasia rifeia*, and the smaller tubes of *Eoalvinelloides annulatus*. A re-examination of these tube fossils using scanning electron microscopy reveals the preservation of several filament morphotypes that strongly resemble modern hydrothermal vent microbial filaments, such as those preserved within the mineralised tubes of the vent polychaete genus *Alvinella*. At least three distinct filament types showing different spatial distributions are found in association with the Yaman–Kasy fossil tubes. These results represent the oldest animal–microbial associations preserved in an ancient hydrothermal vent environment, and shed insights into the diversity of microorganisms in ancient vents, and into the palaeoecology of these systems.

Synchrotron ultraviolet luminescence microscopy and spectroscopy of well-preserved fossils: preliminary results

***Pierre Gueriau**^{1,2}, **Mathieu Thoury**^{2,3}, **Tatiana Séverin-Fabiani**^{2,3}, **Mathieu Réfrégiers**³, **Didier B. Dutheil**¹, **Bouziane Khalloufi**¹ and **Loïc Bertrand**^{2,3}

¹*Muséum national d'Histoire naturelle, CR2P, UMR 7207 CNRS, MNHN, UPMC, 57 rue Cuvier, CP 38, F-75005, Paris, France*

²*PANEMA, CNRS, MCC, USR 3461, BP48 Saint-Aubin, F-91192 Gif-sur-Yvette, France*

³*SOLEIL synchrotron, BP48 Saint-Aubin, F-91192 Gif-sur-Yvette, France*

Ultraviolet (UV) photography is now used on a regular basis in palaeontology, as it allows detection of hidden bony sutures and the separation of bones, scales or soft parts from either the underlying matrix or each other. However, we know almost nothing of the chemical basis behind the structures that can be seen in fossils using UV. Nevertheless, most of these different fossilized tissues – both mineralized skeleton bioapatite and authigenic apatite that have replicated soft-tissues such as muscles, are mineralized in apatite group minerals, which are among the most interesting luminescent minerals, this luminescence being often associated with the incorporation of rare earth elements. We used synchrotron UV luminescence microscopy and spectroscopy at the DISCO beamline (SOLEIL synchrotron, France) on well-preserved fossil fishes and shrimps from the Djebel Oum Tkout Lagerstätte (Late Cretaceous of Morocco) in order to address this issue. Preliminary UV/visible luminescence imaging experiments clearly reveal luminescence distribution patterns and allow highlighting of anatomical structures previously indiscernible. On another hand, high spatial resolution UV/visible luminescence emission spectra display emission bands consistent with cerium incorporation in apatite minerals. Such new tools therefore appear very promising for the visualization of indiscernible or hardly discernible anatomical details and to get insight into diagenetic processes.



Records of Antarctic seasonal variation preserved in bivalve shells across the Cretaceous/Paleogene mass extinction

***Joanna L. O. Hall¹**, Alan M. Haywood¹, Stephen J. Hunter¹, Robert J. Newton¹, Jane E. Francis², J. Alistair Crame² and Elizabeth M. Harper³

¹University of Leeds

²British Antarctic Survey

³University of Cambridge

The Late Cretaceous to Early Paleogene of Antarctica has long been highlighted as a time of extreme seasonality on a scale unseen in modern temperate climates. This potential for heightened seasonal variability is often overlooked in interpretations of geochemical proxy records which may result in misleading palaeoenvironment reconstructions.

Seymour Island's many species of thick-shelled bivalves serve as valuable high-resolution multiproxy archives in the marine realm. Microanalysis of well-preserved original shell carbonate can be used to provide near-monthly palaeoenvironmental data including proxies for temperature, water geochemistry and productivity during annual growing seasons.

Long-lived bivalves of the genus *Labillia* and *Cucullaea*, found in the pre-extinction and recovery fauna across the Cretaceous–Paleogene boundary sequence, have been examined to assess preservation for use as archives of seasonal climate information. High-resolution stable isotope results show trends related to visible annual growth banding in the valve and tooth which allow reconstruction of age and growth history of individual specimens. Here we present the results of preservation studies and initial high resolution geochemical analyses, and discuss subsequent potential for reconstruction of seasonal trends through the stratigraphic sequence on Seymour Island to yield new palaeoecology data.

Seasonal bivalve $\delta^{13}\text{C}$ records from Seymour Island, Antarctica: Implications for Maastrichtian hydrocarbon release

***Joanna L. O. Hall¹**, Alan M. Haywood¹, Stephen J. Hunter¹, Robert J. Newton¹, Jane E. Francis², J. Alistair Crame² and Elizabeth M. Harper³

¹University of Leeds

²British Antarctic Survey

³University of Cambridge

Fossil hydrocarbon seeps are known from the Maastrichtian sequences of the Lopez de Bertodano Formation on Seymour Island, but little attempt has been made to determine the mechanism for their release. Recent discovery of features such as ephemeral ice sheets have highlighted the climate variability of the James Ross Basin during the Late Cretaceous to early Paleogene, including a brief warming period during the latest Maastrichtian which may have produced conditions capable of destabilising sedimentary hydrocarbon reservoirs.

Sub-annual resolution stable carbon and oxygen isotope analysis of well-preserved aragonitic infaunal bivalves from across the Cretaceous–Paleogene Boundary reveals evidence for an annual seasonally-occurring light carbon excursion (up to -34‰) peaking in the early spring. This trend is recorded in specimens of *Cucullaea* and *Labillia* bivalves over several tens of metres both above and below the boundary, providing bottom-up evidence to support the existence of long-term episodes of seasonal hydrocarbon release as a result of bottom water warming. The unprecedented dominance of the bivalve carbon isotope signal by these periodic effusions also has provocative implications about the state of the local circulatory and geochemical environment within the James Ross Basin.



Packed with shells: unusual burrows in the Oligocene of Antigua, West Indies

David A. T. Harper¹, Stephen K. Donovan² and Roger W. Portell³

¹Durham University

²Naturalis Biodiversity Center, Leiden

³Florida Museum of Natural History

Ichnology is a 'Cinderella' area of study in Antillean Earth Sciences, with rare, well-studied exceptions such as the Cenozoic of Jamaica and the Middle Miocene of Carriacou. The authors are currently correcting this omission on one island, Antigua, principally in the Upper Oligocene Antigua Formation. Although identifiable traces include ichnogenera already well known from the region, rare burrows at two sites are unusual, being filled with densely packed debris of the shelly benthos. Unlined burrows (*Planolites*) in deep-water biofacies at Half Moon Bay, parish of Saint Philip, are packed with a monospecific assemblage of large benthic foraminiferans (*Lepidocyclina canelli* Lemoine & Douvillé) and a single brachiopod valve, *Tichosina* sp. A similar burrow in shallower-water biofacies at Hughes Point, parish of Saint Philip, is packed with asteroid marginal ossicles and, particularly, test fragments of the spatangoid echinoid *Lovenia* sp. Fragments of the same echinoid line the burrow attributed to sea anemones, *Bergaueria* isp. The latter is probably a physical accumulation, the common fragments of echinoid being washed into an empty burrow. In contrast, the infill of *Planolites* isp. is more likely to be an accumulation mediated by the burrower.

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Palaeoecological analysis of a highly diverse Late Triassic marine biota from the Cassian Formation (North Italy, Dolomites)

***Imelda M. Hausmann¹ and Alexander Nützel²**

¹Department für Paläontologie, Universität Wien, 1090 Vienna, Austria;

<imelda.hausmann@gmx.de>

²NSB-Bayerische Staatssammlung für Paläontologie und Geologie, Department für Geo- und Umweltwissenschaften, Paläontologie & Geobiologie, Geobio-Centre, Ludwig-

Maximilians-Universität München, 80333 Munich, Germany; <a.nuetzel@lrz.uni-muenchen.de>

A bulk sample of marine invertebrates from the Late Triassic Cassian Formation (North Italy, Dolomites) yields one of the most diverse Early Mesozoic fossil assemblages ever reported. The assemblage is strongly dominated by molluscs, especially by gastropods. Rarefaction analyses suggest that the bulk sample and a surface collection from the same locality share the same diversity. However, taxonomic composition, species richness and rank abundance differ strongly according to sampling method. Most of the fossils are smaller than 1cm, reflecting small adult sizes and size sorting during transport. Fragmentation, microbial encrustation and the high portion of ooids, oncoids and peloids indicate that the fossil assemblage was transported from a carbonate platform into the adjacent basin, where it was embedded within basin clays. The low-grade lithification of clayey sediments facilitates the disaggregation, the discovering of small fossils, and hence the recognition of this especially high diversity. Sample standardization shows that the studied Late Triassic assemblage is much more diverse than other Early Triassic marine assemblages, but diversity is comparable to Anisian (Middle Triassic) assemblages. According to current models, the diversity of the studied marine assemblage meets the predictions for the transition from the niche overlap to the habitat contraction phase.



The Llanfallteg biota – exceptional preservation of a Burgess Shale-type arthropod from the Middle Ordovician of South Wales

***Thomas W. Hearing**^{1,2}, **David A. Legg**³, **Lucy A. Muir**⁴, **Joseph P. Botting**⁴ and **Martin D. Brasier**^{1,3}

¹Department of Earth Science, University of Oxford, South Parks Road, Oxford OX1 3AN, UK

²Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, UK

³Oxford University Museum of Natural History, Parks Road, Oxford OX1 3PW, UK

⁴White Heather, Western Promenade, Llandrindod LD1 5HR

Many groups of soft-bodied invertebrates are well-known from Cambrian *Konservat-Lagerstätten* but are commonly considered to disappear by the end of this period, replaced by a ‘Palaeozoic evolutionary fauna’ dominated by suspension feeding brachiopods, echinoderms and cephalopods. Two principal hypotheses have been invoked to explain this disappearance: a real and immediate biotic turnover, and changing seafloor taphonomic conditions possibly related to increasing bioturbation. Although recent discoveries of post Cambrian Burgess Shale-type Lagerstätten challenge the first hypothesis, available examples have been stratigraphically sporadic (Lower Ordovician Fezouata Formation, Morocco; Upper Ordovician Soom Shale, South Africa) and provide only isolated snapshots of ancient biodiversity. A newly discovered xenopod arthropod from the Middle Ordovician Llanfallteg Formation, South Wales, plus associated fossils, help to bridge the gap. This taxon shows similarities to xenopod arthropods such as *Emeraldella* and *Sidneyia* from the middle Cambrian Burgess Shale Formation. In the Llanfallteg Formation, this Burgess Shale-type taxon co-existed with benthic taxa more typical for the Middle Ordovician of Avalonia, including atheloptic trilobites, some with phosphatised digestive tracts. This site extends the stratigraphic ranges of an otherwise exclusively Cambrian clade, and throws new light upon the taphonomic pathway required to preserve such animals.

Fossil ostracods as proxies for salinity changes on the south-western shelf of the Black Sea during the Holocene

David J. Horne¹, **Lee Bradley**² and **Lorna Williams**³

¹Queen Mary University of London, UK

²University of Liverpool, UK

³Fugro Geosurveys, St John’s, Canada

The Holocene reconnection of the Black Sea to the Mediterranean has provoked debate on several issues including Black Sea salinity prior to the establishment of the present two-way flow through the Bosphorus Strait. Fossil ostracod analyses in sediment cores from the south-western shelf of the Black Sea facilitate a qualitative reconstruction of past salinity levels. Ostracod preservation is good throughout and often excellent, with occasional soft-part preservation. Taphonomic analyses show that most of the significant taxa are *in situ* (with suites of adult and juvenile moult stages) and show little evidence of post-mortem transport, mixing or size-sorting. Before the reconnection, ‘caspi-brackish’ assemblages including *Ammicythere olivia* (Livental, 1938), *Ammicythere quinquetuberculata* (Schweyer, 1949), *Candona schweyeri* Schornikov, 1964, *Euxinocythere bacuana* (Livental, 1929) and *Loxoconcha lepida* Stepanaitys, 1962 are present, indicative of low-salinity brackish water. There is no evidence for freshwater as has been claimed by some authors; indeed there is marked absence of typical freshwater ostracods such as are common in surrounding areas today as well as in the Holocene. After reconnection, assemblages typically include marine species with Mediterranean affinities such as *Carinocythereis carinata* (Roemer, 1838), *Cytheroma marinovi* Schornikov, 1967, *Hiltermannicythere rubra pontica* (Dubowksi, 1939) and *Palmoconcha agilis* (Ruggieri, 1967).



Reconstructing the rangeomorph body plan: fractal models reveal adaptive optimisation in the Ediacaran

***Jennifer Hoyal Cuthill and Simon Conway Morris**

Department of Earth Sciences, University of Cambridge

The large, frond-like 'rangeomorphs', which make a dramatic entrance into the fossil record during the late Ediacaran Period (from 580 Ma), have been called bizarre, fractal and a failed experiment in evolution. As some of the earliest known macro-organisms they offer tantalising insights into the evolution of multicellular eukaryotes. However, rangeomorphs are morphologically distinctive and inhabited the non-uniformitarian Precambrian oceans. As a result, many questions regarding their patterns of growth and development, the validity of the rangeomorph clade, their feeding mode, adaptive optimality, and ultimate extinction have proved difficult to answer. Here, we present a unified quantitative model for rangeomorph growth, development and resultant morphology, using parametric Lindenmayer systems. This provides a formal description of their fractal branching patterns and supports a rangeomorph clade united by a shared body plan. By reproducing rangeomorph branching patterns, we generate realistic 3D computer models which allow us to estimate functionally relevant properties of their morphologies. This sheds new light on their feeding mode and efficiency as well as the reasons for their disappearance around the Cambrian boundary.

New occurrences and extension of the stratigraphical range of discoidal Ediacara-type fossils on the Digermul Peninsula, northern Norway

Anette E. S. Högstrom¹, Jan-Ove Ebbestad², Sören Jensen³, Teodoro Palacios³, Guido Meinhold⁴, Wendy L. Taylor⁵, Linn K. Novis¹, Heda Agic⁶ and Małgorzata Moczyłowska⁶

¹*Tromsø University Museum, Natural Sciences*

²*Museum of Evolution, Uppsala University*

³*Universidad de Extremadura, Badajoz*

⁴*Geoscience Center of the University of Göttingen*

⁵*Department of Geological Sciences, University of Cape Town*

⁶*Department of Earth Sciences, Uppsala University*

In Scandinavia the evolutionary events across the Ediacaran–Cambrian transition can only be studied in continuous section on the Digermul Peninsula, northern Norway, in the siliciclastic Ståhpogiedde Formation. This roughly 500 m-thick unit comprises, in ascending order, the Lillevannet, Innerelva and Manndraperelva members. Trace fossils, including *Treptichnus pedum*, and organic-walled microfossils, including *Granomarginata prima*, position the base of the Cambrian in the upper part of the Manndraperelva Member. Some 20 years ago discoidal Ediacara-type fossils were found in the middle part of Innerelva Member. Recent field seasons have provided abundant new material of *Aspidella*-type fossils and extended their stratigraphical range to within about 15 m above the Lillevannet Member. The exclusive presence of discoidal forms may reflect a taphonomic bias and/or be evidence of a greater age than that of the more diverse Ediacaran assemblages. That the latter may be the case is indicated by the stratigraphic proximity of the lowest occurrences of *Aspidella* to the Mortensnes diamictite, recently tentatively considered a Gaskiers glaciation equivalent (c.580 Ma). This raises the question of hitherto unrecognised breaks in sedimentation in the Ståhpogiedde Formation. In order to explore this question we have sampled the succession for organic-walled microfossils, detrital mineral geochronology and sediment geochemistry.



A new proxy for fossil sunshine based on pollen wall chemistry

***Phillip E. Jardine**¹, **Wesley T. Fraser**², **Barry H. Lomax**³ and **William D. Gosling**⁴

¹*The Open University*

²*Oxford Brookes University*

³*University of Nottingham*

⁴*University of Amsterdam*

Despite the importance of solar irradiance as a dominant control on Earth's energy budget, no proxy has been developed that can provide total solar irradiance (TSI) reconstructions prior to the Holocene. Here, we present a novel proxy based on the chemical composition of sporopollenin, the primary component of the outer walls of pollen and spores (sporomorphs). Sporopollenin chemistry is responsive to levels of ultraviolet-B (UV-B) radiation exposure, which offers the possibility of using fossil sporomorph chemistry as a proxy for past UV-B flux and, by extension, TSI. The high preservation potential of sporomorphs means that this new proxy has the potential to reconstruct UV-B and TSI flux over much longer timescales than has previously been possible. Furthermore, Fourier Transform infrared (FTIR) spectroscopy allows sporopollenin chemistry to be rapidly assessed on small sample sizes (≤ 10 sporomorphs/sample). We demonstrate the utility of this proxy using grass pollen chemistry data from the Late Pleistocene of Ghana, and relate this to modelled mean annual TSI. This proxy provides a new approach for quantifying the relationship between TSI, climate and vegetation change. The unpicking of this information offers the tantalising potential to determine how changes in solar irradiance have driven long-term changes in floral assemblages.

