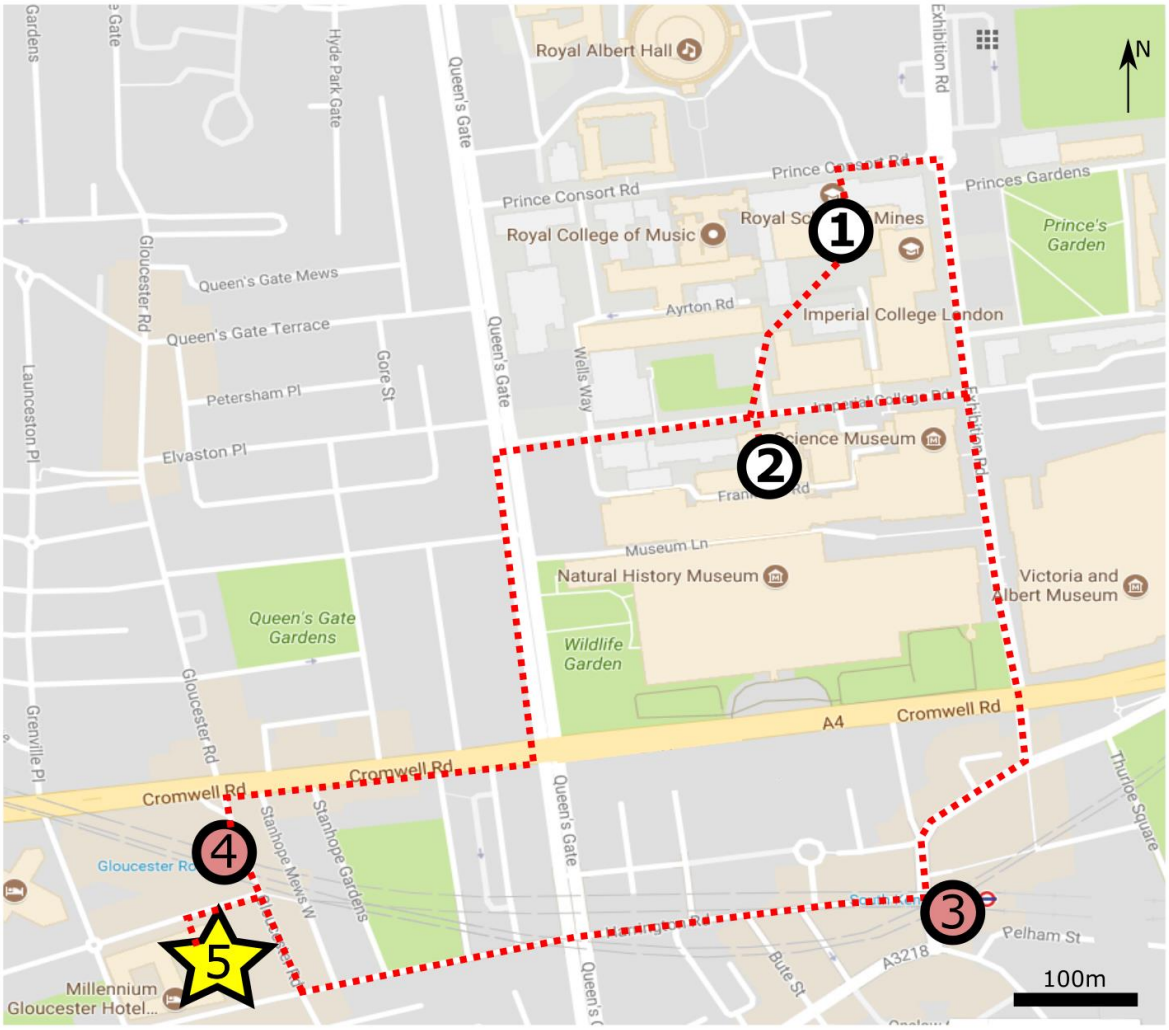
SOUTH KENSINGTON AREA MAP



MAIN VENUES

1. Royal School of Mines (RSM)
2. Sir Alexander Fleming (SAF)
5. Millennium Hotel for Annual Dinner

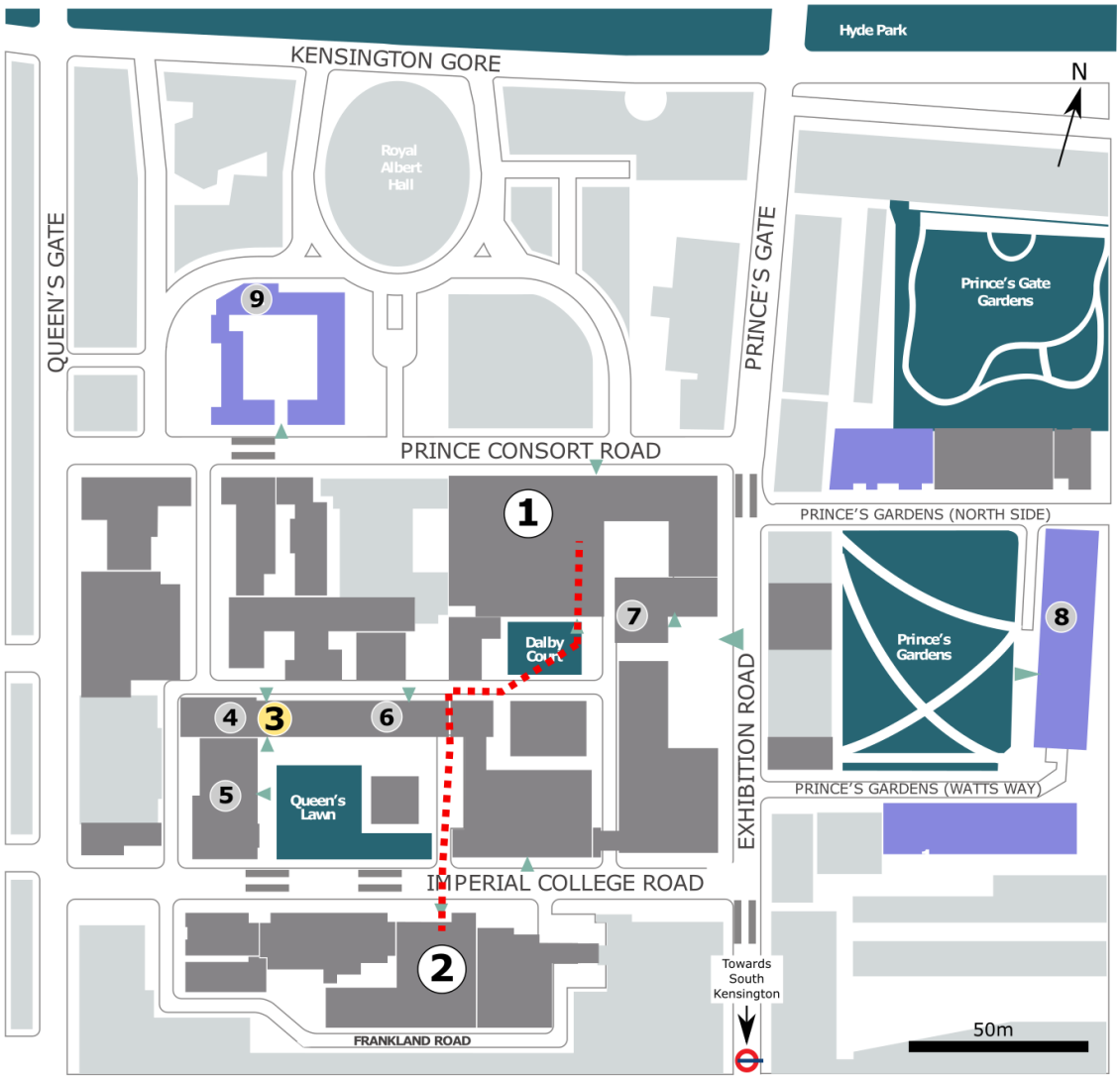
TUBE STATIONS

3. South Kensington
4. Gloucester Road

MISCELLANEOUS

Pedestrian route

IMPERIAL COLLEGE CAMPUS MAP



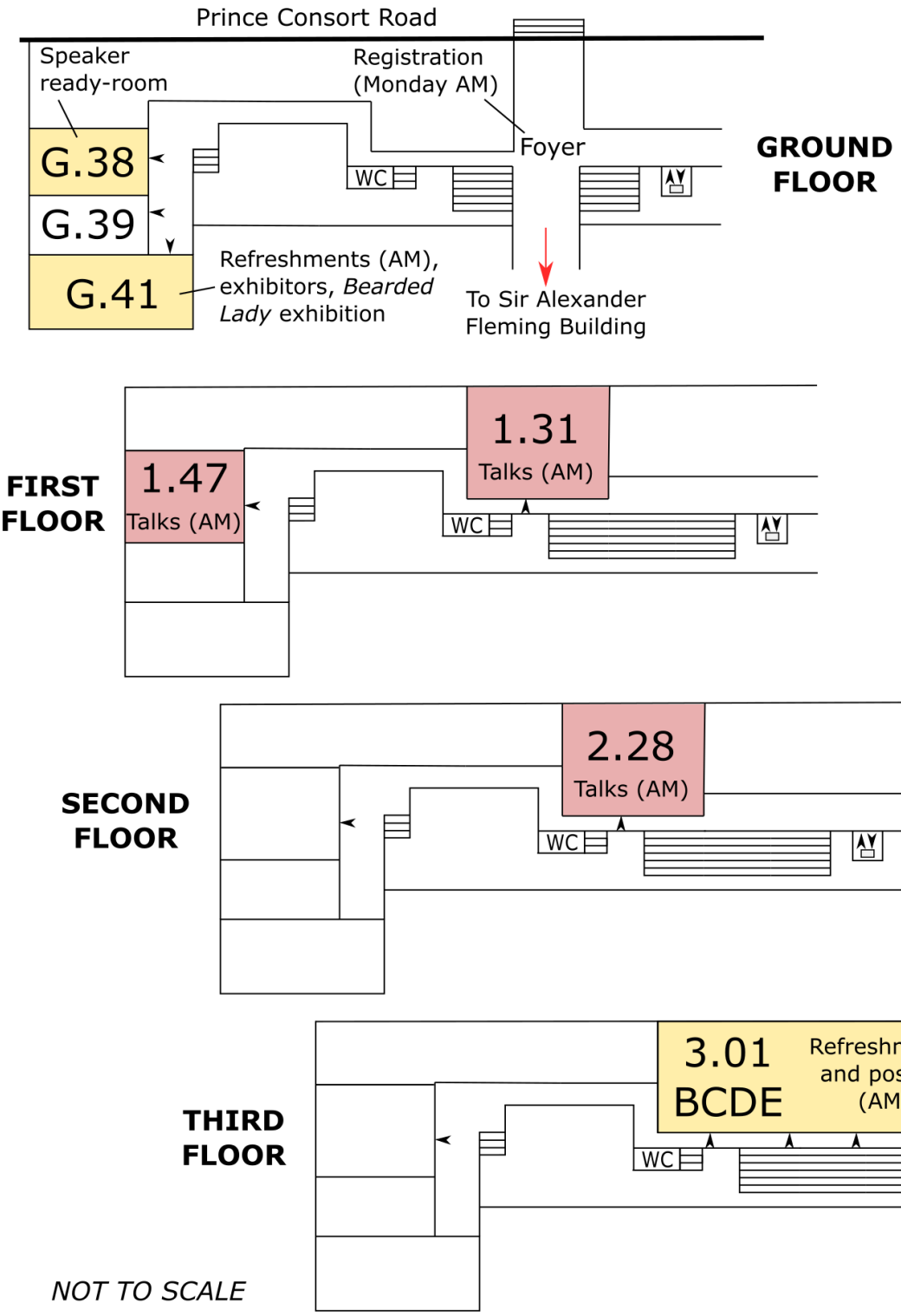
MAIN VENUES

- 1 Royal School of Mines (RSM)
- 2 Sir Alexander Fleming (SAF)
- 3 Queen's Tower Rooms (Icebreaker)
- Best route RSM to SAF
- Entrance

SERVING LUNCH

- 4 H bar
- 5 Library Café
- 6 Senior Common Room
- 7 College Café
- 8 Eastside Bar
- 9 Union Bar

ROYAL SCHOOL OF MINES MAP



61ST ANNUAL MEETING

17TH-19TH DECEMBER 2017

IMPERIAL COLLEGE, LONDON

The programme and abstracts for the 61st Annual Meeting of the Palaeontological Association are provided after the following information and summary.

VENUE

The Conference will take place at the South Kensington Campus of Imperial College, London; see maps on previous pages for details. Further details of the venue and transport advice are provided on the Association website.

NATURAL HISTORY MUSEUM COLLECTIONS

The meeting will take place adjacent to London's Natural History Museum, and we are aware that delegates may see this as an opportunity to visit the Museum collections. Please be aware that the museum curators expect to be very busy in this period, and will not be able to grant *ad-hoc* access to collections during the meeting. Requests for access should be made four weeks in advance to the relevant curator, and will be granted on a first-come first-served basis.

ORAL PRESENTATIONS

All speakers (apart from the symposium speakers) have been allocated either a 15 minute or a 10 minute slot. Most 15 minute talks take place in parallel sessions, while 10 minute talks take place in front of all delegates. If allocated a 15 minute talk slot you should present for 12 minutes to allow time for questions and switching between speakers. If allocated a 10 minute slot, you should likewise present for 8 minutes. All lecture theatres have a digital projector linked to a large screen. All presentations should be in PowerPoint or PDF format. They should be submitted on a memory stick (by hand) to your session chair at least 15 minutes before the session you are taking part in begins. You are strongly advised to check your presentation on the Imperial College system before delivering it; this is particularly relevant for Mac-based presentations as Imperial College uses Windows PCs. A ready-room in the Royal School of Mines building (RSM G.38) will be provided for speakers to test their talks.

POSTER PRESENTATIONS

Individual posters will be on display for only a single day of the conference. Each has been allocated (alphabetically) to either Group A (Monday) or Group B (Tuesday); please find your poster in the abstract list below to determine your group. To ensure that posters are at all times in proximity to the delegates, they will be on display in the Royal School of Mines building in the morning, and the Sir Alexander Fleming building in the afternoon. You will have the choice of (a) bringing two copies of your poster, one for each venue, (b) moving your poster yourself during the lunch-break (less than 5 minutes walk), or (c) leaving us to move your poster for you (the default). Please consider which option you prefer; we will be in touch by email to determine your choice.

Poster boards will accommodate an A0-sized poster presented in PORTRAIT FORMAT ONLY. Materials to affix your poster to the boards will be available at the meeting. Presenters are

responsible for taking their own posters down at the end of the day's sessions. Posters not recovered by their presenters by 7pm on Monday or 6pm on Tuesday will be taken down by meeting organisers, and we cannot guarantee that they will be returned to their owners.

TRAVEL GRANTS TO STUDENT MEMBERS

Students who have been awarded a PalAss travel grant should see the Executive Officer, Dr Jo Hellawell (e-mail <executive@palass.org>) to receive their reimbursement.

SUMMARY OF SCHEDULE

SUNDAY 17TH DECEMBER: REGISTRATION, SYMPOSIUM AND RECEPTION

Registration will open at 12.30 in the foyer of the Sir Alexander Fleming Building.

The Annual Meeting will begin with a welcome at 13.30 in Lecture Theatre G.16 of the Sir Alexander Fleming Building, followed by the symposium "*Evolutionary modelling in palaeontology*".