Sequence stratigraphic control over biofacies distribution and ecological gradients in the Mississippian Lodgepole Formation, Montana

***Emilia Jarochovska**¹, **Allison L. Keller**², **Julien Kimmig**³, **Ekaterina Larina**⁴, **Rhiannon J. LaVine**⁵, **Katharine M. Loughney**⁶, **Emily A. Orzechowski**⁷, **Nadia D. Pierrehumbert**⁵, **Alexis Rojas**⁸, **Judith A. Sclafani**⁹, **Amy Singer**¹⁰, **Joyce A. Yager**¹¹, **Max Christie**⁹, **Sharon K. McMullen**¹², **Steven M. Holland**¹³ and **Mark E. Patzkowsky**⁹

¹*GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany*

²*Department of Earth Sciences, University of California, Riverside, CA, USA*

³*Department of Geological Sciences, University of Saskatchewan, Saskatoon, Canada*

⁴*Earth and Environmental Sciences, Brooklyn College, Brooklyn, NY, USA*

⁵*Department of the Geophysical Sciences, University of Chicago, Chicago, IL, USA*

⁶*Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI, USA*

⁷*Department of Integrative Biology, The University of California, Berkeley, CA, USA*

⁸*Florida Museum of Natural History, Gainesville, FL, USA*

⁹*Department of Geosciences, The Pennsylvania State University, University Park, PA, USA*

¹⁰*Geosciences, University of Montana, Missoula, MT, USA*

¹¹*Earth Sciences, University of Southern California, Los Angeles, CA, USA*

¹²*Department of Geosciences, University of Wisconsin-Madison, Madison, WI, USA*

¹³*Department of Geology, University of Georgia, Athens, GA, USA*

Sequence stratigraphy provides the tools to predict the occurrences of marine taxa and test hypotheses on the diversity of faunal assemblages in response to relative sea-level change.



We examined this relationship during the Stratigraphic Paleobiology field course sponsored by the Paleontological Society in July 2014.

The Mississippian Lodgepole Fm is represented by three depositional sequences developed in a sub-tropical carbonate platform. We counted over 3,000 faunal specimens in 93 field counts within the sequence stratigraphic architecture. Using detrended correspondence analysis (DCA), we have identified two faunal gradients. The first gradient corresponds to water depth, and the second separates taxa by attachment, which we interpret as substrate affinity. DCA reveals no directional change in the position along the onshore-offshore gradient within bedsets representing the same lithofacies across consecutive parasequences, but the influence of the sequence-stratigraphic architecture is visible in the faunal composition at the level of systems tracts. Richness and evenness of samples are both greater in the deep subtidal than in shallower facies. Niche response curves show that more taxa had their preferred environment in deeper-water facies, and that rare taxa have a greater variance in environmental tolerance than common taxa.

In defence of the Fortune Head Cambrian GSSP

Sören Jensen¹ and Graham E. Budd²

¹*Universidad de Extremadura, Badajoz*

²*Department of Earth Sciences, Uppsala University*

The decision to base the Cambrian GSSP on trace fossils was controversial at the time of its ratification in 1994, and has remained so to date. Recently efforts have been set in motion to evaluate if the definition of the base of the Cambrian should be re-opened. We would be more enthusiastic if there were clearly superior globally-correlatable levels, but we do not see this being the case. Rather, there are advantages with the current deep placement of the Cambrian GSSP, and we believe its deficiencies have been overstated. It has considerable conceptual value as it undoubtedly approximates a time of biotic radiation and major changes in benthic ecology. It is readily correlatable into most areas, yet so deep that most questions of inter-regional correlation become intra-Cambrian. Claimed problems of correlation into Siberia do not consider a growing body of trace fossil data from northern Siberia. Efforts are certainly needed on advancing knowledge of the Fortune Head GSSP section, including studies to evaluate the sub-GSSP *Treptichnus pedum*. Work in progress shows that much remains to be done on organic-walled microfossils in this section, and the possibilities to add further chemostratigraphical data should be explored.

Are all characters created equal? Identifying taxonomically meaningful characters in the Ediacaran

***Charlotte G. Kenchington**

University of Cambridge

The late Neoproterozoic witnessed the emergence of the first complex macro-organisms. Among these are the rangeomorphs, a group of enigmatic forms traditionally grouped with the 'Ediacara biota'. Rangeomorphs are pseudo-fractal organisms, including iconic Ediacaran fossils such as *Charnia masoni*. They have no known close biological relations in the modern world; coupled with their morphological simplicity, this renders rangeomorph taxonomy difficult. This has been the subject of recent debate, with some authors placing weight on branching architecture, and others preferring morphological characters. There is no consensus as to which characters are taxonomically meaningful.



The historic Ediacaran sites of Charnwood Forest have yielded a plethora of new individuals following a recent casting and moulding project. These include fifty-seven well preserved specimens of *Primocandelbrum*, which was previously known from only a handful of specimens from Newfoundland. The new specimens show diversity in both morphological and branching characteristics, and can be grouped according to either set of characters, using outgroups of broadly similar but distinct taxa. Comparing the specimen composition of groups defined by each character set identifies those characters that generate the most robust taxonomic groupings. This will constrain our understanding of fundamental aspects of the communities such as species richness and diversity.

Quantitative stratigraphy of Late Devonian and Early Carboniferous ammonoid successions in the Rhenish Mountains (Germany)

***Carina Klein and Dieter Korn**

Museum fuer Naturkunde Berlin

The application of modern biostratigraphical methods, especially to ammonoid biostratigraphy, helps to clarify the stratigraphical order of the ammonoid occurrences and to minimize contradictions without new extensive sampling efforts being required. We investigated the occurrences of 64 late Famennian (Late Devonian) ammonoid species from 12 sections and 52 early Tournaisian (Early Carboniferous) ammonoid species from seven sections using three biostratigraphical methods, (1) Unitary Associations (UA), (2) Constrained Optimization (CONOP) and (3) Ranking and Scaling (RASC).

The three methods lead to similar outcomes and the fit with the empirical data is generally good. UA shows the lowest resolution, but leads to the most robust results; CONOP and RASC show a higher resolution. For the Devonian dataset, only the results of the RASC method coincide with the empirical data; the *Effenbergia lens*, *Muessenbiaergia parundulata* and *Muessenbiaergia sublaevis* zones cannot be resolved by the UA and CONOP methods. For the Carboniferous dataset, the results of all methods coincide with the empirical data.

We consider the faster RASC method to be the most suitable; it perfectly coincides with the empirical data. Nonetheless the UA method facilitates the separation of zones and can thus be seen as a useful method, too.

Functional morphology of non-mammalian cynodonts and their kin

***Stephan Lautenschlager¹, Emily J. Rayfield¹, Pamela Gill¹ and Michael Fagan²**

¹*School of Earth Sciences, University of Bristol, Life Sciences Building, 24 Tyndall Avenue, Bristol BS8 1TQ*

²*School of Engineering, University of Hull, Cottingham Road, Hull HU6 7RX*

The evolution of mammals is a textbook example for the acquisition of morphological and functional modifications. They are most pronounced in the cranial skeleton, including a differentiated, heterodont dentition and the transformation of the jaw joint, resulting.

Although these osteological modifications are well-documented in the fossil record, the fossil remains of cynodonts are often subject to taphonomic deformation and incompletely preserved. Here we present digital reconstructions of the cranial osteology and myology of different non-mammalian cynodonts, including *Thrinaxodon* and *Probainognathus*.



Based on computed tomography (CT) scanning, models of the cranial skeleton of these taxa were digitally restored. Subsequently, the muscle architecture was reconstructed in an iterative approach. The restored osteological models and reconstructed myology were used to perform Multibody Dynamics Analyses to assess muscle and bite forces, as well as Finite Element Analysis to elucidate the biomechanical behaviour.

Results show that the muscle architecture changed between the various taxa. While there are indications for the retention of a pseudotemporalis muscle complex in *Thrinaxodon*, these muscles appear to be absent in the more derived *Probainognathus*. However, this transformation of the muscle arrangement has little effect on the resulting bite forces, which are slightly higher in *Thrinaxodon*.

Reinterpretation of the problematic Ordovician genus *Bolboporites* (?Echinodermata) as a calcareous alga

Bertrand Lefebvre

UMR CNRS 5276, bâtiment Géode, Campus de la Doua, Université Lyon 1, 2 rue Raphaël Dubois, F-69622 Villeurbanne cedex, France; <bertrand.lefebvre@univ-lyon1.fr>

Bolboporites is a relatively small (about 1.5 cm long), cone-shaped fossil, characterized by a typical honeycomb-like sculpture on its external walls; a gently domed upper surface with two adjoining U-shaped structures; and an internal, longitudinal axis. This genus is fairly common in the Ordovician (Floian–Katian) of Baltica (Estonia, Russia, Scandinavia). It was also reported from the Upper Ordovician of Laurentia (Canada, USA). Although initially described as a coral, the genus *Bolboporites* Pander, 1830 was generally considered to represent either a portion of, or the complete body (theca) of an echinoderm of unknown affinities. The Natural History Museum of Oslo contains abundant, exceptionally well-preserved specimens of *Bolboporites* from the Upper Ordovician of Norway. The careful re-examination of this material does not confirm its interpretation as an echinoderm. On the other hand, striking similarities with the morphology of Ordovician cyclocrinidites (e.g., *Coelosphaeridium*) rather suggest that *Bolboporites* more likely represents a calcareous alga.

Testing life-habits of hatchling ammonites using CT data

***Robert R. E. Lemans¹, Rene Hoffmann¹ and Stefan Zachow²**

¹Ruhr Universitaet Bochum

²Zuse Insitute

The reproductive strategy of ammonoids has been considered an important component to their global distribution and survivability through extinction events. High fecundity and small egg sizes (around 1 mm) separate ammonoids from nautiloids who produce a small number of eggs with hatchlings around 2 cm in diameter. Ammonoid hatchlings have been viewed as planktonic, exploiting ocean currents to maximize their geographic distribution. However direct testing of this life-habit through study of the physical properties of the shell has been sparse and quantification of the buoyant and hydrostatic properties of hatchlings has been limited to geometric analysis of hypothetical, ideal shell shapes. Using exceptionally preserved hollow ammonite fossils and synchrotron microtomography (SRμCT) we present a case study testing the validity of geometric approximations of shell volume using a Jurassic ammonite *Cadoceras* sp. hatchling. Buoyancy, hydrostatics and



swimming velocity are calculated for a range of shell parameters. *Cadoceras* exhibits buoyancy values from $-0.25 \mu\text{N}$ to $0.36 \mu\text{N}$. Buoyancy and swimming speeds are similar to extant coleoid hatchlings, demonstrating a possible similarity in hydromechanics. Volumetric calculation based on high-resolution CT data is the most accurate current method and is also important for the utilization of ammonoid shells as archives for palaeoenvironmental data.

Rare non-trilobite arthropods from the Weeks Formation Konservat-Lagerstätte (Cambrian, USA)

Rudy Lerosey-Aubril¹, Javier Ortega-Hernández², Carlo Kier³, Enrico Bonino³ and *Emmanuel L. O. Martin¹

¹*Laboratoire de Géologie de Lyon: Terre, Planètes, Environnement (UMR 5276, CNRS), Université Claude Bernard Lyon 1, Villeurbanne, France*

²*Department of Earth Sciences, University of Cambridge, Cambridge, UK*

³*Back to the Past Museum, Puerto Morelos, Mexico*

The Weeks Formation preserves a diverse, yet largely undescribed, exceptionally preserved fauna of late Guzhangian age (early Late Cambrian). Recent investigations have shown that this fauna contains taxa previously regarded as typical of older or younger Konservat-Lagerstätten, which highlighted its transitional nature. Here we present two rare arthropods of uncertain affinities that further exemplify the uniqueness of the non-trilobite arthropod fauna of the Weeks Formation. *Notchia weugi* is characterized by a short cephalon, a trunk with 12 tergites and weakly differentiated into two morphological regions, and a spine-bearing rectangular telson. This taxon somewhat resembles other Cambrian arthropods, such as strabopids or *Sidneyia*, but detailed comparisons reveal many differences with them, arguing against close phylogenetic relationships. The affinities of *Falcatamacaris bellua* are even more problematic, for this large arthropod exhibits a mosaic of characters as yet known in different groups of Artiopoda, along with unique features. The presence of a calcitic cuticle is particularly remarkable, being observed for the first time in a non-trilobite Cambrian arthropod. The discovery of these two taxa suggests that the Weeks Formation Konservat-Lagerstätte could significantly contribute to a better assessment of arthropod disparity in Late Cambrian time.

Early animals flex their muscles: *Haootia quadriformis* interpreted as a late Ediacaran muscular cnidarian impression

***Alexander G. Liu^{1,2}, Jack J. Matthews³, Latha R. Menon³, Duncan McIlroy⁴ and Martin D. Brasier^{3,4}**

¹*University of Bristol*

²*University of Cambridge*

³*University of Oxford*

⁴*Memorial University of Newfoundland*

In recent years, biomarker and molecular studies have constrained the search for the earliest animal fossils to late Neoproterozoic fossil assemblages. Convincing Neoproterozoic body fossil evidence for members of recognisable metazoan phyla is scarce, and is mostly confined to latest Ediacaran strata younger than 555 million years in age. In older sections, fossil evidence for the presence of metazoans largely stems from ichnological data. We report a remarkable new fossil from the *c.*560 Ma Fermeuse Formation of the Bonavista



Peninsula, Newfoundland. This specimen, found within a turbidite succession alongside frondose rangeomorph taxa more typical of late Ediacaran strata, possesses prominent bundles of fibrous ridges, four-fold radial symmetry, a basal holdfast disc, and bifurcating branches. Our analysis of bundle arrangements, fibre morphology and taphonomy suggests that the fibrous bundles are consistent with the muscular structure of a benthic cnidarian organism possessing a gross morphology that invites comparison with living stauromedusans. The organism, *Haootia quadriiformis*, is thus interpreted as a stem group cnidarian. Such an interpretation has significant implications for both the study of early animal evolution, and for our understanding of ecological complexity in late Ediacaran marine ecosystems.

Understanding taphonomic variance between fern and seed fern preservation from the Mazon Creek Lagerstätte

***Emma R. Locatelli**¹, **Marc Laflamme**², **Laura Krajewski**², **Allen V. Chochinov**², **Komal Pawar**², **Jezrel Torres**² and **Benjamin Tsang**²

¹*Yale University*

²*University of Toronto Mississauga*

Plant fossils from the Mazon Creek Lagerstätte (307 Ma) represent a rare window into the ecosystem of the late Paleozoic. Biases introduced during fossilization may have impacted the flora by selectively preserving particular taxa, inhibiting our ability to utilize the Mazon Creek flora in interpreting the vegetation of the region. Comprehensive databases were constructed by scoring morphologic and taphonomic characters from several hundreds of fern and seed fern fossils in the collections of the Royal Ontario Museum in Toronto. The datasets were analyzed using logistic regression to identify important parameters affecting the preservation of the two groups and to better understand how the flora represents the palaeoenvironment.

Initial results indicate a systematic bias in favour of the preservation of seed fern foliage in terms of completeness and retention of important morphological characters. Ferns, in contrast, tend to be more poorly preserved in terms of morphology and little to no organic material survives. This difference in preservation is attributed to variation in the rate of decay between the two groups. Detailed evaluations like this of discrepancies in preservational quality within Lagerstätten will aid in identifying and understanding taphonomic biases that may compromise evidence of the history of life on Earth.

Effect of carbon dioxide concentration on the digestibility of possible sauropod food plants

Barry Lomax¹, **Fiona Gill**² and **Jürgen Hummel**³

¹*University of Nottingham*

²*University of Leeds*

³*University of Göttingen*

During the Mesozoic, atmospheric carbon dioxide levels were elevated when compared to the present day, with estimates ranging from *c.*650 to *c.*1130ppm. Elevated carbon dioxide leads to accelerated plant growth via the production of carbohydrates. These changes in turn may affect the fibre content, carbohydrate-to-protein ratio, secondary metabolite profiles and other properties related to digestibility. We therefore hypothesize



that the elevated carbon dioxide levels during the Mesozoic may have resulted in variations to the digestibility of Mesozoic plants and that these changes may have cascaded up the food chain. To test this hypothesis we investigated the effect carbon dioxide had on the digestibility of living fossil plant species which are modern analogues to sauropod food. Plants were grown under a range of Mesozoic carbon dioxide concentrations (400 ppm, 800 ppm, 1200 ppm and 2000 ppm), with all other growth parameters held constant. The metabolizable energy content of the plants as a measure of digestibility was evaluated using the Hohenheim gas test. Data show that metabolizable energy content varied considerably between plant species, but no systematic changes as a function of carbon dioxide were found. Variations in diet quality available to sauropods throughout the Mesozoic may have implications for our understanding of sauropod digestion, energy requirements and potentially methane emissions.

Flexure of microbial mats around holdfasts of epibenthic fronds: Ediacaran ecology in the Cambrian of Avalonia (Ireland)

***Breandán Anraoi MacGabhann^{1,2,3}, Paul D. Ryan³ and John Murray³**

¹*Department of Geography, Edge Hill University*

²*School of GeoSciences, University of Edinburgh*

³*Earth and Ocean Sciences, National University of Ireland, Galway*

The Cambrian Explosion was accompanied by a fundamental shift in the nature of marine substrates. In shallow marine environments, characteristic Neoproterozoic microbial matgrounds gave way to typical Phanerozoic mixground substrates, concordant with the evolution of widespread bioturbation. In deep marine environments, the ‘agronomic revolution’ appears to have been delayed, as suggested by strata such as the microbially-bound Middle Cambrian contourites of the Booley Bay Formation, southeastern Ireland.