Following the symposium there will be an icebreaker reception at 18.00 in the Queen's Tower Rooms, less than 5 minutes walk from the Sir Alexander Fleming Building.

MONDAY 18TH DECEMBER: CONFERENCE, AGM, ANNUAL ADDRESS AND DINNER

Registration will open at 08.00 in the foyer of the Royal School of Mines Building.

The conference will commence at 09.00 with a full day of talks and posters. The morning sessions are held in parallel, in rooms 2.28, 1.47 and 1.31 (Royal School of Mines building). During the break, delegates can either view the posters in room 3.01 BCDE (Royal School of Mines Building), or visit the exhibitors and the *Bearded Lady* art exhibition in G.41 (Royal School of Mines Building). Both rooms will serve refreshments.

The afternoon sessions are not parallel, and will commence at 13.45 in Lecture Theatre G.16 (Sir Alexander Fleming Building). The first session comprises 10 shorter (10 minute) talks. During the break, posters, exhibitors, refreshments and the *Raising Horizons* art exhibition will all be available adjacent to the lecture theatre.

The Association Annual General Meeting commences at 17.00, and the Annual Address at 17.30, both in Lecture Theatre G.16 (Sir Alexander Fleming Building).

The Annual Dinner takes place at the Millenium Hotel, Gloucester Road, less than 15 minutes walk from the Imperial College Campus. It will commence with a drinks reception at 19:00.

TUESDAY 19TH DECEMBER: CONFERENCE AND PRIZES

The conference programme will procede as on the previous day, although posters will be rotated so a new set will be available to view.

Talks will complete by 17.00, when the conference will close with the award of the President's Prize and the Council Poster Prize, presentations by the organising committees of upcoming meetings, and concluding remarks.

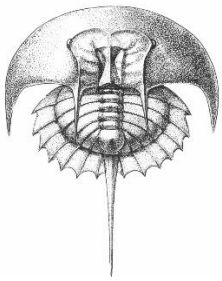
WEDNESDAY 20TH DECEMBER: POST-CONFERENCE FIELDTRIPS

Fieldtrips to Down House and the Isle of Sheppey will depart from the Royal School of Mines at 08.00 and 07.30 respectively. Please see the Association website for further details.

MEETING SUPPORT

The organizers of the Annual Meeting gratefully acknowledge the support of the following sponsors and exhibitors:

nature ecology & evolution



TREATISE on Invertebrate Paleontology

Taylor & Francis Group an informa business

Papers in Palaeontology

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SCHEDULE AND TIMETABLE

Underlined author denotes designated speaker.

* denotes eligibility for President's Prize or Council Poster Prize.

SUNDAY 17TH DECEMBER

REGISTRATION

12.30 – 18.00 Foyer, Sir Alexander Fleming Building

SYMPOSIUM "EVOLUTIONARY MODELLING IN PALAEONTOLOGY"

G.16, Sir Alexander Fleming Building Chair: Paul Smith

13.30 – 13.45	**WELCOME ADDRESS**
13.45 – 14.15	**Journeys through discrete character morphospace** Graeme Lloyd
14.15 – 14.45	**How different is reality from mathematical perfection in taxonomy?** Julia Sigwart
14.45 – 15.15	**Using evolutionary models to assess the accuracy of phylogenies estimated with Bayesian, Maximum-Likelihood, and Parsimony methods** Mark Puttick, Joseph O'Reilly, Davide Pisani and Phil Donoghue
15.15 – 15.45	**BREAK AND REFRESHMENTS**
15.45 – 16.15	**Simulating evolution in space and time** Russell Garwood, Mark Sutton, Chris Knight, Guillaume Gomez, and Alan Spencer
16.15 – 16.45	**Slicing the stratigraphic cake: the effects of time subsample variation in disparity-through-time analysis** Natalie Cooper and Thomas Guillerme
16.45 – 17.15	**Evolution and Earth Systems: modeling population-level processes on palaeontological scales** P. David Polly
17.15 – 17.45	**Modelling biotic interactions using data from the fossil record** Lee Hsiang Liow

RECEPTION

Queen's Tower Rooms, Sherfield Building

18.00 – 20.00 **Icebreaker Reception and *Bearded Lady* Exhibition**

MONDAY 18TH DECEMBER

CONFERENCE, ASSOCIATION AGM, ANNUAL ADDRESS, AND ANNUAL DINNER

REGISTRATION

08.00 – 13.00 Foyer, Royal School of Mines Building

13.15 – 18.00 Foyer, Sir Alexander Fleming Building

POSTERS

08.00 – 09.00 Poster group A – setup in Royal School of Mines

09.00 – 12.45	**Poster group A on display in Royal School of Mines, Room RSM 3.01 BCDE**

12.45 – 13.45 Poster group A – move from Royal School of Mines to Sir Alexander Fleming

13.45 – 17.00	**Poster group A on display in Sir Alexander Fleming Foyer**

SESSION 1A (IN PARALLEL WITH SESSIONS 1B AND 1C).

1.31, Royal School of Mines — Chair: Nick Butterfield

09.00 – 09.15 **A 3.77 (or possibly 4.28) billion year history of microbial communities associated with marine hydrothermal vents**
Crispin Little

09.15 – 09.30 **Life at the end of the Boring Billion: microfossil record from the ca. 1 Ga Bylot Supergroup, Arctic Canada**
*Heda Agic, Susannah M. Porter, Sarah Wörndle, Timothy M. Gibson, Peter W. Crockford, Malcolm S.W. Hodgskiss, Marcus Kunzmann and Galen P. Halverson

09.30 – 09.45 **Substrate relationships and biomineralisation of an Ediacaran encrusting poriferan**
Rachel Wood and *Amelia Penny

09.45 – 10.00 **Evolution of complex life: Late Neoproterozoic co-divergence of bilaterians and their gut microbiota**
Joanna Wolfe

10.00 – 10.15 **Colonies, clones and modularity: a new view of Ediacaran fronds**
Alex Liu, Frances Dunn, Charlotte Kenchington and Philip Wilby

10.15 – 10.30 **What were the Ediacaran biota? Answers from the Chengjiang Lagerstätte**
Jennifer Hoyal Cuthill and Jian Han

10.30 – 10.45 **A mineralogical signature for Burgess Shale-type preservation**
*Ross P. Anderson, Nicholas J. Tosca, Robert R. Gaines, Nicolás Mongiardino Koch and Derek E. G. Briggs

SESSION 1B (IN PARALLEL WITH SESSIONS 1A AND 1C).

2.28, Royal School of Mines — Chair: Richard Butler

09.00 – 09.15 **A 'reptilian' mode of reproduction in pterosaurs and its implications for pterosaur palaeobiology**
David Unwin

09.15 – 09.30 **Scotland's Jurassic Park: new dinosaurs, crocodylomorphs, pterosaurs, and fishes from the Middle Jurassic of Skye**
Stephen Brusatte, Thomas J. Challands, Neil D.L. Clark, Paige de Polo, Davide Foffa, Nicholas C. Fraser, Mojirayo Ogunkanmi, Elsa Panciroli, Dugald A. Ross, Stig Walsh, Mark Wilkinson and Mark T. Young

09.30 – 09.45 **The 'pliable' nature of the phylogenetic relationships within early ornithopods**
Daniel Madzia and Clint A. Boyd

09.45 – 10.00 **High diversity of small dinosaurs preceding the Cretaceous- Paleogene (K-Pg) mass extinction**
Nicholas Longrich

10.00 – 10.15 **Mosiacism, development, and the early evolution of birds**
Ryan Felice and Anjali Goswami

10.15 – 10.30 **The multiple origins of powered flight among paravian theropod dinosaurs: constraints from new phylogenetic, aerodynamic and anatomical data**
Michael Pittman, Rui Pei, Pablo A. Goloboff, Thomas A. Dececchi, Mark A. Norell, Thomas G. Kaye, Hans C.E. Larsson, Michael B. Habib, Stephen L. Brusatte and Xing Xu

10.30 – 10.45 **Newly discovered complete skull of *Ichthyornis* reveals unforeseen mosaicism late in the dinosaur-bird transition**
*Daniel Field, Michael Hanson and Bhart-Anjan Bhullar

SESSION 1C (IN PARALLEL WITH SESSIONS 1A AND 1B).

1.47, Royal School of Mines Chair: Margaret Collinson

09.00 – 09.15 **Tracking genome size variation in a 407 milion year old plant**
Zuzanna Wawrzyniak and Paul Kenrick

09.15 – 09.30 **Assessing changes in leaf morphology in *Ginkgo biloba* and their suitability to act as a palaeo-climate proxy**
Karen Bacon and Claire Belcher

09.30 – 09.45 **Stomata, carbon isotopes and past CO_2 reconstruction: a critical comparison of fossil plant based CO_2 proxy models and methods**
Jennifer McElwain, Amanda Porter, Charilaos Yiotis, Christianna Evans-Fitzgerald and Isabel Montañez

09.45 – 10.00 **Fossil plant cuticles may track SO_2 pollution during LIP volcanisms - implications for understanding mass extinctions**
Margret Steinthorsdottir, Caroline Elliott-Kingston and Karen L. Bacon

10.00 – 10.15 **The Tournaisian recovery of terrestrial vegetation following the end Devonian mass extinction**
*Emma Reeves, John Marshall, Carys Bennett, Sarah Davies, Timothy Kearsey, David Millward, Timothy Smithson and Jennifer Clack

10.15 – 10.30 **Insights into the taphonomy of *Weichselia reticulata***
*Candela Blanco, Hugo Martín-Abad, Bernard Gomez and Ángela D. Buscalioni

10.30 – 10.45 **The importance of microenvironment in determining the roles of early diverging fungi in early terrestrial ecosystems**
Christine Strullu-Derrien, Paul Kenrick and Tomasz Goral

10.45 – 11.15 **BREAK – Refreshments available in TWO rooms:**

Royal School of Mines G.41: Refreshments, Exhibitors, *Bearded Lady* exhibition

Royal School of Mines 3.01 BCDE: Refreshments, Poster Group A

SESSION 2A (IN PARALLEL WITH SESSIONS 2B AND 2C).

1.31, Royal School of Mines — Chair: Derek Briggs

11.15 – 11.30 **Cambrian weird wonders and the origin of ctenophores**
Jakob Vinther, Zhao Yang, Peiyun Cong, Luke Parry, Davide Pisani and Gregory D. Edgecombe

11.30 – 11.45 **Naked chancelloriids from the lower Cambrian of China: evidence for sponge-type growth**
P.-Y. Cong, T.H.P Harvey, M. Williams, D.J. Siveter, D.J. Siveter, S.E. Gabbott, Y.-J. Li, F. Wei and X.-G. Hou

11.45 – 12.00 **Helcionelloid molluscs from Cambrian Series 2, Stages 3-4 of East Antarctica and outline morphometric approaches to problematic taxonomy**
Thomas Claybourn, Illiam Jackson, Lars Holmer, Christian Skovsted, Tim Topper and Glenn Brock

12.00 – 12.15 **Three-dimensional priapulid trace fossils from the early Cambrian (Series 2, Stage 4) of Sweden**
Giannis Kesidis, Graham Budd and Sören Jensen

12.15 – 12.30 **The earliest evidence of metazoan symbiosis**
Xiaoya Ma, Peiyun Cong, Mark Williams, David Siveter, Derek Siveter, Sarah Gabbott, Dayou Zhai, Tomasz Goral, Gregory Edgecombe and Xianguang Hou

12.30 – 12.45 **An Early Ordovician somasteroid from Morocco reveals the origin of crown-group Echinodermata**
Aaron Hunter and Javier Ortega-Hernández

SESSION 2B (IN PARALLEL WITH SESSIONS 2A AND 2C).

2.28, Royal School of Mines — Chair: Michael Benton

11.15 – 11.30 **The Middle Devonian Kačák Event: its identification and effects in Northern Spain**
*Alexander Askew an Charles Wellman

11.30 – 11.45 **Climate change and rates of crocodylomorph body size evolution**
*Maximilian Stockdale and Michael Benton

11.45 – 12.00 **Faunal response to sea level and environmental change in the Jurassic Sundance Seaway, western United States: a stratigraphic palaeobiological approach**
Silvia Danise, Steven Holland

12.00 – 12.15 **The ecological consequences of extinctions: from giant sharks to small mollusks**
Catalina Pimiento, John Griffin, Daniele Silvestro, Alexandre Antonelli and Carlos Jaramillo

12.15 – 12.30 **The Estuary Effect and the origin of lake faunas: critical linkages between global tectonics, sea level and biodiversity**
Lisa Park Boush, Andrew Bush, Michael Hren, Gary Motz and Timothy Astrop

12.30 – 12.45 **A minimum population extinction time driven by stochastic environmental forcing**
Christopher Spalding, Charles Doering and Glenn Flierl

SESSION 2C (IN PARALLEL WITH SESSIONS 2A AND 2B).