Two sets of non-mineralised discoidal structures occur in this unit; millimetre-scale scratch circles, and centimetre-scale partial discs preferentially orientated in the palaeocurrent direction. We investigated the hypothesis that the larger discs were holdfasts of frond-like organisms, preferentially orientated by current pressure on their upper parts, numerically modelling the flexure of a microbial mat around such a holdfast. While highly speculative, the models predict profiles consistent with field observations. We conclude that one admissible interpretation is that the Booley Bay Formation preserves evidence of large stalked frond-like organisms, living in a contour-current environment, anchored to the microbially-bound substrate by discoidal holdfasts. The ecological similarity to deep marine Ediacaran environments such as Mistaken Point suggests that not just Ediacaran matgrounds, but Ediacaran community palaeoecology, survived in deep marine settings until at least the Middle Cambrian.



4D-Virtopsy and taphonomy of an Oligocene mole from the fossil site of Enspel (Germany)

***Bastian Mähler¹, Achim H. Schwermann¹, Michael Wuttke², Julia A. Schultz¹ and Thomas Martin¹**

¹Steinmann-Institut für Geologie, Mineralogie und Paläontologie, Universität Bonn, Nußallee 8, 53115 Bonn, Germany

²Referat Erdgeschichte, Generaldirektion Kulturelles Erbe Rheinland-Pfalz, Große Langgasse 29, 55116 Mainz, Germany

Taphonomic experiments and μ -CT analyses of extant *Talpa europaea* provide a closer look into the decay process of small mammals under fresh water conditions. Carcasses floated on the water surface and after a few hours sank to the bottom. At the same time decomposition of soft tissues began and putrefaction gas was produced. Consequently, carcasses bloated and re-floated to the water surface. The gas-filled body cavities were 3D-reconstructed and volumes were measured. The higher the temperature the faster gas formation and decomposition of soft tissues occurred. With ongoing decomposition, the skeleton was successively disarticulated and disconnected parts were scattered. These observations were used for a taphonomic interpretation of the partial skeleton of an Oligocene mole (*Geotrypus antiquus*) from the fossil site Enspel in Germany. The positions of anterior limbs, the presence of distal hand elements and left femur in addition to an articulated mandible with occluding teeth indicate that an almost completely articulated specimen sank to the ground, without an extended period of floating. After decomposition of most soft tissues some bones were shifted to the left side of the body axis by an underwater current before the skeleton was finally buried.

Exploring the cranial and endocranial anatomy of a Jurassic ichthyosaur using digital techniques

***Ryan D. Marek, Benjamin C. Moon and Michael J. Benton**

University of Bristol

The bicentennial anniversary of the first scientific description of an ichthyosaur is celebrated in 2014. Even after 200 years of study, some details of their cranial anatomy are still unclear. This has implications for understanding the ichthyosaurian phylogeny, and also the function of their skull. Based on computed tomographic (CT) scans of a nearly complete ichthyosaur (*Hauffiopteryx typicus*) skull from the Toarcian of Strawberry Bank, England, elements of cranial anatomy are described, and the occipital region is fully reconstructed, creating the first digital cranial endocast of an ichthyosaur. This endocast reveals evidence that by the Early Jurassic, ichthyosaurs had neuroanatomical adaptations that allowed them to be highly mobile, visual predators in the aquatic realm, with enlarged optic lobes and an enlarged cerebellum. Surprisingly, the olfactory region also appears to be enlarged, leading to the conclusion that olfaction was more important in the lives of ichthyosaurs than previously believed, perhaps because it had to be assumed that the nostrils had to be closed when the animal was submerged. A brief phylogenetic analysis confirmed the initial placement of this specimen as either *H. typicus* or a closely related sister taxon, which is also supported by many broader aspects of the cranial anatomy.



Muscle-powered helens, the missing piece of hyolithid body construction

Mónica Martí Mus¹, Lennart Jeppsson² and John M. Malinky³

¹*Universidad de Extremadura, Badajoz*

²*Lund University*

³*San Diego City College*

Hyolithids are a group of Palaeozoic lophotrochozoans with a four-pieced skeleton consisting of a conch, an operculum, and a pair of lateral ‘spines’ named helens. These later elements are fragile and their morphological details have remained relatively poorly known. As a result, the functional morphology of hyolithids has remained problematic. The material presented herein, consisting of disarticulated, pyritised skeletal elements from the Silurian of Gotland, Sweden, includes the first complete, three-dimensionally preserved helens. The material confirms that helens were massive skeletal elements, whose growth started proximally, in an epithelial invagination, with the deposition of a central lamella. Further shell accretion took place around this lamella, but followed a particular accretion pattern seemingly constrained by the presence of marginal muscle attachment sites on the proximal-most portion of the helens. Diverse and abundant muscle scars had been previously documented on the conch and operculum of hyolithids, but had never been reported on the helens. The location of these attachment sites is coherent with a wide and independent range of movements for the helens, which could have acted as oars, as stabilizers, and to orient and lift the conch aperture.

Tectonic Forcing of Biogeochemical Cycles and Marine Biodiversification

Ronald E. Martin

Department of Geological Sciences, University of Delaware, Newark, DE 19716, USA

Igneous activity associated with seafloor spreading and mountain building has impacted nutrient input to the oceans and marine biodiversity through geologic time. Tectonic cyclicality during the Phanerozoic Eon is coupled to the evolution of the biogeochemical cycles of carbon and sulfur, and marine diversification. Tectonism associated with the emplacement of large igneous provinces (LIPs) enhanced the input of phosphorus from the continents to the oceans on approximately 30-to-60-million-year periodicities, stimulating primary productivity and the pelagic rain of organic matter, thereby affecting redox conditions and phosphorus availability. These findings appear to cross-correlate with cycles of marine diversification on similar durations. Oceanic anoxic events and mass extinction result from similar processes on shorter time scales. The impact of these biogeochemical processes on marine diversification therefore appears to be scale-dependent.

Late Ordovician (early Katian) trilobite faunas from the Myatas Formation, North Central Kazakhstan

Lucy M. E. McCobb and Leonid E. Popov

National Museum Wales

The trilobite collections of the late Michael K. Apollonov include faunas from two Late Ordovician localities, both in the Myatas Formation, exposed on the northern shores of Atansor Lake in northern Central Kazakhstan. The older, oligotaxic fauna derives from



flanks of a carbonate build-up. It is dominated by numerous *Sphaerexochus* specimens. *Amphilichas* is also relatively common, with *Pliomerina* and the asaphid *Farasaphus*? present as rare components. The overlying unit of siliceous argillites contains a different assemblage, representing the raphiophorid biofacies and comprising seven genera. The fauna is dominated by blind trilobites (a trinucleid, a three-segmented raphiophorid, *Malongullia*?, *Lonchodomas* and *Arthrorhachis*) and three species of large-eyed *Telephina*, suggesting that they occupied the disphotic zone in deep water offshore. A single cranidium of the odontopleurid *Primaspis* is also present. The trinucleid has an unusual pit arrangement, with E1 and E2 aligned in sulci and all I arcs irregularly arranged, and likely represents a new genus. The Atansor area is located within the Stepyak tectonostratigraphical unit, which probably represented an Ordovician active margin of the the Kalmykkol–Kokchetav Microplate.

The GB/3D Type Fossils Online Web Portal

Tim McCormick, Michael P. A. Howe and Simon J. Harris

British Geological Survey

From 2011 to 2014 the British Geological Survey has been leading a consortium of UK museums to construct the web portal at <www.3d-fossils.ac.uk>. This gives access to metadata and high-resolution 'flat' and stereo images of over 16,000 type macrofossil specimens from the UK.

We have made 3D digital models of approximately 10% of the fossils either by scanning them with portable 'NextEngine 3D HD' scanners or by photogrammetry. These 3D models can be downloaded as zipped files from the website, or viewed and manipulated directly on screen using current web browsers. We use a Makerbot 3D printer to make physical replicas of fossils which can be used for research, education and outreach.

The resources may be freely downloaded from the website and used subject to a Creative Commons Attribution ShareAlike Non-Commercial licence.

In practice the website is currently most useful to the professional palaeontologist who can use it to discover the whereabouts of the type specimens of a taxon, and to assess the completeness and preservation quality of the material. Future development is likely to focus on improving functionality for public education and outreach.

The hidden diet of cephalopods revealed by scratches, pits and stable isotopes

Alistair J. McGowan¹, Christina Sprinks¹, Peter Chung¹, Rona McGill²

¹*School of Geographical and Earth Sciences, Gregory Building, University of Glasgow G12 8QQ*

²*SUERC, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride G75 0QF*

The feeding ecology of living cephalopods, and their extinct relatives, is underdetermined. While most living cephalopods are predators or scavengers, compositional data about their diets are limited by two factors: 1) Near complete pulping of their food prior to swallowing; 2) Only a small proportion of wild-caught cephalopods yield stomach contents. We propose that a combination of microwear and stable isotope analyses could yield considerable additional information on the diet of extant cephalopods. SEM images of beaks of common and bob-tailed squid were analyzed for differences in microwear. C and N stable isotope analyses were then performed on two beaks of each species. Significant, interpretable differences were found in the proportion of scratches and pits between



the two species, demonstrating that microwear is a suitable tool for dietary analysis in cephalopods. Stable isotope work on extant cephalopods has already been revealing about trophic differences but this is the first attempt to match microwear to trophic level. This conservation palaeobiological approach could help with the analysis of fisheries food webs, as the removal of fish of similar body-size could allow cephalopods to increase their dominance of these ecosystems.

Extinction in the ocean but not on land – tracing the late Silurian Lau event in Sweden

Kristina Mehlqvist and Vivi Vajda

Dept. of Geology, Lund University, Sweden

Upper Silurian successions from Sweden occur both on the island Gotland, situated in the Baltic Sea, and in the southern province Skåne. These sediments are generally near shore marine to intertidal lagoonal based on the low, but persistent occurrence of acritarchs together with the high relative abundance of spores through the main part of these successions (Mehlqvist *et al.*, 2012, 2014). Upper Silurian marine deposits are characterized by extreme conditions manifest by increase of cyanobacteria, cerebroid ooids, evaporite tracers combined with extinctions of conodont faunas and fish. These changes are not reflected in the terrestrial vegetation, which instead reflect a robust, well-established and stable early flora throughout the studied succession represented by the biostratigraphically important species including *Synorisporites ? libycus*, *Hispanaedisca verrucatus*, *H. major*, *H. lamontii*, *Scylaspora scripta* and *Artemopyra radiata*.

MEHLQVIST, K., VAJDA, V., STEEMANS, P., 2012. *GFF* **134**, 133–144.

MEHLQVIST, K., LARSSON, K., VAJDA, V., 2014. *Review of Palaeobotany and Palynology* **202**, 1–14

Early forest soils from the Middle Devonian of New York State

***Jennifer L. Morris¹, David Beerling¹, William Stein², Chris Berry³, John Marshall⁴, Charles Wellman¹ and Jonathan Leake¹**

¹*Animal and Plant Sciences, Sheffield University, Sheffield, UK*

²*Dept. of Biological Sciences, Binghamton University, Binghamton, USA*

³*School of Earth and Ocean Sciences, Cardiff University, Cardiff, UK*

⁴*Ocean and Earth Science, University of Southampton, Southampton, UK*

A Middle Devonian (Givetian) palaeosol horizon at Cairo Quarry, New York, has provided an opportunity to study the *in situ* roots of an early forest ecosystem, as well as the nature and degree of influence they had on weathering and soil development. The morphology and distribution of roots across this surface was mapped by Stein *et al.*, and identified as belonging to archaeopteridalean progymnosperm (*Archaeopteris*) and cladoxylpsid pseudosporochalean (*Wattieza*) trees.

An assessment of rooting depth and root morphology of these two tree types, as well as their influence on weathering, is obtained from detailed sedimentological and geochemical studies of the palaeosol beneath. Eighteen cores were drilled near the bases of archaeopteridalean and cladoxylpsid rooting structures of different sizes. The palaeosol is interpreted as a palaeo-Vertisol, with a maximum thickness of 1.66m. Four groups of



rhizoliths are recognised based on their size, orientation and morphology and assigned as either archaeopteridalean or cladoxlopid. There is a positive relationship between archaeopteridalean tree size and rooting depth, up to 1.61m. *Wattieza* roots do not exceed 30 cm depth, with no correlation to tree size.

Using ICP-MS, elemental distributions and molecular ratios down the palaeosol profile are used as proxies for weathering and pedogenic processes.

Local diversity hot spots in the Middle Miocene of the Central Paratethys: influence of environment and sampling

***Rafal Nawrot¹, Martin Zuschin¹, Mathias Harzhauser², Andreas Kroh² and Oleg Mandic²**

¹Department of Palaeontology, University of Vienna, Vienna, Austria

²Natural History Museum Vienna, Vienna, Austria

Species richness captured by historical fossil inventories is a complex function of true local diversity, degree of outcrop-scale heterogeneity in species composition and sampling intensity. The molluscan fauna of Lapugiu de Sus (Hunedoara District, Romania) constitutes one of the most diverse Early Badenian (Langhian) assemblages of the Paratethys Sea, with almost one thousand species reported during 170 years of extensive studies. We evaluate whether this exceptional local richness reflects the actual diversity hot spot or just a long history of fossil-collecting by comparing the fauna of Lapugiu with other Paratethyan lagerstätten of similar age using literature-derived species lists and bulk-sampled abundance data (42 samples, 24,000 specimens, and 530 species from six localities). Sampling-standardized richness estimates for samples from Lapugiu are all consistently high, reflecting higher evenness and more offshore despositional setting compared to most of other studied sites. Nevertheless, individual samples from other localities can exhibit comparably high diversity levels, in spite of generally lower diversity at the outcrop-scale when all samples are pooled. The three- or four-fold-greater number of species previously reported from Lapugiu may be, therefore, a result of the 'Bonanza Effect', where uniformly species-rich deposits were attracting intensive palaeontological studies.

Dimorphism within the bivalved arthropod *Isoxys* from the Early Cambrian Sirius Passet lagerstätte, North Greenland

***Morten L. Nielsen¹ and Jan A. Rasmussen²**

¹Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark; e-mail <bvm328@alumni.ku.dk>

²Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark; e-mail <janr@snm.ku.dk>

More than 250 specimens of the Early Cambrian arthropod *Isoxys* have been analysed morphometrically. Rare specimens are characterized by preserved soft anatomy such as eyes, but in most specimens only features related to the spines, inner lamellae and the bivalved carapace are preserved. Morphometrical analyses shows that *Isoxys* from North Greenland may be divided into two main morphological groups, particularly distinguished by differences in the relative width of the doublure (Wd). The relative doublure width is computed as the height of one valve (H) divided by the maximum width of the doublure (H/Wd). In the two morphogroups, H/Wd is independent of both the total size and the stratigraphical position of the specimen in the section. F- and t-tests show that the two



main morphogroups are significantly different from each other by means of both H/Wd and the length/height ratio. The dimorphism is probably related to sexual dimorphism or the presence of two distinct species. The holotype of *Isoxys volucris* Williams, Siveter & Peel, 1996 belongs to the most abundant morphogroup distinguished by a relatively wide doubleure.

Palaeoenvironmental reconstruction from well-preserved Mississippian brachiopod shells

***Leah S. P. Nolan¹, Melanie J. Leng², Lucia Angiolini³, Sarah J. Davies¹, Flavio Jadoul³, Vanessa J. Banks², Sarah E. Gabbott¹ and Michael H. Stephenson⁴**

¹University of Leicester, Department of Geology, Leicester, UK

²British Geological Survey, Nottingham, UK

³Università degli Studi di Milano, Dipartimento di Scienze della Terra, Milano, Italy

⁴British Geological Survey, Nottingham, UK.

Stable isotopes ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$) of biogenic calcite are frequently used for assessing palaeoenvironment and palaeoclimate. Preservation of primary calcite needs to be assessed prior to isotope studies to ensure that data generated reflect original seawater chemistry, rather than secondary diagenetic fluids. Preservation analysis encompasses a range of techniques, including scanning electron microscopy, cathodoluminescence microscopy, and analysis of trace element abundances (Mn, Fe, Sr). There are however, no fixed criteria for classifying biogenic calcite as pristine using these techniques, although it is best practice to use material which has passed most screening tests. Here a systematic procedure is outlined for analysis of Mississippian biogenic calcite from gigantoproductid brachiopods collected in the UK. A set of criteria are established based on these tests as well as subsequent high resolution isotope analysis (sampling individual growth bands). Where pristine calcite is identified we calculate seasonal sea surface temperatures through the organism's life-time. This, combined with a detailed sedimentology investigation, enables the identification of preferred environments of *Gigantoproductus* species and helps understand why they dominate such deposits. This study provides a practical methodology, linking quantitative and qualitative data, and will allow a detailed palaeoenvironmental reconstruction of this region of Mississippian palaeoequatorial Britain.

The *messauoudensis-trifidum* acritarch assemblage in the Lower Ordovician Fezouata Shales of Morocco

***Hendrik Nowak¹, Mustapha Akodad², Bertrand Lefebvre³ and Thomas Servais¹**

¹CNRS-UMR 8217 Géosystèmes, Université Lille1, U.F.R. des Sciences de la Terre, Bâtiment SN5, Avenue Paul Langevin, 59655 Villeneuve d'Ascq Cedex, France

²Faculté Multidisciplinaire de Nador, Labo OLMAN-RL, FPN 300, Selouane 67200, Nador, Morocco

³CNRS/ENS-UMR 5276, Université Lyon 1, Campus de la Doua, 2, rue Raphaël Dubois, 69622 Villeurbanne Cedex, France

The upper Tremadocian to lower Floian *messauoudensis-trifidum* acritarch assemblage was first described from the Skiddaw Group of England and subsequently from several localities on the Gondwanan margin that were positioned in high southern latitudes during the Early



Ordovician. Here we report its presence in south-eastern Morocco, from surface samples from the Zagora area in the Draa valley and from the subsurface below Adrar Zouggar mountain. The corresponding strata belong to the Tremadocian to Floian Fezouata Shales. Six acritarch species/form groups that are typical of the Skiddaw Group assemblage were identified: *Acanthodiacrodium? dilatatum*, *Cymatiogalea messaoudensis*, *C. velifera*, *Caldariola glabra glabra*, *Stelliferidium trifidum* and *Veryhachium lairdii* s.l.. The presence of *Cymatiogalea velifera* indicates a Tremadocian age. The absence of *Coryphidium* and *Veryhachium trispinosum* (Eisenack 1938) Stockmans & Willièrè 1962 would be consistent with the *messaoudensis-trifidum* sub-assemblages 1 and 2. This corresponds to the *Araneograptus murrayi* or *Hunnegraptus copiosus* graptolite zones.