1.47, Royal School of Mines — Chair: Anjali Goswami

11.15 – 11.30 **An enigmatic amphibian from the Early Cretaceous of Japan**
Susan Evans and Ryoko Matsumoto

11.30 – 11.45 **High-dimensional geometric morphometric approach to understanding skull shape evolution in squamates**
Akinobu Watanabe, Ryan Felice, Jessica Maisano, Johannes Müller, Anthony Herrel and Anjali Goswami

11.45 – 12.00 **A new chroniosuchian (non-amniotic tetrapod) from Laos revealed by micro-CT scan: anatomy and palaeobiology**
*Thomas Arbez, Christian Sidor and Jean-Sébastien Steyer

12.00 – 12.15 **A bizarre early tetrapod from the Early Permian of Kansas, USA, provides further support for radical polyphyly of 'lepospondyls'**
*Jason Pardo, Aja Carter, Lauren C. Sallan and Jason S. Anderson

12.15 – 12.30 **Sampling biases constrain interpretation of the fossil records of non-marine lepidosaurs and turtles**
*Terri Cleary

12.30 – 12.45 **Increased disparity in Therapsida coincides with emergence of novel ecologies, Cistecephalidae (Therapsida:Anomodontia) as a case study**
*Jacqueline Lungmus and Kenneth Angielczyk

12.45 – 13.45 **LUNCH BREAK – Packed lunches available from Royal School of Mines, G.41**

See maps for locations of cafeterias on campus

SESSION 3

G.16, Sir Alexander Fleming Building — Chair: Mark Sutton

13.45 – 13.55 **Oxygen minimum zones in the early Cambrian ocean**

Romain Guilbaud, Ben J. Slater, Simon W. Poulton, Thomas H.P. Harvey, Jochen J. Brocks, Benjamin J. Nettersheim and Nicholas J. Butterfield

13.55 – 14.05 **Coupling palaeoclimate data and numerical climate models to constrain Cambrian palaeogeography**
*Thomas Hearing, Alexandre Pohl, Mark Williams, Thomas Harvey and Yannick Donnadieu

14.05 – 14.15 **Carbon characterization in the Sirius Passet Biota and a geothermal gradient through Cambrian Lagerstätten**
Timothy Topper, Francesco Greco, Axel Hofmann, Andrew Beeby, Zhifei Zhang and David Harper

14.15 – 14.25 **Experimental modelling of sedimentary processes for the Burgess Shale: implications for the transport and preservation of soft-bodied organisms**
*Orla Bath Enright, Nic Minter, Esther Sumner, Gabriela Mángano and Luis Buatois

14.25 – 14.35 **Burgess Shale fossils reveal the ancestral state of annelid nervous systems**
*Luke Parry and Jean Bernard Caron

14.35 – 14.45 **Dietary ecology of pterosaurs from quantitative 3D textural analysis of tooth microwear**
*Jordan Bestwick, David Unwin, Richard Butler, Don Henderson and Mark Purnell

14.45 – 14.55 **Hidden diversity of small theropods from the Bathonian (Middle Jurassic) of the UK**
*Simon Wills, Charlie J. Underwood and Paul M. Barrett

14.55 – 15.05 **Approaching sexual dimorphism in non-avian dinosaurs and other extinct taxa**
*Evan Saitta, Maximilian Stockdale, Vincent Bonhomme, Michael Benton, Nicholas Longrich, Innes Cuthill

15.05 – 15.15 **Phylogenetic position of a new Late Cretaceous duck-billed dinosaur (Hadrosauroidea) from the Dorotea Formation, Chilean Southern Patagonia**
*Alexis Jujihara, Sergio Soto-Acuña, Wolfgang Stinnesbeck, Alvaro Zúñiga-Reinoso, Penélope Cruzado-Caballero, Alexander O. Vargas, Marcelo Leppe, Hector Mansilla, David Rubilar-Rogers, Jhonatan Alarcón-Muñoz, Manfred Vogt and Eberhard Frey

15.15 – 15.25 **Integrating genomic and fossil evidence to date the tree of life**
*Holly Betts, Mark N. Puttick, Tom A. Williams, Philip C. J. Donoghue and Davide Pisani

15.25 – 16.00 **BREAK**

Posters (group A), exhibitors, refreshments and the *Raising Horizons* exhibition will all be available in the Foyer of the Sir Alexander Fleming Building

SESSION 4

G.16, Sir Alexander Fleming Building — Chair: Phil Donoghue

16.00 – 16.15 **The environmental context of early animal evolution**
Erik Sperling, Una Farrell and the SGP Collaborative Team (https://sites.stanford.edu/sgp/)

16.15 – 16.30 **Geobiology and palaeogenomics: genes that make rocks**
David Bottjer

16.30 – 16.45 **Reconciling the commonality of long-term stasis in the fossil record and the rare detectability of stabilizing selection in extant biota**
Bert Van Bocxlaer

16.45 – 17.00 **The "push of the past": an important bias in the fossil record**
Graham Budd and Richard Mann

Annual General Meeting of the Palaeontological Association
G.16, Sir Alexander Fleming Building

17.00 – 17.30	**Annual General Meeting**

Palaeontological Association Annual Address (Sponsored by *Wiley*)
G.16, Sir Alexander Fleming Building

17.30 – 18.30	**101 uses for a dead fish. Experimental decay, exceptional preservation, and fossils of soft bodied organisms** Professor Mark Purnell, University of Leicester

Palaeontological Association Annual Dinner
Millennium Hotel, Gloucester Road

19.00 – 23.30	**Drinks Reception and Annual Dinner**

TUESDAY 19TH DECEMBER

Conference and Prizes

Posters

08.00 – 09.00 Poster group B – setup in Royal School of Mines

09.00 – 12.45	**Poster group B on display in Royal School of Mines, Room RSM 3.01 BCDE**

12.45 – 13.45 Poster group B – move from Royal School of Mines to Sir Alexander Fleming

13.15 – 17.00	**Poster group B on display in Sir Alexander Fleming Foyer**

Session 5A (in parallel with sessions 5B and 5C).
1.31, Royal School of Mines Chair: Greg Edgecombe

09.00 – 09.15 **Asymmetry of paired endites on frontal appendages in Amplectobeluidae (Radiodonta: stem Euarthropoda) and its taxonomic significance**
Peiyun Cong, Gregory Edgecombe, Allison Daley and Xianguang Hou

09.15 – 09.30 **Diversity and disparity of USA Radiodonta**
*Stephen Pates and Allison C. Daley

09.30 – 09.45 **Punctualistic disparity patterns and step-wise body plan canalization in euarthropods**
*Cedric Aria

09.45 – 10.00 **Molecular clocks on Chelicerata recover monophyly of mites and arachnids and suggest an early colonization of land**
Jesus Lozano-Fernandez, Alastair R. Tanner, Jakob Vinther, Gregory D. Edgecombe and Davide Pisani

10.00 – 10.15 **The central nervous system of Trilobitomorpha – taphonomy, morphology and evolutionary implications**
Javier Ortega-Hernandez

10.15 – 10.30 **A total-evidence approach to resolving pancrustacean phylogeny**
Albert Chen, Davide Pisani, Jesus Lozano-Fernandez, David Legg and Jakob Vinther

10.30 – 10.45 **Trilobite evolutionary faunas**
Jonathan Adrain

SESSION 5B (IN PARALLEL WITH SESSIONS 5A AND 5C).

2.28, Royal School of Mines Chair: Paul Taylor

09.00 – 09.15 **Brachiomatic: automated measurement of brachiopod size using new museum collections digitisation protocols**
Rachel Belben, Kenneth Johnson, Zoë Hughes, Chris Hughes and Richard Twitchett

09.15 – 09.30 **Accounting for differences in species frequency distributions when calculating beta diversity in the fossil record**
Neil Brocklehurst, Michael Day and Jörg Fröbisch

09.30 – 09.45 **The murky history of Cenozoic coral reefs in the Coral Triangle**
Kenneth Johnson, Nadia Santodomingo and Brian Rosen

09.45 – 10.00 **Differences in extinction rates explain contrasting regional diversity patterns in modern tropical bryozoans**
Emanuela Di Martino, Jeremy B.C. Jackson, Paul D. Taylor and Kenneth G. Johnson

10.00 – 10.15 **Species discovery and changing taxon concepts in Cenozoic molluscs - after 50+ years what does revision of a popular handbook tell us?**
Jonathan Todd and Kenneth Johnson

10.15 – 10.30 **New record of an abundant ammonite assemblage from the latest Cretaceous Corsicana Formation, Brazos River, Texas. Implications for the Cretaceous–Paleogene (K–Pg) mass extinction event in the Gulf of Mexico**

James Witts, Neil Landman, Matthew Garb, Nicolas Thibault, David Jones, Ekaterina Larina and Thomas Yancey

10.30 – 10.45 **New insights on the correlation of Permo-Triassic terrestrial faunas of South Africa with those of European Russia**
Michael O. Day, Fernando Abdala, Valeriy K. Golubev, Andrey G. Sennikov and Bruce S. Rubidge

SESSION 5C (IN PARALLEL WITH SESSIONS 5A AND 5B).

1.47, Royal School of Mines — Chair: Zerina Johanson

09.00 – 09.15 **The first functional analysis of the lateral line system in fossil fish**
Tom Challands and Mark Naylor

09.15 – 09.30 **Skull development and biomechanics in the coelacanth *Latimeria*; implication for fossil coelacanths and fossil lobe-finned fishes**
Hugo Dutel, Peter J. Watson and Michael J. Fagan

09.30 – 09.45 **The evolution of acellular bone in teleosts: structure-function relationship in fish bone histology**
Donald Davesne, François J. Meunier, Olga Otero, Matt Friedman and Roger B.J. Benson

09.45 – 10.00 **Tooth replacement and tooth resorption mechanisms in Osteichthyes**
Martin Ruecklin, Phillip C.J. Donoghue, Kate Trinajstic, John A. Cunnigham and Floortje P.C. Mossou

10.00 – 10.15 **A new ray-finned fish from the late Devonian: fresh insights into the rise of actinopterygians**
Sam Giles, Stephanie Pierce and Matt Friedman

10.15 – 10.30 **A chondrichthyan-like shoulder girdle in an "acanthodian" helps tease apart early chondrichthyan relationships**
*Richard Dearden, Jan den Blaauwen, Carole Burrow, Mike Newman, Bob Davidson and Martin Brazeau

10.30 – 10.45 **Patterns of morphological evolution in Pelagia (Teleostei: Acanthomorpha) consistent with ancient adaptive radiation**
*Hermione Beckett, Zerina Johanson, Sam Giles and Matt Friedman

10.45 – 11.15 **BREAK – Refreshments available in TWO rooms:**

Royal School of Mines G.41: Refreshments, Exhibitors, *Bearded Lady* exhibition

Royal School of Mines 3.01 BCDE: Refreshments, Poster Group B

SESSION 6A (IN PARALLEL WITH SESSIONS 6B AND 6C).