Conservation of pyritized Autunian shale: Framboidal pyrite, pyrrhotite and sulfur as source of degradation

***Giliane P. Odin**^{1,2}, **Georges Gand**³, **Sébastien Steyer**² and **Véronique Rouchon**¹

¹Centre de Recherche sur la Conservation des Collections (MNHN-CNRS-MCC, USR 3224)
36 rue Geoffroy Saint Hilaire 75005 Paris, France

²Centre de Recherche sur la Paléodiversité et les Paléoenvironnements (MNHN-CNRS-UPMC, UMR 7207), CP 38, 8 rue Buffon, 75005 Paris, France

³Biogéosciences (Université de Bourgogne, CNRS, UMR uB6282), 6 Bd Gabriel, 21000 Dijon, France

Some collections of French museums (MNHN, Paris; MHNA, Autun) include many fossils preserved within Autunian shale. Those containing unstable sulfur compounds (e.g. pyrite) oxidize, resulting in iron sulfate efflorescence.

To better understand the processes underlying these degradations, a study was made on material from the Autun Basin (Saône-et-Loire, France; Permian) on both damaged historical specimens ('HS'; characteristic of a final state), and on new excavated samples ('NS'; comparable to an initial state). Presence and reactivity of iron and sulfur were studied and completed by artificial ageing, supposed to accelerate the degradation.

Iron was found to be mainly present in clays, partly as pyrite or sulfates. Similar amounts of Fe²⁺ between HS and NS seems to imply a weak oxidation of iron. Sulfur occurs mostly as sulfates in the shale and as reduced reactive compounds in organic matter ('OM'). Gypsum (CaSO₄·2H₂O) is the main product obtained by artificial ageing of NS free from OM. Damaging iron sulfates are reproduced in NS presenting, at the shale/ OM interface, framboidal pyrite, pyrrhotite and sulfur. This configuration was also detected in HS and should be used for the determination of fossils' possible oxidation. Current investigation regards the evaluation of conservative treatment.

Homology of cephalic sclerites in Burgess Shale euarthropods recognized through comparative palaeoneurology

***Javier Ortega-Hernández**

University of Cambridge

The evolutionary transition from soft-bodied lobopodian-type taxa (lobopodians, gilled-lobopodians, radiodontans) to completely sclerotized euarthropods (e.g. fuxianhuids, arthropods) is partially reflected by a substantial rearrangement of the segmental



organization of the head region. Although advances in palaeoneurology and developmental biology have provided some clarity on the serial homology between cephalic limbs in stem and crown-group euarthropods, such comparisons are less straightforward when dealing with non-appendicular exoskeletal structures. The recent description of the brain morphology in the Chengjiang radiodontan *Lyrarapax unguispinus*, however, draws attention to a fundamentally similar organization of non-appendicular and sclerotized anterior structures between lower and upper stem-Euarthropoda. A revision of the head region of exceptionally preserved taxa from the middle Cambrian Burgess Shale suggests the existence of preserved neurological remains associated with the anterior sclerite and the stalked eyes, more specifically the presence of putative protocerebral ganglia. These observations support the homology of isolated sclerotized plates on the head region of radiodontans, and the ‘anterior sclerite’ observed in fuxianhuids, bivalved Cambrian forms and phylogenetically basal arthropods. These comparisons have direct implications for the formulation of characters used in phylogenetic analyses, and demonstrate that it is possible to recognize relationships of homology between exoskeletal features in taxa with a fundamentally distinct body organization.

First Lower Cambrian record of *Wiwaxia* from north-west Gondwana: small carbonaceous fossils from the Lancara Formation, Cantabrian Mountains, northern Spain

Teodoro Palacios, Sören Jensen, *Iván Cortijo Sánchez and Mónica Martí Mus

Universidad de Extremadura, Badajoz

Sclerites of the bilaterian metazoan *Wiwaxia* are here reported from the upper part of the lower member of the Lancara Formation in the Porma area, Cantabrian Mountains, northern Spain. The material is preserved as small carbonaceous fossils extracted from fine-grained siliciclastic interbeds in dolostone levels. Earlier reports of scarce trilobites and archaeocyaths from the upper part of the lower member of the Lancara Formation in other sections in the Cantabrian Mountains have been assigned to the late Early Cambrian Bilbilian regional stage. New biostratigraphical age constraints come from acritarchs in the *Wiwaxia*-bearing samples, which include *Skiagia ciliosa*, *S. compressa*, *S. orbiculare* and *Globosphaeridium cerinum*, an association restricted to the *Heliosphaeridium dissimulare* – *Skiagia ciliosa* Zone, suggesting Late Cambrian Age 3 or Early Cambrian Age 4. This is only the second record of *Wiwaxia* from Cambrian rocks of north-west Gondwana, with a previous report from Cambrian Stage 5 beds of the Czech Republic. *Wiwaxia* spans the Lower to Middle Cambrian transition in Laurentia and South China and now also in north-west Gondwana.

High-resolution vegetation and climate fluctuations during the Late Pliocene derived from the palynological record of ODP Site 642B, Norwegian Sea

***Sina S. P. Panitz¹, Ulrich Salzmann¹, Stijn De Schepper², Bjørg Risebrobakken² and Emma Hocking¹**

¹*Department of Geography, Northumbria University, Newcastle upon Tyne NE1 8ST, UK*

²*Bjerknes Centre for Climate Research, Uni Research Climate, Allégaten 55, N-5007 Bergen, Norway*

During the warmer-than-present Late Pliocene, warming was particularly accentuated at high latitudes. Most recent data-model comparison studies identified weaknesses in



the reconstruction of high latitude climate variability due to the insufficient resolution of terrestrial records.

In order to resolve these uncertainties, we present high-resolution vegetation and climate reconstructions for the sub-polar marine sediment core ODP Site 642B, Norwegian Sea for the Late Pliocene.

Initial results show that the Late Pliocene (3.53–3.14 Ma) is marked by an expansion of wetlands and deciduous woodlands at the expense of cool temperate pine forests. An opening of the pine forests is indicated by an increase in the relative abundance of Asteraceae and Poaceae between 3.45 and 3.26 Ma. Thereafter, the decrease in *Pinus* percentages and the increase in *Sphagnum* and abundance of deciduous trees (*Alnus*, *Betula*, *Corylus*, *Quercus*, *Ulmus*) indicate a spread of moist mixed forests, suggesting wetter climate conditions.

Using the Coexistence Approach the forest-dominated intervals are associated with temperatures on average 7–8.5°C higher than present. The expansion of open grasslands is accompanied by cooler, but still 2.5 to 4°C warmer-than-present temperatures. This initial climate reconstruction will be refined by incorporating data on mean annual precipitation and seasonal temperatures.

A stable isotopic investigation of chemosymbiosis through geological time

***Edine Pape, Fiona L. Gill, Crispin T. S. Little and Robert J. Newton**

University of Leeds

To investigate the palaeobiology of fossil invertebrates, our research aims to directly reconstruct nutritional strategies of bivalves, gastropods and brachiopods, by looking at the stable isotopic signatures of the organic matter preserved in fossil shells. Two other research projects are presented by Elms *et al.* and Stirk *et al.* (2014, this volume).

Shells consist of calcium carbonate minerals enclosed by a three-dimensional organic framework, the shell-bound organic matter (SBOM). Modern SBOM has similar carbon, sulfur and nitrogen isotopic values to the animal's soft tissues that reflect feeding strategies. Differentiation between feeding strategies is possible because the isotopes track both trophic level and isotopic source; in particular it shows the distinct reduced values of sources needed for chemosymbiosis. The chemosynthetic bacteria living in chemosymbiosis with invertebrates use these chemical compounds to obtain energy (see: Stirk *et al.*).

Our project focuses on chemosymbiosis through geological time. Despite the importance of chemosymbiosis at modern vents and seeps, its origin and evolutionary history are poorly understood. We present SBOM isotope data from modern and fossil bivalves and brachiopods across a range of feeding strategies, and fossil SBOM signatures allow investigation of the relationship between chemosymbiosis and the evolution of seep and vent fauna.



***Harpax spinosa* (Bivalvia: Plicatulidae) a preferred prey target for drilling predators during the Pliensbachian (Lower Jurassic) time?**

***Ricardo Paredes¹ and Elizabeth M. Harper²**

¹*Palaeontology Department, Earth Sciences Faculty, Complutense University of Madrid, C/ José Antonio Novais, 2, 28040-Madrid, Spain*

²*Earth Sciences Department and Sedgwick Museum, University of Cambridge, Downing Site, Cambridge CB2 3EQ, United Kingdom*

Several instances of Jurassic bivalves bearing gastropod-like drillholes have been documented in the last decades. However, only a few of them are from the Lower Jurassic. It is still under debate who were their producers, since none of the known drillers like carnivorous gastropod extend into the Jurassic. Temporally and geographically constrained predated material from England and Iberia (Central Spain and Portugal) has been reported. The bivalve plicatulid *Harpax spinosa* (Sowerby) has been revealed as a common prey taxon from two-valved macrobenthic organisms (bivalves and brachiopods) from the various assemblages we have studied. This is despite any deterrent effect of the spinous ornamentation of the right valve. Data show that ten drilling predation levels at two Pliensbachian (Margaritatus Chronozone) Iberian sections range from <10–22% in drilling frequencies. Those data seem to corroborate the idea that drilling frequency reflects abundance of predators in a particular habitat and a prey preference. A possible explanation to interpret this selection of small-sized prey could be a cost-benefit strategy by the predators. These chronostratigraphically well-constrained examples help to emphasise the drilling predation occurring during Pliensbachian time in England and the Iberian basins.

Cambrian Polychaetes and the Origin of the Annelid Bodyplan

***Luke Parry^{1,2}, Gregory D. Edgecombe² and Jakob Vinther¹**

¹*University of Bristol*

²*Natural History Museum*

Annelid worms are segmented metazoans that are important components of ecosystems spanning terrestrial realms to the deep sea, and have a fossil record extending to the Early Cambrian. They are remarkably diverse, possessing high taxonomic diversity and exceptional morphological disparity, having evolved numerous feeding strategies and ecologies. Their inter-relationships and evolution have been a source of controversy over the past century, with the composition of the crown group, internal relationships and the body plan of the ancestral annelid having undergone major revisions. Burgess Shale-type Lagerstätten are critical for understanding the assembly of the body plans of metazoan phyla, but the relationship of Cambrian polychaete body fossils to living annelids has remained obscure. We present new observations from Sirius Passet and from the Burgess Shale, including new taxa, muscle anatomy and the head organization of the oldest annelids. Their simple parapodia, heads and chaetae suggest that they lie outside of the crown group forming a paraphyletic grade, allowing us to formulate a novel hypothesis for the origin of the annelid Bauplan. The Cambrian fossil record suggests that annelids are derived from an epibenthic ancestor that possessed simple chaetae, protective notochaetae, paired palps and paired longitudinal and circular muscle bands.



Palaeoecology of calcified metazoans from the Nama Group, Namibia

***Amelia M. Penny¹**, Rachel Wood¹, Andrew Curtis¹, Frederick Bowyer¹, Rosalie Tostevin² and Karl-Heinz Hoffman³

¹University of Edinburgh

²University College London

³Geological Survey of Namibia

The oldest known calcified metazoans are from the Ediacaran Period, around 550Ma. These metazoans are the first known adopters of the skeleton-building strategy which became widespread among metazoan taxa during the Cambrian. Three Ediacaran taxa, *Cloudina*, *Namacalathus* and *Namapoikia*, are locally abundant in shallow and mid-ramp settings of the Nama Group of southern Namibia, a mixed carbonate and clastic succession extending from around 552 to 541Ma.

New fossil material from the Nama Group permits new insights into the palaeoecology of these calcified metazoans. In particular, the Nama Group contains extensive microbial-metazoan reefs, where the presence of free-growing, reef-building *Cloudina*, as well as thrombolite-associated *Cloudina* and *Namacalathus* and fissure-dwelling *Namapoikia*, indicates a differentiation of metazoans into the distinct open surface and cryptic biotas characteristic of Phanerozoic reefs, with accompanying complex ecological interactions.

Ongoing work on the calcified metazoans of the Nama Group seeks to further investigate their palaeoecology, adding to the picture of ecological complexity in the early skeletonised metazoan communities of the Nama Group.

The first evidence of Mesozoic wrinkle structures (cyanobacterial mats) from Sweden

Olof Peterffy, Mikael Calner and Vivi Vajda

Department of Geology, Lund University, Sweden

Microbial mats are formed by cyanobacteria, generally by multilayer microbial communities composed of different cyanobacterium species (Kershaw, 2012). When fossilized, they are termed wrinkle structures – microbially-induced sedimentary structures (MISS) – and are relatively common in Precambrian and Cambrian siltstones and sandstones but are otherwise rare in the Phanerozoic geological record. This paper reports on the first findings of Mesozoic wrinkle structures from Sweden. These are preserved in fine-grained and organic-rich heterolithic strata of the basal Jurassic (Hettangian) Höganäs Formation in Skåne, southern Sweden (Vajda and Wigforss-Lange 2009). Palynological analyses performed on sandstones hosting the wrinkle structure itself shows that the local terrestrial environment most probably consisted of a wetland hosting ferns, cypress and the typical Early Jurassic pollen taxon, *Classopollis* produced by today extinct conifers (Vajda, 2001). The palynostratigraphy indicates a Hettangian age, still within the floral recovery phase following the Triassic–Jurassic extinction event. The finding of wrinkle structures is significant as the presence of microbial mats in the sub-tidal zone suggests decreased benthic biodiversity and suppressed grazing in shallow marine environments in the early aftermath of the end-Triassic mass extinction event.

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There's pollen (and gold) in them thar hills: Palynological evidence for a warmer boreal climate during the Late Pliocene of the Yukon, Canada

***Matthew J. Pound**¹, **Robert I. Lowther**², **Jeff Peakell**², **Robert J. Chapman**² and **Ulrich Salzmann**¹

¹*Northumbria University*

²*University of Leeds*

The Late Pliocene (3.6 – 2.6 Ma) was a period of significant global warmth and it is considered a potential analogue for future anthropogenic climate change. Recent fieldwork in Bonanza Creek, Yukon has revealed a previously unknown fine-grained sediment in gravel-dominated stratum. The newly-discovered fine-grained sediments from between the gold bearing lower and upper White Channel Gravels have yielded a diverse assemblage of pollen and spores. The pollen assemblage recovered from the fine-grained sediments of the White Channel gravels shows the presence of a taxonomically diverse mosaic environment in Bonanza Creek during the Late Pliocene.

Climate parameters were reconstructed using two different nearest-living-relative techniques. The mean annual temperature was at least 6°C warmer than modern, with significantly warmer winters and warm summers. Mean annual precipitation was greater than modern and rainfall was more evenly distributed throughout the year. The reconstructed climate of the Late Pliocene Bonanza Creek flora indicate an environment more akin to those 10° latitude further south today.

Reconstructing relationships of fossil jawless fish (Pteraspidoformes, Heterostraci)

***Emma Randle** and **Robert J. Sansom**

University of Manchester

Fossil jawless vertebrates (stem-gnathostomes) are central to our understanding of vertebrate evolution, yet lack of understanding of their inter- and intra-relationships makes interpretation problematic. Key amongst those are the Heterostraci for which no reliable phylogenetic framework exists. For example, the inclusion of the Psammosteiformes within the larger Pteraspidoformes has long been debated, altering interpretations of heterostracan evolutionary histories. Here, a comprehensive analysis is made of the largest and most iconic clade of heterostracans, the Pteraspidoformes. Using a combination of observations of museum specimens and data from published literature, unique characters have been constructed and cladistic analysis applied using Mesquite and TNT. All described Pteraspidoformes genera (42) are included along with four out group taxa (*Anglaspis*, *Nabanniaspis*, *Drepanaspis* and *Psammolepis*). Psammosteiformes are found to belong with the Pteraspidoformes, positioned between the Anchipteraspididae and the rest of the Pteraspidoformes. This new phylogeny sheds light on a poorly understood clade, central to understanding of evolution of jawed vertebrates. Utilising this new phylogeny and stratigraphical and geographic occurrence of the taxa, dispersal histories are reconstructed in light of recent discussions regarding limited dispersal and endemism.



Plants and palaeoclimate: reconstructing past hydrological changes in the Neogene using plant compound isotopes

***Rhian L. Rees-Owen¹**, **Robert J. Newton¹**, **Ruza Ivanovic¹**, **James B. Riding²** and **Jane E. Francis³**

¹University of Leeds

²British Geological Survey

³British Antarctic Survey

Recent evidence from marine sediment records, as well as terrestrial glaciovolcanic sequences, suggest that during the late Neogene (14–2.5 Mya), the EAIS underwent periods of marginal retreat in response to warmer climates. A suite of exceptionally well-preserved fossil wood fragments, identified as *Nothofagus beardmorensis*, has been recovered from palaeosol deposits in the Sirius Group sediments at Oliver Bluffs in the Beardmore Glacier region, Transantarctic Mountains, Antarctica (85° S). The fossils are ambiguously dated, but sit in this time period of interest.