1.31, Royal School of Mines — Chair: David Harper

11.15 – 11.30 **Breathing life into an extinct sea scorpion: revealing the gill structure of a three-dimensionally preserved eurypterid through MicroCT scanning**
James Lamsdell, Victoria McCoy and Melanie Hopkins

11.30 – 11.45 **The Downton Bonebed: insights into a lost world**

*Luke Hauser

11.45 – 12.00 **Rotten livers, muscles and guts: controls on exceptional preservation of internal organs**
*Thomas Clements, Mark Purnell and Sarah Gabbott

12.00 – 12.15 **The end-Ordovician Anji Biota (Zhejiang, China) and a wider Hirnantian sponge mega-community**
Joseph Peter Botting, Lucy A. Muir, Yuandong Zhang and Wenhui Wang

12.15 – 12.30 **Biomineralisation of Palaeozoic sponges and aragonite-calcite seas**
Uwe Balthasar, S Kershaw, A.C Da Silva, B. Seuss, M. Cusack, K. Eichenseer and P. Chung

12.30 – 12.45 **Phylogenomic analysis of Brachiopoda and Phoronida: implications for morphological evolution, biomineralization, and the Cambrian radiation**
Aodhan Dermot Butler, Michael Eitel, Gert Wörheide, Sandra J. Carlson and Erik A. Sperling

SESSION 6B (IN PARALLEL WITH SESSIONS 6A AND 6C).

2.28, Royal School of Mines Chair: Christine Janis

11.15 – 11.30 **Long-term mammalian stable isotope record across the Great American Biotic Interchange**
Laura Domingo, Rodrigo L. Tomassini, Claudia I. Montalvo and Paul L. Koch

11.30 – 11.45 **The influence of cranial biomechanics on the evolution of the mammalian jaw joint and definitive mammalian middle ear**
Emily Rayfield, Stephan Lautenschlager, Pamela Gill, Zhe-Xi Luo and Michael Fagan

11.45 – 12.00 **Evolutionary adaptation to aquatic lifestyle can lead to systemic alteration of bone structure**
Eli Amson, Guillaume Billet and Christian de Muizon

12.00 – 12.15 **A model for marine reptile taphonomy in the Late Jurassic Slottsmøya Member Lagerstätte**
*Lene L. Delsett, Aubrey J. Roberts, Patrick S. Druckenmiller an Jørn H. Hurum

12.15 – 12.30 **First virtual endocasts of fossil Aplodontidae and their relevance in understanding the relationship between brain evolution and locomotion**
*Ornella Bertrand, Farrah Amador-Mughal, Madlen Lang and Mary Silcox

12.30 – 12.45 **Sporadic sampling not climatic forcing drives early hominin diversity**
*Simon Maxwell, Philip Hopley, Paul Upchurch and Christophe Soligo

SESSION 6C (IN PARALLEL WITH SESSIONS 6A AND 6B).

1.47, Royal School of Mines Chair: Lesley Cherns

11.15 – 11.30 **A dichotomous key for the morphological identification of coprolites**
*Sandra Barrios, Francisco Jose Poyato-Ariza, Jose Joaquin Moratalla and Ángela D. Buscalioni

11.30 – 11.45 **Evolution or revolution at the J/K boundary: The case of the Ammonoidea**
Luc Georges Bulot and William A.P. Wimbledon

11.45 – 12.00 **Jurassic onychites (arm hooks from squid-like cephalopods) associated with the statolith occurrences in the Wessex Basin, southern England**
Malcolm Hart, Zoe Hughes, Gregory Price and Christopher Smart

12.00 – 12.15 **Get across the wood: exceptional preservation of Cretaceous soft-bodied xylophagous mollusks**
Ninon Robin, Anaïs Boura, Marcel Velasquez, Géraldine Garcia, Clément Jauvion, Jean-Marie Boiteau and Xavier Valentin

12.15 – 12.30 **A Triassic-Jurassic window into the early evolution of Lepidoptera**
Bas van de Schootbrugge, Timo Eldijk, Torsten Wappler, Paul Strother, Carolien van der Weijst, Hosein Rajaei and Henk Visscher

12.30 – 12.45 **Gymnosperm–insect pollination relationships in Early Cretaceous amber from Spain**
Ricardo Pérez-de la Fuente, David Peris, Antonio Arillo, Eduardo Barrón, Xavier Delclòs, David A. Grimaldi, Conrad C. Labandeira, André Nel, Patricia Nel and Enrique Peñalver

12.45 – 13.45 **LUNCH BREAK – Packed lunches available from Royal School of Mines, G.41**

See maps for locations of cafeterias on campus

SESSION 7

G.16, Sir Alexander Fleming Building Chair: Philip Mannion

13.45 – 13.55 **Evaluating bite marks and predation of fossil jawless fish during the rise of jawed vertebrates**
*Emma Randle and Robert Sansom

13.55 – 14.05 **The other old red continent: ichnological signatures of arthropod terrestrialization throughout the Silurian of Australia**
*Anthony Shillito and Neil Davies

14.05 – 14.15 **High-resolution virtual histology in 3D for understanding development in living and fossil birds**
*Katherine Williams, Neil J. Gostling, Gareth Dyke, Richard O.C. Oreffo and Philipp Schneider

14.15 – 14.25 **Get low: the evolution of the baleen whale auditory pathway**
Travis Park, Alistair Evans and Erich Fitzgerald

14.25 – 14.35 **Evidence for a rapid recovery of snakes following the Cretaceous-Paleogene mass extinction**
*Catherine G. Klein, Davide Pisani, Daniel J. Field, Matthew A. Wills and Nicholas R. Longrich

14.35 – 14.45 **The contrasted early evolution of taxonomic richness and morphological disparity of the Ammonoidea: The Devonian record from Morocco**
*Ninon Allaire, Claude Monnet and Catherine Crônier

14.45 – 14.55 **Towards more accurate inference of phylogeny from morphology: a case study in extant crocodilians**
Roland Sookias

14.55 – 15.05 **The positive influence of continuous characters and extended implied weighting on phylogenetic reconstruction: a crocodylian case study**
*Selina Groh, Paul Upchurch, Julia Day and Paul Barrett

15.05 – 15.15 **Is parsimony dead? Bayesian and parsimony phylogenies tested using both empirical and simulated morphological data**
*Joseph Keating, Russell Garwood, Mark Sutton and Robert Sansom

15.15 – 15.25 **Incorporating inapplicable data in phylogenetic analysis**
Martin Smith, Martin D. Brazeau and Thomas Guillerme

15.25 – 16.00 **BREAK**

Posters (group B), exhibitors, refreshments and the *Raising Horizons* exhibition will all be available in the Foyer of the Sir Alexander Fleming Building

SESSION 8

G.16, Sir Alexander Fleming Building — Chair: Paul Barrett

16.00 – 16.15 **The search for physical sedimentary-stratigraphic signatures of ancient life**
Neil Davies

16.15 – 16.30 **Re-evaluating the function of cephalopod septa**
Robert Lemanis

16.30 – 16.45 **Decoupled morphological and phylogenetic diversification during the rise of the ruling reptiles and their kin**
Richard Butler and Martin Ezcurra

16.45 – 17.00 **Closing the gap between palaeontological and neontological speciation and extinction rate estimates**
Daniele Silvestro, Rachel C.M. Warnock, Alexandra Gavryushkina and Tanja Stadler

CLOSING BUSINESS

G.16, Sir Alexander Fleming Building

17.00 – 17.15 **Presentations from the organising committees of Palass 2018 (Bristol), Progressive Palaeontology 2018 (Manchester) and the 5th International Palaeontological Congress [Paris)**

17.15 – 17.25 **Presentation of the President's Prize and the Council Poster Prize**

17.25 – 17.30 **Closing remarks**

WEDNESDAY 20TH DECEMBER

FIELDTRIP 1 – DARWIN'S DOWN HOUSE

08:00 – 10.00 **Coach travel from the Royal School of Mines to Downe**

10.00 – 13.00 **Down House and Garden tours**

13.00 – 15.00 **Lunch in the Queen's Head, Downe Village**

15.00 – 17.00 **Coach travel from Downe to the Royal School of Mines. Return time is approximate**

FIELDTRIP 2 – ISLE OF SHEPPEY

07:30 – 10.00 **Coach travel from the Royal School of Mines to Isle of Sheppey**

10.00 – 13.00 **Fossil hunting at Warden Point**

13.00 – 13.30 **Coach travel from Warden Point to Sheerness**

13.30 – 15.30 **Lunch at the Abbey Hotel Restaurant and Conference Centre, Sheerness**

15.30 – 18.00 **Coach travel from Sheerness to the Royal School of Mines. Return time is approximate**

ABSTRACTS OF SYMPOSIUM PRESENTATIONS

Evolutionary modelling in palaeontology

Slicing the stratigraphic cake: the effects of time subsample variation in disparity-through-time analysis

Natalie Cooper[1], Thomas Guillerme[2,3]
[1]Natural History Museum, London
[2]Imperial College London
[3]University of Queensland

Disparity-through-time analyses are commonly conducted in palaeontology. These analyses investigate how the morphological diversity of a group changes through time, and are used to answer key questions, such as how do mass extinction events influence diversity beyond loss of species richness, and whether some groups out-competed another by filling their ecological niche. These analyses are common but we don't always carefully consider the details of the methods used. Yet how you choose to measure disparity and time subsample your data can have consequences for your conclusions, sometimes changing them dramatically. Using a variety of palaeontological datasets, we show how decisions about time binning your data can change the results of your analyses. We present a new method for time slicing datasets taking into account the group of interest's phylogeny and several evolutionary models, implemented in dispRity, a new R package that allows you to use this method and more, in a flexible and reproducible manner. We also present results for groups with no available phylogeny.

Simulating evolution in space and time

Russell Garwood[1], Mark D. Sutton[2], Chris Knight[1], Guillaume Gomez[1], Alan R.T. Spencer[2]
[1]University of Manchester
[2]Imperial College

The identification of evolutionary patterns in deep time is frustrated by biases in the fossil record. Geology, taphonomy, and collection all alter what ancient life can tell us about evolution. These filters can be both avoided and studied through *in silico* simulation, i.e. by using a simplified, abstracted model to explore the patterns and processes of evolution. We present such a model, coded into complementary software packages, *EvoSim* and *EvoTree* that incorporate many aspects of biological evolution. They allow experimental investigation on palaeontological timescales with sizeable populations of individuals, each with an explicit genome (millions of digital organisms over millions of generations). The software: operates with (or without) geography and environmental variation; allows asexual and sexual reproduction; identifies species (which arise naturally); and documents true evolutionary trees. We present data created by the simulation, and demonstrate patterns also observed in microbial evolutionary experiments. We can use these models to address key evolutionary questions: how evolutionary patterns/rates are impacted by rates of environmental change; the evolution of sexual reproduction; and the dynamics of mass extinctions. These simulations allow a range of hypotheses developed in palaeontology, and evolutionary biology, to be tested, and new ones to be developed.

Modelling biotic interactions using data from the fossil record

Lee Hsiang Liow[1]
[1]University of Oslo

Biotic interactions such as predation, disease, competition, symbiosis, mutualism, sexual selection are important processes that influence ecology and evolution in major ways. However, neither direct nor indirect evidence of such interactions are easy to observe or infer from the fossil record. I present two disparate approaches I use to approach the problem of describing and inferring fossilized biotic interactions. The first is a tool for causal

inference (in the Granger sense) that involves linear stochastic differential equations that we have applied to diversification time series of bivalves and brachiopods over the Phanerozoic. I present evidence that bivalves deterred brachiopods evolutionarily by "allowing" brachiopods to diversify when bivalve extinctions are high. The second is an empirical system in which we could directly observe outcomes of intra- and interspecific competition. This system involves encrusting bryozoans which compete for space on hard substrates; we have collected data on thousands of interactions in order to understand the causes and consequences of competition through more than 2 million years of bryozoan evolution. I demonstrate how we modelled competition using ordinal regression, with a twist, to figure out which organismal traits were responsible for competitive outcomes.

Journeys through discrete character morphospace

Graeme Lloyd[1]
[1]*University of Leeds*

The rich morphological data set that is the fossil record has been summarised in the form of discrete character-taxon matrices since at least the middle of the 20th century. Such matrices have been used to understand evolutionary tempo, infer phylogenetic trees, and measure morphological diversity (disparity). Historically these have been seen as separate endeavours, but they may be better understood within a common framework: a discrete-character phylomorphospace. Such a space is hyperdimensional, with points representing nodes of a phylogenetic tree (tips and reconstructed ancestors) and the branches linking them reflecting the journeys morphological evolution has taken. Such spaces thus offer the potential to better understand how patterns of morphological diversity emerge. Here I outline several difficulties in generating such spaces. These include: 1) the non-Euclidean nature of most morphological distances, 2) difficulties in incorporating various uncertainties (including phylogenetic), and 3) problems associated with visualising high dimensional spaces. In addition there are multiple routes to generating such phylomorphospaces, the main difference being whether ancestors are reconstructed pre- or post-ordination. I explore this major division using an empirical data set of theropod dinosaurs and show that some routes are likely to generate phylomorphospaces that better reflect phylogenetic than morphological distances.

Evolution and Earth Systems: modeling population-level processes on palaeontological scales

P. David Polly[1]
[1]*Indiana University*

Evolution is fundamentally a population-level process in which variation, drift, and selection interact to produce patterns of change (or stasis) that are both spatial and temporal. Palaeontology provides empirical data on the outcomes of evolution, which sometimes point to unexpected macroevolutionary patterns that arise from interactions between evolutionary processes and large-scale phenomena like tectonics, climatic change, or clade coevolution. Because population and palaeontological data often differ in granularity, it can be difficult to relate processes at these two scales to one another. Computational modelling can be used as a tool for extrapolating population level processes over palaeontological scales, allowing *in silico* experimental tests of competing evolutionary explanations for the same paleontological outcomes. Here I review basic properties of population level processes – variation, drift, selection, and population size – and I discuss the relationship between their spatial and temporal dynamics. I then show how typical evolutionary models used in palaeontology and phylogenetics (Brownian motion, Ornstein-Uhlenbeck, and directional) incorporate the temporal component of these dynamics, but not the spatial. Finally, I show using computational modelling that large scale Earth system processes can create evolutionary outcomes that depart from basic population-level notions from these standard macroevolutionary models.

Using evolutionary models to assess the accuracy of phylogenies estimated with Bayesian, Maximum-Likelihood, and Parsimony methods

Mark Puttick[1,2], **Joseph O'Reilly**[2], **Davide Pisani**[2], **Phil Donoghue**[2]
[1]*University of Bath*
[2]*University of Bristol*

Placing fossils in the tree of life is a fundamental aim of evolutionary biology, but it is unclear which phylogenetic methods are most accurate when estimating phylogenies based on morphological data. Molecular phylogeneticists have generally abandoned parsimony as it exhibits statistically undesirable properties and is less accurate than probabilistic phylogenetic models. In palaeontology, equal weights and implied weights parsimony are widely used, but recent research suggests probabilistic alternatives, mainly the Bayesian Mk model, may provide greater accuracy. Here we review these recent debates to show that parsimony generally performs poorly in comparison to probabilistic models such as the Bayesian Mk model. Many of these differences are due to Bayesian model incorporating uncertainty not accommodated in equal weights or implied weights parsimony. However, when this uncertainty is incorporated in parsimony approaches, probabilistic methods still achieve higher accuracy. Finally, we show that even when data are simulated to be biased towards parsimony, and implied weights parsimony in particular, Bayesian estimation still achieves higher accuracy in datasets rich in homoplasy. The simplistic Mk model of evolution used in Bayesian phylogenetics is more accurate than parsimony alternatives, and unlike parsimony, it offers future scope to model the complexities of morphological data.

How different is reality from mathematical perfection in taxonomy?

Julia Sigwart[1,2]
[1]*UC Berkeley*
[2]*Queen's University Belfast*

There are intrinsic mathematical patterns in nature. Species are natural units that are formed from branching phylogenetic processes that also have a mathematical structure. We should be able develop a set of general principles that describe global patterns of species groups, like genera, or families. Understanding such patterns would lend considerable power to "taxonomic surrogacy", the common practice of substituting genus or family-level names where species identification is impractical. Assessing the error introduced by taxonomic surrogacy could also improve comparisons of diversity patterns in the fossil record to the living biota. But some higher taxa are "natural" or monophyletic groups, while others are mixed or paraphyletic melting pots awaiting taxonomic revision. Finally, the use of species group designations are potentially different in living and fossil taxa. All of these issues can be addressed through simulation approaches, *in silico* approximations of both large scale phylogenetic scenarios that underpin the evolution of species groups, combined with simulation of an "idealised" taxonomic practice. Clarity and confidence in fundamental patterns for taxonomy based on a robust null model – species-poor genera are very common, large genera are very rare – may provide tools that accelerate species discovery in fossil and living groups.

ABSTRACT OF ANNUAL ADDRESS

Monday 18th December, 17:30

101 uses for a dead fish. Experimental decay, exceptional preservation, and fossils of soft bodied organisms

Mark Purnell[1]
[1]*University of Leicester*

[NOT YET AVAILABLE]

ABSTRACTS OF ORAL PRESENTATIONS

* Candidates for the President's Prize are marked with an asterisk.
Underlined author denotes designated speaker.

Trilobite evolutionary faunas

Jonathan Adrain[1]
[1]*University of Iowa*

Evolutionary faunas were defined by Sepkoski as "sets of higher taxa...that have similar histories of diversification and together dominate the biota for an extended period of geologic time." Trilobite evolutionary faunas were first explored (in 1998 and 2004) using intervals of the Ordovician, with families as units of analysis and genus occurrence by interval as data. This resulted in the proposal of the Whiterock and Ibex faunas. It is now possible to explore evolutionary faunas at the species level across the group's entire history. A taxonomic database compiled from the primary literature, with ongoing systematic revision, indicates that 21,889 valid trilobite species have been proposed, distributed among 4,025 genera and 165 families. Multivariate analyses using families as units, 37 temporal intervals from Early Cambrian to end-Permian as variables, and species diversity by interval as data, indicate that all known trilobites belong to one of six evolutionary faunas. Three that had previously been detected using Ordovician data (previously termed the Whiterock Fauna, and the Ibex Fauna I and II) are confirmed by the new analyses; three others, not previously recognized, are apparent in the Cambrian. Three of the faunas originated in the wake of significant mass extinction events.