Analysis of plant compound isotope ratios from these fossils (namely, cellulose and leaf waxes) provide unique insight into the global hydrological cycle during this vital part of Antarctica's history, allowing reconstruction of precipitation isotope ratios. This is the first time this technique has been applied to the Antarctic continent. Here, we present initial results from $\delta^{18}\text{O}$ analysis of tree ring cellulose, which suggests the plants had access to precipitation that was significantly enriched ($\delta^{18}\text{O}_{\text{precip}} = c.-15\%$ for ancient; $\delta^{18}\text{O}_{\text{precip}} = -80\%$ to -30% for modern) relative to precipitation at similar latitudes today. This has wide-ranging implications for our understanding of the hydrological cycle during this time period, implying that atmospheric circulation and moisture delivery patterns were markedly different.

A new species of early brachyuran crab (Late Bathonian, France) and episkeletozoans: palaeoecological insights

***Ninon Robin¹**, **Barry Van Bakel²**, **Jean-Loup D'Hondt³** and **Sylvain Charbonnier¹**

¹Muséum national d'Histoire naturelle, Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements CNRS-MNHN-UPMC. 8, rue Buffon, 75005 Paris

²Oertijdmuseum De Groene Poort, Bosscheweg 80, NL-5283 WB Boxtel

³Muséum national d'Histoire naturelle, UMR 7205, CNRS-MNHN-UPMC-EPHE, Institut de Systématique, Evolution, Biodiversité. 55 rue Buffon 75005 Paris

Early and Middle Jurassic crabs are rare and correspond to the earliest known brachyurans. We report here a new species of early Brachyura, from the Late Bathonian of Sarthe (France) that we describe as *Tanidromites raboeufi*, a homolodromioid crab. This specimen with a mostly well-preserved cuticle shows two epibiotic bryozoan colonies on its dorsal side, a unique fact for a representative of first brachyurans. One of these colonies seems settled on the internal side of the crab, indicating their probable post-mortem settlement and growth on the carapace of *T. raboeufi*. Colonies' sizes indicate a growth lasting at least one month on this emptied carapace abandoned on the seafloor, which argues for a certain resistance of the carapace. This is noteworthy for Homolodromioidea, known in present-day environments for having very fragile carapaces. We identify bryozoans as young colonies of *Reptomultisparsa incrustans*, a Jurassic cyclostome specific of gastropod shells, inhabited by paguroids. This demonstrates that *R. incrustans* larvae were able to



test several kinds of substrates for ensuring their growth (hard substrates emerging at the soft sediment surface, like carapaces of dead crabs or gastropod shells); but that only some of them enabled the complete proliferation of colonies (shells inhabited by paguroids).

An enigmatic crinoid *Pentamerocrinus* Jaekel, 1918: Systematic position and possible structures of the aboral nervous system

***Sergey V. Rozhnov**

Borissiak Paleontological Institute RAS, Moscow, Russia

Pentamerocrinus Jaekel, 1918, was described based on a single cup from the Middle Ordovician of the St. Petersburg. Incomplete preservation and unusual structure of the cup make it difficult to determine its systematic position. The second cup, stored now in the Borissik Paleontological Institute, comes from Darriwilian (Azeri regional stage, Dubroviki Formation) near Volkhov town. The cup is large, wide, monocyclic with a complex radial C formed by inferradial and axillar superradial. Two facets are situated on the distal part of the superradial C. It can be assumed that the left facet served for the attachment of the anal tube. Such morphology suggests the possibility of the relationship of *Pentamerocrinus* with disparid crinoids Iocrinidae. Radials as well as brachials of the adjacent rays bonded together by a special lock-groove on one plate and a corresponding projection on the other. The ridges extending along the inner surface of the cup with channels quite exactly match the structure of the aboral nervous system of modern crinoids. Apparently, they reflect aboral nervous system structure.

The Enigmas of Phacopid Eyes

Brigitte Schoenemann^{1,2} and Euan N. K. Clarkson³

¹*University of Cologne, Zoology Institute, Dep. Neurobiology/Animal Physiology, Zùlpicherstrasse 47b, D-50674 Cologne, Germany*

²*University of Bonn, Steinmann Institute (Palaeontology), Nussalle 8, D-53115 Bonn, Germany*

³*University of Edinburgh, Grant Institute, School of Geosciences, West Mains Road, Edinburgh EH9 3JW, UK*

Trilobites are equipped with highly differentiated compound eyes which are present in the fossil record from the Early Cambrian until the Late Permian. Several different types of these eyes are distinguishable by the pattern of their lenses, which are preserved often as a lattice of hexagons. Quite often the original calcitic lenses are retained. For a long time it seemed that nothing would ever be discovered about the internal structures of these ancient eyes, and thus about how they actually worked. Using modern X-ray and synchrotron techniques, however, it has proved possible, recently, to establish the general structural principle of the schizochroal eyes of phacopid trilobites and to compare it with that of recent arthropods, especially with the visual system of *Limulus* (Schoenemann and Clarkson 2013). Besides this, there are other sublensar structural elements in phacopid trilobite eyes, not known so far in any Recent marine arthropods. Amongst other, we find muscles that might have allowed the lenses of these ancient compound eyes some degree of rotation, and there are other enigmatic internal structures of the visual system which will be demonstrated and whose function will be discussed.

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The Ediacaran–Cambrian transition: the record from small carbonaceous fossils (SCFs)

***Ben J. Slater**¹, **Thomas H. P. Harvey**² and **Nicholas J. Butterfield**³

¹*Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB23EQ, UK; e-mail: <bjs58@cam.ac.uk>*

²*Department of Geology, University of Leicester, University Road, Leicester LE17RH, UK; e-mail: <thph2@le.ac.uk>*

³*Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB23EQ, UK; e-mail: <njb1005@cam.ac.uk>*

The emergence of metazoan-dominated ecosystems that characterize the Phanerozoic is arguably the most striking signal in the fossil record. The Ediacaran biosphere was already populated by an array of complex multicellular forms prior to the advent of the Cambrian, however, the origins of metazoans remains frustratingly obscure. Current perceptions of this transition are largely based on the record from mineralized components preserved as small shelly fossils (SSFs) and from spatiotemporally sparse lagerstätten such as the Burgess Shale and Chengjiang. Ideally a more cosmopolitan source of data is required. Small carbonaceous fossils (SCFs) provide an abundant source of information which complements the record from mineralized SSFs and lagerstätten. SCFs encompass an array of organic-walled fossils that represent the disarticulated remains of non-biomineralizing organisms. Often SCFs are too delicate to survive traditional palynological processing, but low-manipulation extraction techniques can yield abundant and morphologically informative fossils. SCFs recovered from mudrocks of the Baltoscandian Basin bridging the Ediacaran–Cambrian boundary were used to track biotic changes across this transition. Preliminary results support the case for a ‘Cambrian Explosion’ of metazoans, with Ediacaran assemblages being characterized by forms attributable to the problematic ‘vendotaenids’, while earliest Cambrian sediments yield an increasing diversity of metazoan-derived elements.

Stable Isotopic signatures of modern chemosynthesis-based bivalves and gastropods associated with hydrothermal vents

***Emma B. Stirk**¹, **Edine Pape**¹, **Fiona L. Gill**¹, **Crispin T. S. Little**¹, **Robert J. Newton**¹, **Cindy L. Van Dover**² and **Christopher J. Sweeting**³

¹*University of Leeds*

²*Duke University*

³*Newcastle University*

This work is part of a larger project using stable isotopic signatures of organic matter preserved in fossil shells to reconstruct nutritional strategies (see: Pape *et al.* 2014 and Elms *et al.*, 2014, this volume). One of these strategies is chemosymbiosis, well known from modern deep-sea hydrothermal vents. Chemosynthetic bacteria living symbiotically with vent invertebrates use methane and/or sulfur from vent fluids as an energy source for the fixation of carbon. This research investigates the relative contribution of environmental sources and chemosymbiosis-related fractionation to the stable isotopic signature of hydrothermal vent animals. We present stable isotope data from five bivalves and three gastropod chemosymbiotic vent species. Several species of *Bathymodiolus* were investigated from different locations within the East Pacific Rise, Manus Basin and



Lau Basin to compare different environmental influences. Conversely, multiple species, namely *Alvinoconcha hessleri* and *Ilfremeria nautili*, from the same locality were studied to compare different species under the same environmental conditions.

Our results provide insights into controls on the stable isotopic composition of soft tissue and shell-bound organic matter (SBOM) which can be applied to fossil shells in order to understand the evolution of chemosymbiosis and its relationship with changing seawater chemistry through geological time.

A comprehensive supertree of the Crocodylomorpha

***Maximilian T. Stockdale**¹, **Michael J. Benton**¹, **Mario Bronzati**², **Marco B. Andrade**³ and **Gavin Thomas**⁴

¹*School of Earth Sciences, University of Bristol*

²*Bayerische Staatssammlung für Paläontologie und Geologie, Paläontologie & Geobiologie LMU München*

³*Departamento de Paleontologia e Estratigrafia, Universidade Federal do Rio Grande do Sul*

⁴*Department of Animal and Plant Sciences, University of Sheffield*

The crown-group Crocodylomorpha have an ecomorphology that is limited to amphibious ambush predators. During the Mesozoic and Cenozoic eras the stem-group Crocodylomorpha were represented by a much greater diversity of ecomorphologies, including exclusively marine, highly terrestrialised, insectivorous and herbivorous forms. The reason for the difference in diversity and disparity between stem- and crown-group crocodylomorphs is not clear. Crocodylomorphs have extensive crown- and stem-groups that are well represented in a fossil record of great longevity. Therefore the crocodylomorpha present a unique opportunity for studying large-scale evolutionary processes among amniotes. We present a new, comprehensive phylogeny of the crocodylomorpha assembled using the Matrix Representation Parsimony method. This phylogeny serves as a basis for a study of body size distribution and rates of transition within crocodylomorph groups using time-series and phylogenetic models.

Cracking dinosaur endothermy: palaeophysiology unscrambled

***Maximilian T. Stockdale**¹, **Michael J. Benton**¹ and **Octávio Mateus**²

¹*School of Earth Sciences, University of Bristol*

²*Departamento de Ciências da Terra, Universidade Nova de Lisboa*

The amniote eggshell is a respiratory structure adapted for the optimal transmission of respiratory gases to and from the embryo according to its physiological requirements. Therefore amniotes with higher oxygen requirements, such as those that sustain higher metabolic rates, can be expected to have eggshells that can maintain a greater gas flux to and from the egg. Here we show a highly significant relationship between metabolic rates and eggshell porosity in extant amniotes that predicts highly endothermic metabolic rates in dinosaurs. This study finds the eggshell porosity of extant endotherms to be significantly higher than that of extant ectotherms. Dinosaur eggshells are commonly preserved in the fossil record, and porosity may be readily identified and measured. This provides a simple tool to identify metabolic rates in extinct egg-laying tetrapods whose eggs possessed a mineralized shell.



An investigation into ceramic technology and provenance using calcareous microfossils from Iron Age pottery at Burrough Hill hill fort, Leicestershire

***Christopher P. Stocker**¹, **Mark Williams**¹, **Ian P. Wilkinson**², **Jeremy Taylor**³ and **Ian K. Whitbread**³

¹*Department of Geology, University of Leicester, Leicester, UK*

²*British Geological Survey, Keyworth, Nottingham, UK*

³*School of Archaeological Studies, University of Leicester, UK*

One of the key questions in archaeology is the provenance of artefacts, and here micropalaeontology can play a key role. Previous palaeontological research on Iron Age ceramics from the East of England has focused on thin section petrography of pottery, demonstrating the widespread occurrence of foraminifera and ostracods. However, the identification of microfossils in thin section is complex and specialised. In this study thin-section data are coupled with a novel technique for disaggregating calcareous microfossils from fired Iron Age pottery fragments at Burrough Hill hill fort in Leicestershire: the microfossils provide sufficient data for species-level identifications and suggest an origin for the pottery clays from the local Oadby Till. Experimental firing of the Oadby Till provides a comparative dataset for understanding the distribution and context of the microfossils and fabrics in the pottery at Burrough Hill.

Late Eocene to Oligocene vegetation and climate changes of Wilkes Land, East Antarctica (IODP Expedition 318)

***Stephanie Strother**¹, **Ulrich Salzmann**¹, **John Woodward**¹, **Francesca Sangiorgi**², **Peter Bijl**², **Alexander Houben**² and **Jörg Pross**³

¹*Northumbria University*

²*Utrecht University*

³*Heidelberg University*

The Oligocene Epoch (33.9–23 Ma) is an important transitional period in Antarctica and little is known about the terrestrial response to global climate cooling. Here we present palynological results from site U1356 from Wilkes Land, East Antarctica (IODP 318). Preliminary results indicate that Late Eocene/Oligocene vegetation was dominated by temperate forest and shrub including Cyatheaceae, *Microcachrys*, *Nothofagus*, and *Podocarpus*. No major changes are found in the Late Eocene and early Oligocene pollen assemblages. However, increases in the taxa *Phyllocladidites mawsonii* and *Dacrydiumites praecupressinoides* indicate slightly warmer temperatures in the Late Eocene/Early Oligocene between c.45.5 and 33 Ma, with a decline observed in the Late Oligocene (c.25–23 Ma). A greater abundance of reworked palynomorphs possibly indicates climate deterioration and increased glacial activity. Temperature reconstructions derived from the fossil pollen assemblages using the Coexistence Approach suggest mean annual temperatures between 6.7 and 13.7°C during the Late Eocene/Early Oligocene. The absence of *Dacrydiumites praecupressinoides* in most Late Oligocene samples suggests a drop of the minimum annual temperatures to 5.8°C.



Computer modelling of heterochronic change in gastropod morphology

Andrew R. H. Swan

Kingston University

Raup's classic helicoid logarithmic spiral cone model is isometric, and hence organisms that approximate to this model cannot evolve a change in shape by heterochrony of the whole shell morphology. A computer model (HETEROSIM) is presented here in which Raup's parameters are permitted to change through ontogeny, and this allometric model is a good fit to a variety of gastropod species, especially Pulmonata. Simulated heterochrony (neoteny, acceleration, progenesis and hypermorphosis) can be applied to the generated shell shapes and a variety of sometimes surprising shapes can result. Suites of simulated shell shapes connected by heterochronic transformations often match well with the patterns of variation within gastropod families. The model can therefore engender hypotheses of heterochronic evolution that can then be tested against phylogenies. The model is also advocated as a stimulating pedagogic tool in teaching heterochrony.

Reassessing the Hirnantian macrofauna extinction in the central Anti-Atlas of southern Morocco

***Lorena Tessitore¹, Thijs R. A. Vandenbroucke², Jean-François Ghienne³, Marie-Pierre Dabard⁴, Alfredo Loi⁵ and David A. T. Harper⁶**

¹UMR 8217 du CNRS: Géosystèmes, Université Lille 1, France;

<lorena.tessitore@ed.univ-lille1.fr>

²UMR 8217 du CNRS: Géosystèmes, Université Lille 1, France;

<thijs.vandenbroucke@univ-lille1.fr>

³UMR 7516 du CNRS: Institut de Physique du Globe de Strasbourg, Université de Strasbourg, 1, France; <ghienne@unistra.fr>

⁴UMR 6118 du CNRS: Géosciences Rennes, Université de Rennes 1, France;

<marie-pierre.dabard@univ-rennes1.fr>

⁵Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Italia;

<alfloi@unica.it>

⁶Department of Earth Sciences, Durham University, England;

<david.harper@durham.ac.uk>

The Hirnantian glaciation, one of the largest in the Phanerozoic, was long thought to have occurred in two phases, accompanying a double-phased extinction, respectively linked to the initial cooling and final melting of the ice sheets. Recent work in high palaeolatitudinal settings, however, has identified a much more complex 'Cenozoic style' scenario for the Hirnantian glaciations, comprising over 15 high-order glacial cycles (Ghienne *et al.* 2014).

Our contribution aims to plot the entire macro- and micro-fauna record of the Central Anti-Atlas, southern Morocco, collected by Destombes (2004) against the revised architecture for the Hirnantian. Our database will allow us to evaluate if macro-faunal turnovers relate to other specific phases of the many glacial cycles. So far, our data compilation includes 150 species from seven sites and up to 200 km of section. We report a decrease in faunal abundance and biodiversity, moving from Southwest towards Northeast, and through time, from the first glacial cycle towards the glacial maximum.



DESTOMBES, J., 2004. Mémoire explicative des cartes géologiques au 200 000° de l'Anti-Atlas Marocain. Paléozoïque inférieur. Privately printed. 714pp.

GHIENNE, J.F. *et al.* 2014. A Cenozoic-style scenario for the end-Ordovician glaciation. *Nature Communications*, 5: 4485.