Life at the end of the Boring Billion: microfossil record from the ca. 1 Ga Bylot Supergroup, Arctic Canada

***Heda Agic**[1], **Susannah M. Porter**[1], **Sarah Wörndle**[2], **Timothy M. Gibson**[2], **Peter W. Crockford**[2], **Malcolm S.W. Hodgskiss**[3], **Marcus Kunzmann**[4], **Galen P. Halverson**[2]
[1]*University of California Santa Barbara, USA*
[2]*McGill University, Canada*
[3]*Stanford University, USA*
[4]*Australian Resources Research Centre, Australia*

The Mesoproterozoic–Neoproterozoic transition marked the end of environmental and evolutionary stability of the "Boring Billion". This interval was characterised by gradual oxygenation of shallow marine environments, assembly of Rodinia, and appearance of crown-group eukaryotes. However, the number of studied stratigraphic units of this age is limited. High-resolution micropalaeontological and palaeoenvironmental analyses were conducted on the Bylot Supergroup (Borden Basin, Arctic Canada) to evaluate eukaryotic diversity in this poorly studied interval. Well-preserved organic-walled microfossils occur throughout siliciclastic sediments of Arctic Bay and Iqqittuq formations that are constrained by Re-Os geochronology to ~1.05 Ga. The recovered microfossils include diverse prokaryotes and eukaryotes, including *Culcitulisphaera revelata*, *Fabiformis baffinensis*, *Microlepidopalla mira*, *Satka favosa*, *Squamosphaera colonialica*, and 3 new taxa with striated vesicle walls. Stratigraphic range of the late Tonian *C.revelata–M.mira* association is extended to late Mesoproterozoic. Moderate diversity was recorded within the restricted basin facies of the Arctic Bay Formation. The transitional, shallower facies of the Iqqittuq Formation host the most diverse assemblage. The nadir of microfossil diversity co-occurs with a positive $\delta^{13}C_{carb}$ excursion (-4 to +3‰). This new biostratigraphic record indicates that several characteristic Tonian taxa appear 200 myr earlier, and eukaryotes were more diverse around 1 Ga than previously known.

The contrasted early evolution of taxonomic richness and morphological disparity of the Ammonoidea: The Devonian record from Morocco

***Ninon Allaire[1], Claude Monnet[1], Catherine Crônier[1]**
[1]Université Lille, CNRS, UMR 8198 – Evo-Eco-Paleo

Within the Anti-Atlas of Morocco the Devonian ammonoids are particularly abundant and well preserved. These rich faunas are well documented in the literature, and this fossil record can help to constrain the palaeobiodiversity fluctuations that characterize the macroevolution of the early Ammonoidea during the Devonian period. With the aim to better understand the response of these organisms to the environmental perturbations identified during the Devonian (e.g. anoxic events), a database was constructed to analyze both the taxonomic diversity and the morphological disparity of these organisms. Diversity can be measured in different ways and for any taxonomic rank. For this study, the taxonomic richness (species and genus) was investigated, and several standard indices based on incidence data were calculated to quantify this signal of diversity. The morphological disparity was analyzed considering three modules (the shell geometry, the aperture outline and the suture line shape), which were quantified by standard linear measurements and by geometric morphometrics. Finally, this study compares, at the substage level, the taxonomic richness and the morphological disparity patterns observed for the Moroccan ammonoids, through the Devonian time interval.

Evolutionary adaptation to aquatic lifestyle can lead to systemic alteration of bone structure

Eli Amson[1], Guillaume Billet[2], Christian de Muizon[2]
[1]Humboldt Universität zu Berlin
[2]Muséum national d'Histoire naturelle (MNHN, CNRS, UPMC, Sorbonne Université)

Bone inner structure in tetrapods is marked by lifestyle adaptations. Those of shallow-diving taxa are the best understood, and associated with postcranial bone mass increase (BMI). However, the potential implications of these adaptations on the cranial anatomy are not known. Here we show that the Mio-Pliocene (semi)aquatic sloth *Thalassocnus* was affected by systemic BMI, which leaded to changes in cranial structures as aberrant as dramatically thickened turbinates (usually paper-thin bones of the nasal cavity). We used micro-computed tomography to compare endocranial structure among the species of *Thalassocnus*, including early *T. natans* (postcranium with incipient BMI), middle *T. littoralis* (postcranium with intermediate BMI), and late *T. carolomartini* (postcranium with strong BMI). In the late species, the whole skull is osteosclerotic (denser), notably involving the infilling of frontal sinuses with solid bone. A gain of fitness from pachyostotic turbinates being implausible, they likely are a secondary consequence of the systemic BMI. In addition to leading to a systemic modification of bone structure, we thus suggest that such an evolutionary adaptation can involve evolutionary byproducts. An understanding of the whole skeleton's structural adaptations should be acquired before drawing (paleo)biological interpretations related to the structure of some skeletal elements.

A mineralogical signature for Burgess Shale-type preservation

***Ross P. Anderson[1,2,3], Nicholas J. Tosca[2], Robert R. Gaines[4], Nicolás Mongiardino Koch[3], Derek E. G. Briggs[3,5]**
[1]All Souls College, University of Oxford
[2]Department of Earth Sciences, University of Oxford
[3]Department of Geology and Geophysics, Yale University
[4]Geology Department, Pomona College
[5]Peabody Museum of Natural History, Yale University

Burgess Shale-type (BST) fossils provide essential evidence of the early evolution of complex life, as they include organic remains that usually decay. Despite its importance, the factors contributing to BST fossilization remain controversial. Sediment composition—in particular clay mineralogy—has been one of the hypotheses championed. We provide the first major data set exploring the association of clay mineral assemblages with BST fossils based on X-ray diffraction data from 213 Cambrian shales over 19 successions on four different continents. Samples containing BST fossils have a constrained clay mineralogy compared to those containing only

mineralized fossils. Logistic regression and classification tree methods show that BST fossils are associated with sediments containing higher abundances of berthierine/chamosite and lower amounts of celadonite and illite, likely reflecting a high kaolinite/smectite ratio in the original sediment combined with high iron concentrations during early diagenesis. BST preservation was influenced by a combination of unusual diagenetic conditions as well as palaeogeographic/climatic factors. Statistical methods using clay mineralogy can predict which lithologies will preserve BST fossils with ~80% accuracy, providing a potential tool for narrowing the search for carbonaceous fossils on Earth and possibly Mars.

A new chroniosuchian (non-amniotic tetrapod) from Laos revealed by micro-CT scan: anatomy and palaeobiology

***Thomas Arbez[1], Christian Sidor[2], Jean-Sébastien Steyer[1]**
[1]CNRS - MNHN
[2]University of Washington

Chroniosuchians, a clade of non-amniotic tetrapods similar in overall body shape to modern crocodiles, are known in Germany, Kyrgyzstan, Russia and China, from the middle Permian to Late Triassic. The rarity of complete or articulated specimens implies that relatively little is known on this group in terms of anatomy, paleobiology, or evolutionary history.
A new genus and species of chroniosuchian is described based on a nearly complete skull and articulated left hemimandible, from rocks preserving the PT boundary of the Luang-Prabang Basin of Laos. This specimen is one of the best-preserved chroniosuchian skulls and the first fossil amphibian discovered in Laos. Its discovery reveals an unexpected geographic extension of the group in southeastern Pangea, and provides new insights about chroniosuchian paleobiology and paleoecology.
In particular, CT scan data reveal internals canals observed in the skull roof and the hemimandible with two morphologies: 1) simple canals interpreted as internalized sulci belonging to the lateral system; 2) ramified canals may be involved in the detection of surface waves generated by prey moving in water. Our interpretation of these canals suggests an amphibious life style for the Laotian chroniosuchian.

Punctualistic disparity patterns and step-wise body plan canalization in euarthropods

***Cedric Aria[1,2,3]**
[1]Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario M5S3B2, Canada
[2]Department of Natural History (Palaeobiology Section), Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario, M5S2C6, Canada
[3]Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39, East Beijing road, 210008 Nanjing, China

Reconstructing patterns of macroevolution has become a central endeavor in palaeobiology, as it offers to comprehend evolutionary models shaping the history of life. As the most diverse and abundant animals since the Cambrian period, arthropods constitute ideal data to elucidate the emergence of body plans in metazoan lineages, but this effort has so far been impeded by the uncertain role of fossils in the structuration of the underlying morphological patterns. Using a current cladogram including fossil and extant taxa and its corresponding morphological matrix, I here describe disparity patterns in Euarthropoda, in light of exceptionally fast evolutionary rates known to characterize the base of extant clades. Quantified morphology shows that extant euarthropods evolved from a trilobitomorph supercluster by successively reduced punctualistic events, forming more constrained morphogroups, with the exception of malacostracans. A change in the mode of disparity is also consistent with the expectations of mosaic evolution. Such patterns suggest that extant euarthropod body plans arose during the Cambrian through large displacements of adaptive landscape optima, accompanied by relatively increasing—but not irreversible—developmental canalization. This would explain the great stability of extant euarthropod body plans over the Phanerozoic, in contrast to shorter-lived stem lineages with sub-optimal relative fitness.

The Middle Devonian Kačák Event: its identification and effects in Northern Spain

***Alexander Askew[1], Charles Wellman[1]**
[1]University of Sheffield

The Kačák is an extinction event at the base of the Givetian Stage (Middle Devonian) associated with marine transgressions and benthic anoxia. It is best documented in central Europe and the Americas but is believed to be of worldwide distribution. Here we identify the Kačák Event in Northern Spain, document its effects and consider its cause. The Devonian sequence of Northern Spain accumulated in a relatively isolated setting in Peri-Gondwana. It is extensive, relatively complete and entirely marine. The coeval Naranco, Huergas and Gustalapiedra formations of Asturias, Léon and Palencia are Eifelian-Givetian in age and span the Kačák Event. Palynological analysis has yielded an extensive record of marine (acritarchs, chitinozoans, scolecodonts) and land-derived (spores) palynomorphs. Their biostratigraphy, allied with sedimentological and palaeoenvironmental analysis, suggests a period of acute environmental change. This is represented by rapid, cyclical sand and silt deposition, temporarily supplanting the background limestone deposition. The disruption immediately follows the Kačák Event, suggesting a close link between the extinction event and the palaeoenvironmental upheaval taking place in Northern Spain. These findings support an existing hypothesis postulating that the Kačák Event represents the creation of a monsoonal climate, which greatly increased terrigenous input to the oceans, devastating marine communities.