Dinosaur trackways and palynology from Maastrichtian deposits in Bolivia

Vivi Vajda

Department of Geology, Lund University

There are four sites in Bolivia known for Late Cretaceous dinosaur trackways, all dated to Campanian–Maastrichtian. Toro-Toro is the most northerly located of these sites. The first trackways were described in 1968, and 2,500 tracks have been recorded since. The footprints represent entire dinosaur faunas, with sauropods, ankylosaurs, hadrosaurs and ‘raptors’. A sedimentological study shows that the lithology mainly comprises coarse-grained sandstones and limestone with a relatively high clay content. Some beds host stromatolites, ooids and evaporates but the successions are devoid of palynomorphs. A palynological study from coeval deposits in the north western part of the country, however, reveals a diverse and rich vegetation (Vajda, 1999). Angiosperm pollen dominate heavily, mainly comprised by small monocolpate, tricolpate and tricolporate grains, generally with a finely reticulate exine, but psilate and striate forms are also recognized. Interestingly spore masses belonging to the water fern *Azolla* are abundant in a few beds (Vajda and McLoughlin, 2005). Key taxa include *Crassitricolporites brasiliensis*, *Proteacidites dehanii*, *Tricormites elongatus* and species belonging to *Aquilapollenites*.

VAJDA, V., 1999. Miospores from Upper Cretaceous–Paleocene strata in northwestern Bolivia. *Palynology* 23, 183–198.

VAJDA, V. and McLOUGHLIN, S. 2005. A new Maastrichtian–Paleocene *Azolla* species from Bolivia, with a comparison of the global record of coeval *Azolla* microfossils. *Alcheringa* 29, 305–329.

A small-scale study of sampling bias: the Chalk of Hampshire, UK

***Fiona M. Walker**

University of Bristol

The fossil record captures past biodiversity imperfectly. Does sampling bias obscure biological diversity signals in palaeontological richness data? Global studies find a correlation between sampling proxies and sampled fossil diversity. However, regional studies find that this relationship breaks down on small scales, or that the strength of this relationship depends on the taxon, tectonic and depositional setting and rock exposure. The relationship between global (gamma) and local (alpha) diversity measures is of course modified by inter-regional differentiation (beta diversity), but comparisons across scales are intriguing. A newly-compiled dataset of fossil occurrences from the Chalk of Hampshire, UK, is presented. Analysis of diversity in this succession per formation and per map square reveals a correlation between diversity and sampling effort measured at this scale. Genus richness counts are driven by sampling bias in this dataset, but this masks real local faunal turnover as demonstrated by the episodic nature of species distributions in the Chalk and similarity indices for each formation. Historic exposure will be quantified using maps from



the early 1900s, when these fossils were collected, and this will be compared with modern maps and satellite imagery to examine how exposure area has changed over the time palaeontologists have been sampling.

Changing morphospace occupation of the Ammonoidea from the Devonian to the Jurassic

***Sonny A. Walton and Dieter Korn**

Museum fuer Naturkunde, Berlin

Measurements taken from over 5,900 ammonoid species were used to calculate three cardinal conch parameters, the conch width index (CWI), umbilical width index (UWI) and the whorl expansion rate (WER). These three parameters are very descriptive in terms of the conch morphology of an ammonoid: the CWI affects the hydrodynamic properties of the conch, the UWI the shape of the whorl cross section, and the WER the length of the body chamber and the degree of coiling of the conch. A principal components analysis was performed on the conch parameters of all of the ammonoids and a two-dimensional empirical morphospace was plotted based on the first two principal components.

The PCA was broken down into the five major geological periods. The morphospace analysis reveals some interesting changes to the ammonoid conch morphs over time. The morphological range quickly fills out in the Devonian, the Carboniferous is heavily represented by globular conch morphs, and despite the Permian–Triassic mass extinction event there is a strong recovery and repopulation of the morphospace. The Jurassic shows a particularly interesting trend as there is a strong reduction in the globular conch morphs, leaving a morphospace heavily populated by serpenticonic and lenticular conch morphs.

The first holomorphic fossil chimaeroid fish (Chondrichthyes, Holocephali) from the Mesozoic of Africa

David J. Ward¹, Emma L. Bernard¹, Martha Richter¹ and Evgeny V. Popov²

¹NHM UK

²Saratov State University, Russia

In February 2014, at the Arizona Mineral and Fossil Show at Tucson, USA, the Natural History Museum, London purchased a slab of dark grey mudstone containing an impression of a chimaeroid fish. Following discussions with academics, commercial collectors and fossil dealers, the consensus was that the specimen could have come from one of the old Jebel Tselfat localities, most likely Ain el Kerma, to the west of Fez.

With the kind assistance of Professor Driss Ouahache, Faculty of Science, University of Fez, DJW visited Jebel Tselfat and located the Ain el Kerma excavation in the side of a badland erosion gully. The sediment, a weathered black organic-rich shale, closely matched the specimen and incidentally yielded a couple of impressions of bony fish skulls.

The fish is most probably *Elasmodectes willetii*, only known from the English Cenomanian chalk.

Mesozoic holomorphic chimaeroids are an extremely rare occurrence in the fossil record and are only known from the Late Jurassic of southern Germany (Solenhofen, Eichstätt), from the Late Cretaceous (Cenomanian) of Lewes England, and the Lebanese Chalk



(Santonian). This is the first documented example of a holomorphic fossil chimaeroid fish, of any age, from the continent of Africa.

Recovery from the K-Pg mass extinction in Antarctica

Rowan J. Whittle¹, James D. Witts², Vanessa Bowman¹, Jon Ineson³, Jane E. Francis¹ and J. Alistair Crame¹

¹*British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET*

²*School of Earth and Environment, University of Leeds, Woodhouse Lane, Leeds LS2 9JT*

³*Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350, Copenhagen, Denmark*

The modern Antarctic marine fauna arose following the Cretaceous–Paleogene (K-Pg) mass extinction event, and biotic recovery occurred throughout the Cenozoic Era. New stratigraphic analysis linked with comprehensive fossil collections from Seymour Island, located on the Antarctic Peninsula (65°S), has enabled the detailed study of this critical time interval. This locality comprises one of the best exposed and most complete high latitude Cretaceous–Eocene sedimentary sequences anywhere in the world. The K-Pg boundary occurs between Units 9 and 10 of the López de Bertodano Formation, which were deposited in a mud-dominated mid-shelf environment.

A bed of disarticulated fish material occurs immediately above the K-Pg boundary suggesting the presence of unstable environmental conditions. The early Paleocene fauna was dominated by infaunal mollusc taxa; two deposit feeding bivalves, three suspension feeding bivalves, one deposit feeding gastropod and one predatory gastropod. A radiation of new molluscan taxa began around 0.5 million years after the K-Pg event close to the contact between the López de Bertodano and Sobral formations. Infaunal and epifaunal carnivorous neogastropods became more prominent at this level. Overall, the fossil community of the lower to middle Sobral Formation was dominated by molluscs living in a shallow water deltaic environment.

The palynology of the Bajocian of Swabia, south-west Germany: a rapid dinoflagellate cyst radiation during the Middle Jurassic

***Nickolas J. Wiggan¹, James B. Riding² and Matthias Franz³**

¹*Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK*

²*British Geological Survey, Keyworth, Nottingham NG12 5GG, UK*

³*Regierungspräsidium Freiburg–Dept. 9, State Authority for Geology, Mineral Resources and Mining, Albertstraße 5, Freiburg D-79104, Germany*

During the Bajocian (Middle Jurassic, 170.3–168.3 Ma), the dinoflagellates underwent an explosive radiation, resulting in *c.*50 dinoflagellate cyst species (mainly of family Gonyaulacaceae) appearing by the end of this interval. This is broadly coincident with diversification within coccolithophores, and the appearance of the first planktonic foraminifera, indicating that major evolutionary changes in plankton occurred at this time.

Material has been collected and analysed from Swabia, south-west Germany; in this region the Bajocian is expanded and largely complete. Diversity increases dramatically through



the stage and considerable morphological changes in archaepyle (excystment aperture) formation occurs. Assemblages from the Lower Bajocian are of low diversity, being dominated by *Dissiliodinium giganteum*, the first dinocyst to shed multiple precingular plates during excystment. A rapid increase in diversity occurs in the 'middle' Bajocian, with c.20 first occurrences, including that of *Acanthaulax crispa*, the first gonyaulacoid dinocyst to evolve a one-plate precingular archaepyle. This would become one of the main excystment modes in gonyaulacoids, and remains so to the Recent. Diversity increases throughout the Upper Bajocian with the emergence of several species of *Ctenidodinium*; this represents the development of epicystal archaepyles, which would become a prominent excystment mode for the rest of the Middle Jurassic.

Sternal morphology and soaring flight

***Megan E. Williams**

University of Cambridge

The sternum is the origin of major flight muscles in birds; both of the down stroke and upstroke. Morphological aspects, such as carina reduction, have been associated with flight loss. This study investigates the association of sternal morphology with soaring flight (where lift energy is gained from atmospheric movements rather than flapping). I focused on dynamic (energy from wind shear) and static (energy from thermals) soaring as these make little use of flapping flight.

Traditional and geometric morphometric techniques were used to examine sterna. These were sampled from adult specimens of static soaring, dynamic soaring and non-passerine neoavian flapping/flap-gliding species.

Sternal morphology differed significantly with flight style, with both traditional and geometric morphometrics. PCA performed on the geometric data demonstrated that different flight styles occupied distinct areas of morphospace, with dynamic and static soaring birds clearly separated.

Assignment tests displayed high accuracy, with higher accuracy achieved using geometric morphometric techniques. However, in the geometric study, assignment accuracy was greatly reduced when allometry was accounted for, despite accounting for <10% of morphological variation.

These results indicate that the sternum has an important role in flight style and will allow the subsequent identification of potential soaring birds in the fossil record.

Exploring phosphatization biases: evidence from Lebanese fossil polychaetes

***Paul Wilson, Luke Parry and Jakob Vinther**

Life Science Building, Tyndall Avenue, Clifton, Bristol

The preservation of soft-tissues is rare in the fossil record but, where preserved, they yield unprecedented insights. Among the processes responsible for the permineralization of labile tissues, phosphatization is key, often replicating muscle tissue and digestive tracts in three-dimensional calcium phosphates. While efforts have elucidated the broad triggers of this process, understanding of the fine scale geochemical controls that drive phosphatization is poor, due to the limited extent of such tissue permineralization. However, the discovery of polychaetes showing full-body phosphatization from the Cretaceous Lebanese Lagerstätten



of Hakel and Hjoula allows an opportunity to explore this territory and elucidate the triggers responsible for extensive phosphatization, particularly as other polychaetes in these beds rarely show mineralization. Analysis via myoanatomical mapping, SEM and comparison to extant CT-scanned polychaetes reveals that these fossils belong to a single taxon in the Amphinomidae, revealing three prominent biases in the process of phosphatization: 1) a taxon bias, where extensive phosphatization is limited to a single polychaete taxon; 2) a tissue bias, where different tissues within a fossil have varying fidelities; 3) a locational bias, where fidelity varies along the body. However, ready explanations for these biases are lacking, highlighting a need for more experimental data on phosphatization.

Late Jurassic to Early Cretaceous dinoflagellate cysts from the Eastern Gulf of Mexico: facilitating future exploration and development

***Stephanie Wood**¹, **Charles Wellman**¹, **Katrin Ruckwied**² and **Iain Prince**²

¹*University of Sheffield*

²*Shell Exploration and Production, USA*

The Late Jurassic to Early Cretaceous deposits of the Eastern Gulf of Mexico (EGoM) are one of the world's major hydrocarbon reserves. However, the Gulf of Mexico is a structurally complex area in terms of its tectonic setting. This unusual basin therefore requires establishment of a high-resolution biostratigraphy to facilitate correlation and aid understanding of its sedimentary fill. Unfortunately there is a distinct lack of published studies on dinoflagellate cysts from these strata. This research project aims to fill that data gap by producing a high-resolution dinoflagellate cyst biostratigraphy from data collected from three wells around the EGoM. 175 samples have been processed and analysed using light microscopy. Rich assemblages of well-preserved palynomorphs, dominated by dinoflagellate cysts, have been recovered. These have been systematically described and quantitative occurrence/abundance data have been collected and analysed using the data storage and analysis packages PAST and STRATABUGS. These data have been utilised in a detailed analysis of the biostratigraphy, palaeoecology, palaeoenvironments and palaeogeography of the deposits and in developing a robust high-resolution biostratigraphy. This will greatly facilitate upcoming exploration and development activities in this basin and ensure future energy security.

Identification of life-history stages in fusulinid foraminifera

Yukun Shi¹ and **Norman Macleod**^{1,2}

¹*Natural History Museum, London*

²*Nanjing Institute of Palaeontology and Stratigraphy, Chinese Academy of Sciences, Nanjing, China*

The whorls of fusulinid foraminifera preserve a record of each individual's ontogeny, and therefore provide proxy access to morphological life-history patterns. Morphometric analysis has revealed that different fusulinid genera exhibit characteristically different, ontogenetic trajectories within a space defined by size, shape, and whorl number variables. In other groups, less dramatic ontogenetic transitions have been used to define juvenile, sub-adult, and adult life history stages. For example, whorl shape in *Schwagerina* turns progressively from a spherical to fusiform shape whereas *Robustoschwagerina* and



Sphaeroschwagerina change from an early spherical character to a fusiform shape and then back to a spherical. More intriguing is our finding that, on occasion, the ontogenetic patterns of individuals assigned to the same species on the basis of superficial 'adult' morphology differ in characteristic and consistent ways. While care must be taken not to confuse pattern-level observations with process-level inferences, if additional investigations confirm the generality of these patterns they may enable fusulinids to be used to test a variety of developmental, taxonomic, phylogenetic, evolutionary and ecological hypotheses.

**The
Palaeontological
Association**

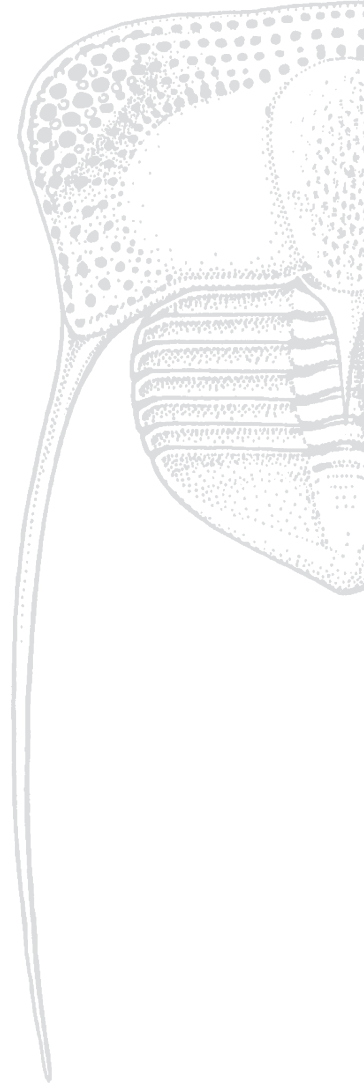
**Annual
General
Meeting**

17.45

Wednesday

17th December

Papers





Annual Meeting 2014

Notification is given of the 2014 Annual General Meeting

This will be held at the University of Leeds, UK, 17th December 2014, following the scientific sessions of the Annual Meeting.

AGENDA

1. Apologies for absence
2. Minutes of the 2013 AGM, University of Zurich
3. Trustees Annual Report for 2013
4. Accounts and Balance Sheet for 2013
5. Election of Council and vote of thanks to retiring members
6. Report on Council Awards
7. Annual Address

DRAFT AGM MINUTES 2013

Minutes of the Annual General Meeting held on Saturday 14th December 2013 at the University of Zurich, Switzerland.

1. Apologies for absence: Prof. D. Donovan, Prof. J. Kennedy, Ms J. Lawrence, Dr A. McGowan, Dr P. Orr, Dr M. Sutton, Dr T. Vandenbroucke.

2. Minutes: Proposed by Mr D. J. Ward and seconded by Mr A. Spencer, the minutes were agreed a correct record by unanimous vote of the meeting.

3. Trustees Annual Report for 2012: Proposed by Prof. G. Sevastopulo and seconded by Dr H. A. Armstrong, the report was agreed by unanimous vote of the meeting.

4. Accounts and Balance Sheet for 2012: Proposed by Dr C. T. S. Little and seconded by Prof. D. A. Harper, the accounts were agreed by unanimous vote of the meeting.

5. Proposed changes to the Constitution: As proposed by Prof. M. P. Smith and seconded by Dr M. Munt, the members agreed by a unanimous vote to accept the following changes to the Constitution (new text in bold):

a. Paragraph 6: The business of the Association shall be undertaken by a Council and by committees of the Council. The Council shall consist of a maximum of twenty members. The Officers shall consist of a President, and, at least, two Vice-Presidents, a Treasurer, a Secretary, **an Editor-in-Chief**, and such other Officers as the Council may from time to time determine. At any meetings of the Council six members shall form a quorum which shall always include the President, or a Vice-President or the Secretary. The committees of the Council may co-opt members of the Association as non-voting committee members. Committees of Council shall be open to all members of Council.



b. Paragraph 7: Periods of service for Officers shall be flexible but should normally not exceed two years for President and Vice-Presidents, and five years for Secretary, Editors, and Treasurer. Total consecutive service as an Officer (excluding service as President) should **normally** not exceed ten years. Other members of the Council shall be elected for a period of three years. All members of Council are Trustees of the Association in accordance with charity law.

6. Subscriptions: Following discussion, members agreed to Council's proposed changes to subscriptions. From 2015, the rates for retired and student members will be £15 (for online access to the journal only) or £36 (including a paper copy of the journal); the rates for ordinary members will be £30 (for online access only) or £45 (including a paper copy of the journal).

7. Election of Council and vote of thanks to retiring members

Prof. M. J. Benton extended a vote of thanks to the following members of Council who were retiring from their positions this year: Dr H. A. Armstrong, Dr C. Klug, Dr P. Upchurch. The following members were elected to serve on Council. *President:* Prof M. J. Benton; *Vice Presidents:* Dr M. Sutton and Dr A. B. Smith; *Treasurer:* Mr P. Winrow; *Secretary:* Prof R. J. Twitchett; *Editor-in-Chief:* Dr A. B. Smith; *Editor Trustees:* Prof C. H. Wellman, Dr M. Ruta; *Newsletter Editor:* Dr A. McGowan; *Book Review Editor:* Dr C. Jeffrey-Abt; *Publicity Officer:* Dr L. Herringshaw; *Education Officer:* Dr C. Buttler; *Outreach Officer:* Dr F. Gill; *Internet Officer:* Mr A. Spencer; *Meetings Coordinator:* Dr T. Vandenbroucke; *Ordinary Members:* Dr R. J. Butler, Dr C. T. S Little, Dr M. Munt, Dr R. Owens and Mr D. Ward. Dr C. T. S. Little will organise the annual meeting in 2014 at the University of Leeds, UK.

8. Association Awards: The following awards were made: Lapworth Medal to Prof. D. Edwards (University of Cardiff); President's Medal to Prof. C. H. Wellman (University of Sheffield); Hodson Award to Dr M. Friedman (University of Oxford); and the Mary Anning award to Dr Hans Hess (Basel, Switzerland). Under the Small Grants Scheme, the following awards were announced: Sylvester-Bradley Awards to Dr M. Barham, N. Barling, L. Hauser, L. McLennan, and M. O'Sullivan; Callomon Award to E. Pape; and Whittington Award to Dr C. Apaldetti. Research Grants were awarded to Dr A. McGowan (University of Glasgow), Dr T. Challands (University of Edinburgh) and Dr S. Danie (Plymouth University). The President's Award was made to J. Clarke (University of Oxford) and the Council Poster Prize was presented to D. Button (University of Bristol).

9. Annual Address: The Annual Address entitled "Sharks and the deep origin of modern jawed vertebrates" was given by Prof. M. Coates (University of Chicago).



Trustees Annual Report 2013

Nature of the Association. The Palaeontological Association is a Charity registered in England and Wales, Charity Number 276369. Its Governing Instrument is the Constitution adopted on 27th February 1957, amended on subsequent occasions as recorded in the Council Minutes. The aim of the Association is to promote research in Palaeontology and its allied sciences by (a) holding public meetings for the reading of original papers and the delivery of lectures, (b) demonstration and publication, and (c) by such other means as the Council may determine. Trustees (Council Members) are elected by vote of the Membership at the Annual General Meeting. The contact address of the Association is c/o The Executive Officer, Dr T. J. Palmer, Institute of Geography and Earth Sciences, University of Aberystwyth, Aberystwyth, SY23 3DB, Wales, UK.

Trustees. The following members were elected to serve as trustees at the AGM on 18th December 2012: *President:* Prof. M.J. Benton; *Vice Presidents:* Dr A.B. Smith and Dr H.A. Armstrong; *Treasurer:* Mr P. Winrow; *Secretary:* Prof. R.J. Twitchett; *Chair of Publications Board:* Dr P.J. Orr; *Editor Trustees:* Dr P.C.J. Donoghue and Dr H.A. Armstrong; *Book Review Editor:* Dr C. Jeffrey-Abt; *Newsletter Reporter:* Dr L. Herringshaw; *Newsletter Editor:* Dr A. McGowan; *Web Officer:* Dr M. Sutton; *Meetings Coordinator:* Dr T. Vandenbroucke; *Ordinary Members:* Dr C. Klug, Dr R. Owens, Dr W. Renema, Dr P. Upchurch, Mr D. Ward. *The Executive Officer:* Dr T.J. Palmer and *Editor-in-Chief:* Dr S. Stouge continued to serve Council but are not Trustees. Dr C. Buttler, Dr F. Gill and Prof M.A. Purnell were co-opted onto Council but are not Trustees.

Membership. Membership on 31st December 2013 totalled 1,163 (1,182 at end 2012). Of these 660 were Ordinary Members, 147 Retired Members, 19 Honorary Members, 285 Student Members and 52 Institutional Members. There were 80 institutional subscribers to *Special Papers in Palaeontology*. Wiley Blackwell also separately manage further Institutional subscribers and distribute publications to these Institutional Members on behalf of the Association.

Professional Services. The Association's Bankers are NatWest Bank, 42 High Street, Sheffield, S1 1QF. The Association's Independent Examiner is G. R. Powell BSc FCA, Nether House, Great Bowden, Market Harborough, Leicestershire LE16 7HF. The Association's investment portfolio was managed by Quilter, St Helen's, 1 Undershaft, London EC3A 8BB.

Reserves. The Association holds reserves of £790,665 in General Funds, which enable the Association to generate additional revenue through investments, and thus to keep subscriptions to individuals at a low level, whilst still permitting a full programme of meetings to be held, publications produced and the award of research grants and grants-in-aid. They also act as a buffer to enable the normal programme to be followed in years in which expenditure exceeds income, and new initiatives to be pursued. The Association holds £64,246 in Designated Funds which contribute interest towards the funding of the Sylvester-Bradley, Hodson, Callomon, and Whittington Funds and towards the Jones-Fenleigh awards. Total funds carried forward to 2014 totalled £854,911.

Finance. Total charitable expenditure, through grants to support research, scientific meetings and workshops in 2013, was £295,456. Governance costs were £16,158. Total resources expended were £341,665. The Association continues its membership of the International Palaeontological Association and remains a Tier 1 sponsor of *Palaeontologia Electronica*, and the *Treatise on Invertebrate Paleontology*.



Risk. The Association is in a sound financial position. Succession planning for the Executive Officer remains a concern and will be considered as part of the Annual Review of Officers in 2014.

Charitable Activities. The Association continues to increase its range and investment in charitable activities. We have continued to provide funds to support student and speaker attendance at our own and international meetings.

Research Grants. Palaeontological Association Research Grants were awarded to Dr A. McGowan (University of Glasgow) for a project entitled 'Determining whether damming of the River Kerry (NW Scotland) produced a deleterious growth spurt in a threatened *Margaritifera margaritifera* population with high-precision dating methods'; to Dr T. Challands (University of Edinburgh) for 'Palaeoneurology and sensory systems in Devonian lungfish: morphological diversity or conservatism in the neurological system?'; and Dr S. Danise (Plymouth University) for 'Mesozoic marine reptile dead-falls: analogues of whale fall communities?'

Grants-in-aid. The Association provided funds to support the following meetings and workshops: 'Biological and Environmental Feedbacks in the Colonization of the Water Column' (GSA Annual Meeting 2013, Session T236, Denver, CO, USA); 'Konservat-Lagerstätten: Morphology, Ecology, and Taphonomy of Exceptionally Preserved Fossils' (GSA Annual Meeting 2013, Session T243); Stan Wood's Palaeontological Legacy meeting (National Museum of Scotland); 'Prehistoric colours in fossil insects and feathers' (Royal Society Summer Science Exhibition); a workshop entitled 'Introduction to Research Methods in Quantitative Palaeobiology' (University of Bristol); the 9th European Palaeobotany and Palynology Conference (Padova, Italy); the Arthur Smith Woodward 150th Anniversary Symposium (NHM, London); a workshop entitled 'Challenges in Macroecology – scaling the time barrier' (NHM, London); 'Dead organisms as data archives: Conservation and global change palaeobiology' (EGU session SSP4); the 2014 Society of Vertebrate Palaeontology and Comparative Anatomy meeting (York, UK); the 9th International Congress on Cephalopods Past and Present (Zurich, Switzerland); and a meeting entitled 'The Old Red Sandstone of the South-Western Province' (South Wales). In addition, funds were provided to support the following sessions at IPC4, to be held in Mendoza, Argentina: 'Cretaceous marine biotas and seaways in Gondwana'; 'Research and Management of Palaeontological UNESCO World Heritage Sites'; 'Rotten fossils? Experimental and analytical approaches to decay and exceptional preservation of soft tissues'; and 'Evolution of photosynthesizing organisms – from microbiota to plants'.

Small Grants Scheme. The scheme received eleven applications. Seven were recommended for funding in 2014, totalling £9,183.50. Sylvester-Bradley Awards were made to Dr Milo Barham, Nathan Barling, Luke Hauser, Laura McLennan, and Michael O'Sullivan. The Callomon Award was awarded to Edine Pape, and the Whittington Award to Dr Cecilia Apaldetti.

Online activities. The online activities of the Association continue to expand with investment in a larger, faster, and more secure server. The Association is now the sole host for the online-only journal *Palaeontologia Electronica*. The Association also continues to host websites for other societies (The Palaeontographical Society; International Organisation of Palaeobotany), palaeontological online resources (EDNA fossil insect database; the Kent Fossil Database), and online outreach projects (*Palaeontology* [Online]). The Association launched a Twitter account, @ThePalAss, which had c.500 followers by the end of the year.



Public meetings. Four public meetings were held in 2013, and the Association extends its thanks to the organisers and host institutions of these meetings.

57th Annual Meeting. This was held on 13th – 16th December at University of Zurich, Switzerland. Dr Klug with local support from colleagues and PhD students organised the meeting which included a symposium on “Fossilised ontogenies and evolution” and comprised a programme of internationally recognised speakers. There were 268 attendees. The Annual Address entitled “Sharks and the deep origin of modern jawed vertebrates” was given by Prof. Michael Coates (University of Chicago). The President’s Prize for best oral presentation from an early career researcher was made to John Clarke (University of Oxford). The Council Poster Prize was presented to David Button (University of Bristol). A choice of two post-conference field trips was offered: to the dinosaur museum at Aathal or to Monte San Giorgio.

British Science Festival, Palaeontological Association Symposium. This is an annual forum for presentations to the public and general scientists. The Symposium “Bodies of Evidence” was organised by Dr Liam Herringshaw at the Great North Museum, Newcastle. Funds were provided to support presentations by Prof. Mark Purnell and colleagues (University of Leicester), Dr Howard Armstrong, Prof. Dave Harper and Ms Katie Strang (Durham University), Dr Martin Ruecklin (Bristol/Leiden) and Mr Esben Horn (10 Tons, Copenhagen).

Progressive Palaeontology. The annual open meeting for presentations by research students was organised by T. Fletcher and a team of other colleagues, and was held at the University of Leeds.

Lyell Meeting. The Lyell Meeting in 2013 was held in London on the topic of “The Cambrian Explosion – understanding Earth systems at the origin of modern ecosystems”, organised by Prof. M.P. Smith (Oxford University Museum of Natural History) and Prof. D.A.T. Harper (Durham University).

Publications. Publication of *Palaeontology* and *Special Papers in Palaeontology* is managed by Wiley Blackwell. Volume 56 of *Palaeontology*, comprising six issues, was published. *Special Papers in Palaeontology* **89**, “Devonian spore assemblages from northwestern Gondwana: taxonomy and biostratigraphy”, by P. Breuer and P. Steemans; and *Special Papers in Palaeontology* **90**, “Latest Ordovician and earliest Silurian brachiopods succeeding the Hirnantia fauna in south-east China”, by Rong Jiayu *et al.*, were also published during the year. The Association is grateful to the National Museum of Wales and the Lapworth Museum (University of Birmingham) for providing storage facilities for publication back-stock and archives. Council is indebted to Meg and Nick Stroud for assistance with the publication and distribution of *Palaeontology Newsletter*.

Publicity. The Association continues to promote palaeontology and its allied sciences through press releases to the national media, radio and television. The Association had a stand at the Lyme Regis Fossil Festival, which was staffed by members of Council, the Executive Officer and volunteers.

Awards. The Lapworth Medal, awarded to people who have made a significant contribution to the science by means of a substantial body of research, was presented to Prof. D. Edwards (University of Cardiff). The President’s Medal for a palaeontologist in recognition of outstanding contributions in his/her earlier career, coupled with an expectation that they will continue to contribute significantly to the subject in their further work, was awarded to Prof. C.H. Wellman (University of Sheffield). The Hodson Award, for a palaeontologist under the age of 35 who has made an outstanding



achievement in contributing to the science through a portfolio of original published research, was awarded to Dr M. Friedman (University of Oxford). The Mary Anning award, for an outstanding contribution by an amateur palaeontologist, was made to Dr Hans Hess (Basel, Switzerland). Council also awards an undergraduate prize to each UK and Irish university department in which palaeontology is taught beyond Level 1.

Governance. The Association continues to improve its administration with further improvements to the *Newsletter* and website. Trustees were members of the Joint Committee for Palaeontology: Prof. M.J. Benton and Prof. R.J. Twitchett represented the Association. During the year, substantial changes were made to the post of Editor-in-Chief following the retirement of Dr Stouge, and a new post of Publications Officer was created. The post of Chair of the Publications Board ceased to exist and the duties were transferred to the new post of Editor-in-Chief. These changes required a minor change to the wording of the Constitution, which was approved by members at the AGM.

Forthcoming plans. Council will continue to make substantial donations, from both General and Designated funds, to permit individuals to promote the charitable aims of the Association. Resources will be made available from General Funds to support the Association Research Grant, Grants-in-Aid, provided to carry out research into palaeontological subjects, to disseminate findings in print and at conferences, and support the provision of palaeontological workshops. The Association will continue to recognise the contribution individuals have made to palaeontology and associated sciences through its awards. In 2014, a similar programme of public meetings and publications will be carried out. Funds will be made available to develop the website further, with the aim of encouraging outreach and to support other outreach, education and publicity initiatives. The Association will launch a new undergraduate research bursary scheme and a new fund to support outreach activities in 2014. The 58th Annual Meeting will be held at the University of Leeds. Progressive Palaeontology will be held at the University of Southampton. The Association will sponsor a symposium at the British Science Festival and will provide travel grants and symposium sponsorship for the Congress of the European Geosciences Union and the 4th International Palaeontological Congress.



THE PALAEOLOGICAL ASSOCIATION Registered Charity No. 276369
STATEMENT OF FINANCIAL ACTIVITIES for the YEAR ENDED 31st DECEMBER 2013

		General Funds	Designated Funds	TOTAL 2013	TOTAL 2012
Incoming Resources					
Generated Funds					
Voluntary income	Subscriptions	55,744		55,744	58,627
	Donations	<u>3,221</u>	<u>1,340</u>	<u>4,561</u>	<u>2,741</u>
		58,965	1,340	60,305	61,368
Charitable activities					
Sales	<i>Palaeontology</i>	257,385			
	<i>Special Papers</i>	13,677			
	Offprints	110			
	<i>Newsletter</i>	0			
	<i>Field Guides</i>	7,230			
	Distribution	<u>426</u>			
		278,828		278,828	230,050
Investment income		<u>13,932</u>	<u>75</u>	<u>14,007</u>	<u>15,050</u>
TOTAL INCOMING RESOURCES		<u>351,725</u>	<u>1,415</u>	<u>353,140</u>	<u>306,468</u>
Resources expended					
Costs of generating funds					
...for voluntary income	Admin.	26,514			27,805
Investment management	S'broker fees	<u>3,537</u>			<u>3,186</u>
		30,051	0	30,051	30,991
Charitable activities					
Publications	<i>Palaeontology</i>	113,470			
	<i>Special Papers</i>	6,485			
	Offprints	1,128			
	<i>Field Guides</i>	0			
	<i>Newsletters</i>	18,035			
	Distribution	752			
	Marketing	1,102			
	Editorial costs	<u>65,135</u>			
	Total Publications	206,107		206,107	158,458
Scientific Meetings & Costs		26,591		26,591	6,946
Grants and Awards		5,903	9,506	15,409	32,060
Research Grants		5,685		5,685	16,197
Administration of charitable activities		<u>41,664</u>		<u>41,664</u>	<u>34,756</u>
		206,107		295,456	248,417
Governance costs	Examiner's fee	500			
	Trustee expenses	8,083			
	Administration	<u>7,575</u>			
		16,158	0	16,158	15,555
TOTAL RESOURCES EXPENDED		<u>332,159</u>	<u>9,506</u>	<u>341,665</u>	<u>294,963</u>
NET INCOMING RESOURCES		19,566	-8,091	11,475	11,505
INVESTMENT GAINS/LOSSES					
Realised gain		1,993			
Unrealised gain		<u>59,222</u>			
		61,215		61,215	27,625
DEFICIT/(SURPLUS) FOR THE YEAR		80,781	-8,091	72,690	39,130
FUNDS BROUGHT FORWARD		<u>709,884</u>	<u>72,337</u>	<u>782,221</u>	<u>743,091</u>
FUNDS CARRIED FORWARD		<u>790,665</u>	<u>64,246</u>	<u>854,911</u>	<u>782,221</u>



THE PALAEOLOGICAL ASSOCIATION Registered Charity No. 276369

BALANCE SHEET as at 31st DECEMBER 2013

2012 £		Note	2013 £
	INVESTMENTS		
546,214	At market value	1.6	594,639
	CURRENT ASSETS		
166,901	Cash at Banks	162,483	
<u>119,767</u>	Sundry Debtors	6	<u>128,438</u>
<u>286,668</u>	Total Current Assets		290,921
	CURRENT LIABILITIES		
19,681	Subscriptions in Advance	21,010	
<u>30,980</u>	Sundry Creditors	7	<u>9,639</u>
50,661	Total Current Liabilities		30,649
<u>236,007</u>	NET CURRENT ASSETS		<u>260,272</u>
<u>782,221</u>	TOTAL ASSETS		<u>854,911</u>
	Represented by:		
709,884	GENERAL FUNDS		790,665
	DESIGNATED FUNDS	8	
11,230	Sylvester-Bradley Fund		5,052
23,286	Jones-Fenleigh Fund		23,720
10,386	Hodson Fund		9,152
8,599	Callomon Fund		7,573
<u>18,836</u>	Whittington Fund		<u>18,749</u>
72,337			64,246
<u>782,221</u>			<u>854,911</u>

Approved by the Board of Trustees 7th May 2014



THE PALAEOLOGICAL ASSOCIATION Registered Charity No. 276369

DESIGNATED FUNDS, Year ended 31st December 2013. Note 8 to the Accounts

	Sylvester- Bradley	Jones- Fenleigh	Hodson	Callomon	Whittington	TOTAL 2013	TOTAL 2012
Donations	270	410	0	207	453	1,340	2,566
Interest Received	<u>12</u>	<u>24</u>	<u>11</u>	<u>9</u>	<u>19</u>	<u>75</u>	<u>80</u>
TOTAL INCOMING RESOURCES	282	434	11	216	472	1,415	2,646
Grants made	<u>6,460</u>	<u>0</u>	<u>1,245</u>	<u>1,242</u>	<u>559</u>	<u>9,506</u>	<u>11,299</u>
NET SURPLUS/(DEFICIT)	-6,178	434	-1,234	-1,026	-87	-8,091	-8,653
TRANSFERS BETWEEN FUNDS	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
SURPLUS/(DEFICIT) FOR THE YEAR	-6,178	434	-1,234	-1,026	-87	-8,091	-8,653
FUNDS BROUGHT FORWARD	<u>11,230</u>	<u>23,286</u>	<u>10,386</u>	<u>8,599</u>	<u>18,836</u>	<u>72,337</u>	<u>80,990</u>
FUNDS CARRIED FORWARD	<u>5,052</u>	<u>23,720</u>	<u>9,152</u>	<u>7,573</u>	<u>18,749</u>	<u>64,246</u>	<u>72,337</u>



Notes to the Financial Statements for the year ended 31st December 2013

1. Accounting Policies

The principal accounting policies adopted in the preparation of the financial statements are set out below and have remained unchanged from the previous year and also have been consistently applied within the same financial statements.

1.1 Basis of preparation of financial statements

The accounts have been prepared in accordance with the Statement of Recommended Practice issued by the Charity Commission in 2011 and cover all the charity's operations, all of which are continuing.

The effect of events relating to the year ended 2013 which occurred before the date of approval of the statements by Council have been included to the extent required to show a true and fair state of affairs at 31st December 2013 and the results for the year ended on that date.

1.2 Fund Accounting

General Funds are unrestricted funds which are available for use at the discretion of the Council in furtherance of the general objectives of the charity and which have not been designated for other purposes.

Designated funds comprise unrestricted funds that have been set aside by Council for particular purposes. The aim of each designated fund is as follows:

Sylvester-Bradley Fund: Grants made to permit palaeontological research.

Jones Fenleigh Fund: Grants to permit one or more students annually to attend the meeting of the Society of Vertebrate Palaeontology and Comparative Anatomy (SVPCA).

Hodson Fund: Awards made in recognition of the palaeontological achievements of a worker under the age of 35.

Callomon Fund: Grants made to permit palaeontological research with a fieldwork element.

Whittington Fund: Grants made to permit palaeontological research with an element of study in museum collections.

1.3 Incoming Resources

The charity's income principally comprises subscriptions from individuals and institutions which relate to the period under review, and sales of scientific publications which are brought into account when due.

1.4 Resources Expended

All expenditure is accounted for on an accruals basis and has been classified under the appropriate headings.

Charitable expenditure is that which is incurred in furtherance of the charity's objectives.

Administrative costs have been allocated to the various cost headings based on estimates of the time and costs spent thereon.

1.5 Investments

Investments are stated at market value at the balance sheet date. The statement of financial activities includes net gains and losses arising on revaluations and disposals throughout the year of both investments and foreign cash balances.

1.6 SCHEDULE OF INVESTMENTS (per analysis sheet)



2. Analysis of Financial Resources Expended

	Staff costs £	Other costs £	Total 2013 £	Total 2012 £
Generating Funds	17,635	12,416	30,051	30,991
Charitable activities	61,865	233,591	295,456	248,417
Governance	<u>5,039</u>	<u>11,119</u>	<u>16,158</u>	<u>15,555</u>
	<u>84,539</u>	<u>257,126</u>	<u>341,665</u>	<u>294,963</u>

3. Staff Costs

	Salary £	National Insurance £	Pension Contributions £	Total 2013 £	Total 2012 £
Publications: 1 employee (2012 - 1)	29,323	1,539	3,290	34,152	38,987
Administration: 1 employee (2012 - 1)	<u>32,167</u>	<u>3,384</u>	<u>14,836</u>	<u>50,387</u>	<u>46,300</u>
	<u>61,490</u>	<u>4,923</u>	<u>18,126</u>	<u>84,539</u>	<u>85,287</u>

4. Trustees Remuneration and Expenses

Members of Council neither received nor waived any emoluments during the year (2012 – nil).

The total travelling expenses reimbursed to 17 Members of Council was £8,083 (2012 – £8,154).

5. Costs of Independent Examiner

	2013 (£)	2012 (£)
Examination of the accounts	500	450
Accountancy and payroll services	<u>1,500</u>	<u>1,450</u>
	<u>2,000</u>	<u>1,900</u>

6. Debtors

	2013 (£)	2012 (£)
Accrued income – receivable within one year	128,438	119,767

7. Creditors – falling due within one year

	2013 (£)	2012 (£)
Social Services costs	1,796	3,196
Accrued expenditure	<u>7,843</u>	<u>27,784</u>
	<u>9,639</u>	<u>30,980</u>

8. Designated Funds (per analysis sheet)



Nominal	Holding	Cost (bought pre 2013)	Value end 2012
£18,000	UK 4.75% Stock 07/03/20 GBP 100	£ 18,145.87	£ 22,498.00
£20,000	UK 4.5% Gilt 07/03/19 GBP 0.01	£ 20,092.99	£ 24,352.00
£64,176.46	COIF Charities Fixed Interest Fund	£ 85,000.00	£ 86,477.78
	804 Royal Dutch Shell B shares	£ 12,432.00	£ 17,487.00
	1,425 BP Ord 25c shares	£ 5,047.35	£ 6,053.00
	600 BHP Billiton \$0.5 shares	£ 4,341.48	£ 12,777.00
	500 BG Group Ordinary 10p shares	£ 3,977.95	£ 5,063.00
	1,465 HSBC Holdings Ordinary 0.5 US Dollar shares	£ 4,425.44	£ 9,477.00
	1,800 Barclays 25p Ord shares	£ 4,034.84	£ 4,723.00
	450 Barclays 25p Ord shares rights issue		
	105 Next Ord 10p shares		
	230 Weir Group 12.5p shares	£ 5,064.75	£ 4,322.00
	1,000 3I Group Ordinary £0.738636 shares	£ 3,058.76	£ 2,172.00
	1,150 Tesco Ord GBP 0.05	£ 4,583.22	£ 3,864.00
	1,550 Kingfisher Ord GBP 0.157142857	£ 3,554.45	£ 4,404.00
	500 IMI Ord 25p shares	£ 4,905.57	£ 5,485.00
	175 Carnival Plc Ord USD 1.66	£ 3,996.49	£ 4,127.00
	650 Glaxo Smithkline Ordinary 25p shares	£ 10,232.42	£ 8,678.00
	220 Shire Ord 5p shares	£ 4,986.29	£ 4,151.00
	2,499 Bluecrest Allblue Ord Npv GBP shares	£ 3,020.28	£ 4,251.00
	550 Amec ord 50P	£ 6,133.62	£ 5,517.00
	2,200 Melrose Indust Ord 0.1p		
	4,175 Vodaphone Group Ord USD 0.11428571	£ 6,034.20	£ 6,448.00
	2,150 BT Group Ordinary 5p shares	£ 7,787.53	£ 4,969.00
	225 Brit Amer Tobacco Ord GBP 0.25	£ 4,991.81	£ 7,022.00
	300 Unilever PLC Ord GBP 0.031111	£ 4,326.21	£ 7,098.00
	460 Pearson Ordinary 25p shares	£ 8,069.00	£ 5,465.00
	490 Serco Group Ord 2P	£ 3,005.01	£ 2,622.00
	700 National Grid Ord GBP 0.113953	£ 3,648.26	£ 4,921.00
	420 Experian Ord 10C	£ 3,444.95	£ 4,116.00
	670 Blackrock World Mining Ord 5P	£ 4,019.09	£ 3,930.00
	400 Persimmon Ord 10p		
	650 RIT Capital Partners Ordinary £1 shares	£ 4,903.90	£ 7,352.00
	4,400 TR Property Ord 25p shares	£ 7,560.85	£ 7,612.00
	1,000 Balfour Beatty 50P	£ 2,913.17	£ 2,737.00
	1,225 Brown Advisory US Equity Value £B	£ 14,789.62	£ 14,945.00
	1,500 British Empire Sec & Gen Trust Ordinary 10p shares	£ 5,005.61	£ 7,110.00
	425 Findlay Park Partners US Smaller Companies	£ 6,158.47	£ 14,336.00
	2,825 Ishares S&P 500 GBP	£ 20,319.63	£ 24,263.00
	900 JPMorgan Am UK Ltd Emerging Markets I Instl	£ 5,043.10	£ 5,257.00
	8,000 Bny Mellon Glb Fds Erg Mkts Debt Loc Crr C	£ 10,776.59	£ 10,434.00
	425 Fidelity EUR Value Ordinary 25P shares	£ 4,059.07	£ 5,470.00
	3,900 Edinburgh Dragon Trust Ordinary £0.20 shares	£ 4,478.10	£ 10,452.00
	160 GLG Japan Corealpha Equity IT Acc	£ 11,330.79	£ 10,629.00
	5,194 Scottish Widows Property Trust B	£ 4,669.49	£ 4,451.00
	26 Veritas Asset Mgmt Veritas Asian A GBP	£ 8,182.27	£ 7,671.00
	65 Roche Hldgs Ag Genusscheine Nvp	£ 7,226.55	£ 8,040.00
	6,600 Henderson Gbl Invs European Special Sits I Inc	£ 7,037.91	£ 8,210.00
1,283.80	COIF Charities Investment Fund Acc Units	£ 75,000.00	£ 114,775.57
	Total	£ 451,814.95	£ 546,214.35



Proceeds (sold in 2013)	Cost (bought in 2013)	Gain realised during 2013	Value end 2013	Gain unrealised during 2013
			£ 20,813.00	-£ 1,685.00
			£ 22,688.00	-£ 1,664.00
			£ 80,836.67	-£ 5,641.11
			£ 18,331.00	£ 844.00
			£ 6,955.00	£ 902.00
			£ 11,214.00	-£ 1,563.00
			£ 6,488.00	£ 1,425.00
			£ 9,704.00	£ 227.00
			£ 4,895.00	£ 172.00
			£ 1,224.00	£ 391.50
			£ 5,723.00	£ 1,074.12
£ 4,838.85	£ 832.50	£ 516.85		
£ 3,124.67	£ 4,648.88	£ 952.67		
			£ 3,845.00	-£ 19.00
£ 4,687.62		£ 283.62		
			£ 7,625.00	£ 2,140.00
			£ 4,377.00	£ 250.00
			£ 10,475.00	£ 1,797.00
			£ 6,274.00	£ 2,123.00
			£ 4,378.00	£ 127.00
			£ 5,984.00	£ 467.00
	£ 7,039.88		£ 6,725.00	-£ 314.88
			£ 9,895.00	£ 3,447.00
			£ 8,157.00	£ 3,188.00
£ 8,317.58		£ 1,295.58		
			£ 7,446.00	£ 348.00
			£ 6,169.00	£ 704.00
			£ 2,446.00	-£ 176.00
			£ 5,516.00	£ 595.00
			£ 4,679.00	£ 563.00
			£ 3,116.00	-£ 814.00
	£ 5,035.71		£ 4,956.00	-£ 79.71
			£ 8,190.00	£ 838.00
			£ 9,966.00	£ 2,354.00
			£ 2,869.00	£ 132.00
			£ 19,931.00	£ 4,986.00
			£ 7,275.00	£ 165.00
			£ 18,322.00	£ 3,986.00
			£ 31,358.00	£ 7,095.00
			£ 4,946.00	-£ 311.00
£ 9,816.77		-£ 617.23		
			£ 6,481.00	£ 1,011.00
			£ 9,543.00	-£ 909.00
			£ 17,104.00	£ 6,475.00
			£ 4,780.00	£ 329.00
			£ 8,192.00	£ 521.00
			£ 10,994.00	£ 2,954.00
			£ 10,006.00	£ 1,796.00
			£ 133,747.44	£ 18,971.87
£ 30,785.49	£ 17,556.97	£ 2,431.49	£ 594,639.11	£ 59,221.79



**Independent Examiner's Report
on the Accounts of The Palaeontological Association
for the year ended 31st December 2013**

Respective responsibilities of trustees and examiner

The charity's trustees are responsible for the preparation of the accounts. The charity's trustees consider that an audit is not required for this year under section 144 of the Charities Act 2011 (the Charities Act) and that an independent examination is needed.

It is my responsibility to:

examine the accounts under section 145 of the Charities Act,

follow the procedures laid down in the general Directions given by the Charity Commissioners (under section 145(5)(b) of the Charities Act), and

to state whether particular matters have come to my attention.

Basis of independent examiner's statement

My examination was carried out in accordance with the general Directions given by the Charity Commissioners. An examination includes a review of the accounting records kept by the charity and a comparison of the accounts presented with those records. It also includes consideration of any unusual items or disclosures in the accounts and seeking explanations from the trustees concerning such matters. The procedures undertaken do not provide all the evidence that would be required in an audit, and consequently no opinion is given as to whether the accounts present a "true and fair" view and the report is limited to those matters set out in the statement below.

Independent examiner's statement

In connection with my examination, no matter has come to my attention:

(1) which gives me reasonable cause to believe that in any material respect the requirements:

to keep accounting records in accordance with section 130 of the Charities Act;

to prepare accounts which accord with the accounting records and comply with the accounting requirements of the Charities Act

have not been met; or

(2) to which, in my opinion, attention should be drawn in order to enable a proper understanding of the accounts to be reached.

Dated: 2nd May 2014

G R Powell F.C.A.

Nether House, Nether Green,
Great Bowden,
Market Harborough
Leicestershire
LE16 7HF



Nominations for Council

At the AGM in December 2014, the following vacancies will occur on Council:

- Vice-President
- Newsletter Editor
- Book Review Editor
- Meetings Coordinator
- two Ordinary Members

The following nominations have been received:

Vice President: Mr David J. Ward

Newsletter Editor: Dr Jo Hellawell

Meetings Coordinator: Dr Thijs Vandenbroucke (2nd term)

Book Review Editor: Dr Tom Challands

Ordinary Members (two vacancies): Prof. Andy Gale, Dr Maria McNamara, Dr Imran Rahman*

- * More nominations have been received for the positions of Ordinary Member than are vacant and so as stipulated in the Association's constitution a ballot will be held at the AGM. All members of the Association are eligible to vote. Provision has been made for a postal vote for those members who are unable to attend the AGM. **A voting form was included with the Newsletter.** Personal statements from the candidates are copied over the page:



Prof. Andy Gale (Portsmouth): I am an enthusiastic stratigrapher and palaeontologist who has concentrated his research over 45 years on the Cretaceous Period, working also on the taxonomy, phylogeny and fossil record of starfish and more recently, barnacles. I have published extensively, including a *Special Paper in Palaeontology* and in *Palaeontology*. I have taught palaeontology to BSc students in various UK university departments, and supervised a succession of PhD students. On the committee, I offer the Association the benefits of long experience of teaching, administration and research in the academic world, together with an enthusiastic commitment to palaeontology. I give numerous lectures on palaeontological topics to regional geological societies and university student societies that may be used to promote the work of the Association. For example, I am lecturing to the Sedgwick Club in Cambridge in November, which provides an excellent opportunity to remind the audience of what the Association offers to students.

Dr Maria McNamara (Cork): Maria is a Lecturer in Geology at University College Cork in Ireland and has been a member of the Association for the past 12 years. Over this time she has contributed numerous oral and poster presentations at the Annual Meeting and published in *Palaeontology*, and has represented the Association at public outreach events. She now wishes to stand for the position of Ordinary Member on the Association Council as she is keen to make a more active contribution to the running of the Association. She hopes to assist with various Council activities, such as the review of grant applications and preparation of the Association Newsletter. In particular, she is keen to help develop and implement new initiatives to support palaeontological research, especially by early career researchers, and to help develop and deliver outreach activities to foster an enhanced appreciation and awareness of palaeontology in Europe and further afield. In doing so she aims to encourage and support researchers from all fields of palaeontology and to raise the profile of palaeontology in the public sphere.

Dr Imran Rahman (Bristol): I am a research fellow at the University of Bristol working on the palaeontology and evolution of early echinoderms. I have been a member of the Palaeontological Association since 2003 and have regularly attended Annual Meetings during this period. I am a scientific editor of the Association's flagship journal, *Palaeontology*, and co-founder and commissioning editor of *Palaeontology* [online], an outreach website sponsored by the Association. I wish to stand for election as an Ordinary Member of the Council so that I can contribute to the continued success of the Association, promoting the study of palaeontology and allied sciences within the UK and abroad. In particular, I am keen to support the activities of early-career researchers, and would like to ensure that the Association plays an important role in helping to develop their careers.