Assessing changes in leaf morphology in *Ginkgo biloba* and their suitability to act as a palaeo-climate proxy

Karen Bacon[1], Claire Belcher[2]
[1]University of Leeds
[2]University of Exeter

Ginkgo biloba has a long evolutionary history, with leaves of a strikingly similar morphology to those of the modern plant found in sediments over 100 million years old and well-preserved representatives of the family identified in the Early Triassic. This makes the sole survivor of this once diverse clade of significant interest to palaeobotany and palaeoecology. *G. biloba* is known for its fan-shaped leaves and noted for the variety of shapes that these leave can produce. A survey of *G. biloba* trees growing in 15 cities in Great Britain and Ireland was conducted to sample leaf shape and leaf trait variation along a relatively mild climate gradient. Twenty leaves were collected from each tree and between one and three trees were sampled at each location, with one to three locations per city. Analysis of these leaves has shown a strong leaf shape variation with temperature – leaves growing in the warmer, southern locations (e.g. Exeter, London) had significantly ($p < 0.5$) rounder and larger leaves than those growing in more northern locations (e.g. Aberdeen). This analysis suggests that leaf shape in *G. biloba* is correlated to mean annual temperature and may provide a useful palaeo-temperature proxy.

Biomineralisation of Palaeozoic sponges and aragonite-calcite seas

Uwe Balthasar[1], S. Kershaw[2], A.C. Da Silva[3], B. Seuss[4], M. Cusack[5], K. Eichenseer[1], P. Chung[6]
[1]Plymouth University
[2]Brunel University
[3]Liège University
[4]Universität Erlangen-Nürnberg
[5]University of Sterling
[6]University of Glasgow

Many Palaeozoic reef environments were dominated by stromatoporoids and it has been proposed that skeletal mineralogy of such hypercalcifying reef builders mirrors the mineralogy of non-skeletal $CaCO_3$ through time. However, the original skeletal composition of stromatoporoids is not well understood, with different authors arguing for an original composition of aragonite or high-Mg calcite (HMC). The skeletal composition and underlying biomineralization of stromatoporoids was reassessed using electron backscatter diffraction of

stromatoporoids from the Silurian and Devonian. In addition, a chaetetid sponge from the Carboniferous Buckhorn Asphalt, a deposit renowned for its preservation of calcareous microstructures, was studied. The analysis shows that the main building blocks of the stromatoporoid and chaetetid skeletons were bundles of single-crystal fibres of HMC. The preservation is characterised by a distinct microporosity and micro-dolomite inclusions that is interpreted to reflect the disintegration of inclusions of hydrated amorphous calcium carbonate during early diagenesis. Using these new insights, we analysed Palaeozoic sponge-dominated reefs in the PaleoReef Database and find that they correlate closely with the marine Mg:Ca ratio but, unlike inorganic $CaCO_3$ precipitation, appear to not be influenced by temperature variation.

A dichotomous key for the morphological identification of coprolites

***Sandra Barrios[1], Francisco Jose Poyato-Ariza[1], Jose Joaquin Moratalla[2], Ángela D. Buscalioni[1]**
[1]Universidad Autónoma de Madrid
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Las Hoyas is an upper Barremian continental Konservat-Lagerstätte located in Cuenca (Spain), with an abundant body fossil, as well as a diverse ichnologic record. Trace fossils correspond to Mermia ichnofacies that nonetheless do not contain coprolite data. The study of a representative number of coprolites (N=433) has resulted in twelve different morphotypes: spiral, circular, irregular, elongated, rosary, ellipsoidal, cylinder, bump-head lace, Christmas-tree, cone, straight lace and thin lace coprolites. A morphological key was built, and the variation and utility of the different features used to describe the morphotypes have been tested. The size, matrix colour and content density are not useful features because they are not morphotype-specific, whereas the overall shape, outlines, shape of the ends, constrictions and the increase of the diameter of the coprolites are optimal characters to build the dichotomous key. This key is precise and meaningful because: (1) just a few coprolites among the 433 studied differ slightly from the combination of characters proposed; (2) with few features all the morphological variation is comprised, and (3) it can be used as a base to identify and compare coprolites from other Mesozoic fossil sites.

Experimental modelling of sedimentary processes for the Burgess Shale: implications for the transport and preservation of soft-bodied organisms

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Understanding if soft-bodied organisms within fossil assemblages could have been transported, or not, is fundamental to the study of palaeoecology. In regards to the Burgess Shale Lagerstätte, a fundamental debate remains as to whether these animals were living within or close to the environment of deposition, or could they have been transported from one environment to another? Experimentation allows us to place constraints on this problem. In a two-factorial design using an annular flume tank, experiments were conducted to explore the effect of both pre-transport decay (up to 48 hours) and transport duration (equating to distances ranging from less than 1 km to 21.6 km) on the overall completeness and preservation potential of the polychaete, *Alitta virens*. Fieldwork and laboratory analysis of material from the Walcott Quarry of the Burgess Shale was used to feed directly into the experimental design to replicate Burgess Shale flow conditions. The flow consisted of 11% volume of kaolinite at 0.4 ms^{-1} to create quasi-laminar to upper transitional plug flow conditions.
The results of these experiments are used make direct comparisons to the preservation state of *Burgessochaeta* and *Canadia* from the Burgess Shale. The implications are discussed for the palaeoecology of Cambrian marine communities.

Patterns of morphological evolution in Pelagia (Teleostei: Acanthomorpha) consistent with ancient adaptive radiation

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Pelagia is an anatomically disparate clade of open-ocean fishes that appears to have originated near the Cretaceous-Paleogene boundary. This differs from model 'adaptive radiations' (cichlid fishes, *Anolis* lizards) in age and geographic scale, but corresponds to the pattern for which the concept was first defined: Cenozoic mammals. We collected computed tomographic data for the crania of 73 extant species of Pelagia, sampling all 15 extant families and a third of living species, and used three-dimensional geometric morphometrics to generate a shape space for the clade. Cranial anatomy separates families, paralleling differences in body shape. Divergent examples include gempylids (snake mackerels) and trichiurids (scabbardfishes), with elongate skulls, and deep-sea chiasmodontids (black swallowers) with reduced opercular series, posteriorly directed suspensoria, and long gapes. We constructed a morphological dataset for scombrids (tunas and mackerels) and combined this with existing molecular phylogenies to place a diverse series of early fossil scombroids into this phylogenetic framework. A disparity-through-time analysis tested for deviations from a Brownian motion model of phenotypic evolution, finding substantially lower-than-expected levels of subtree disparity early in the history of the clade, providing quantitative support for an adaptive radiation in Pelagia early in the Cenozoic.

Brachiomatic: automated measurement of brachiopod size using new museum collections digitisation protocols

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Brachiopods are useful for understanding how biota have responded to environmental changes in deep time. Museums are increasingly digitising collections, using high-throughput workflows based on rapidly imaging material. We are interested in whether these images can be used to collect standardised morphological data more efficiently to document changes in size across intervals of past environmental change. Using a collection of fossil brachiopods spanning the Early Toarcian hyperthermal event, we aim to test whether body size measurements generated automatically from images of specimens are more accurate, more precise and quicker to generate than measurements made by hand of the physical specimens. We completed a pilot study of a collection of 1200 brachiopods from the Jurassic of Spain. The results show that image quality and specimen orientation are important for the automated extraction of size data. Precision varies between taxa: automated measurements from those which are harder to orientate (smaller specimens) or which are harder to balance (lateral and anterior) are less precise. Precision of measurements using callipers also varies between individual researchers. Overall, length and width are more precise than depth using both methods. An additional benefit of the automated approach is better reproducibility compared to manual measurements.

First virtual endocasts of fossil Aplodontidae and their relevance in understanding the relationship between brain evolution and locomotion

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Previous studies suggest that the burrowing adaptations of the living mountain beaver, *Aplodontia rufa*, are derived, and that basal members of Aplodontidae were more arboreal, similar to Sciuridae (squirrels), their closest relative. This evolution of adaptations for fossoriality has never been studied from the perspective of brain evolution. We describe the first virtual endocasts of *Aplodontia rufa* and of two fossil aplodontids, *Prosciurus relictus* (Early Oligocene), and *Mesogaulus paniensis* (late Miocene). Our results show that the endocast of *Prosciurus* is more similar to the early arboreal squirrels *Protosciurus* and *Cedromus* than to the younger aplodontids in being relatively larger (higher EQ), with larger paraflocculi and a more ventrally positioned

orbitotemporal canal, associated with a larger neocortex. These endocranial features have been tied to better vision and the development of arboreality in squirrels, and their presence in *Prosciurus* may be related to more arboreal habits. The smaller paraflocculi and smaller neocortices of the younger *Aplodontia* and *Mesogaulus* could reflect their burrowing adaptations. These results are consistent with previous observations that brain size and shape vary as a function of locomotion in rodents, and provide a rare example of apparent relative brain size decrease through time in the fossil record.

Dietary ecology of pterosaurs from quantitative 3D textural analysis of tooth microwear

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Pterosaurs were a successful group of Mesozoic flying reptiles. For 150 million years they were integral components of terrestrial and coastal ecosystems, yet their feeding ecology remains poorly constrained. Postulated pterosaur diets include insectivory, piscivory and/or carnivory, but many dietary hypotheses are little more than speculation based on scant evidence. We have developed a more robust approach based on quantitative analysis of the micron-scale 3D textures of worn pterosaur tooth surfaces – dental microwear texture analysis – never before applied to pterosaurs. Microwear is produced as scratches and chips generated by food items create characteristic surface textures on teeth that vary according to diet.
We compared microwear from non-occlusal tooth surfaces of 11 species of pterosaur with data from extant organisms with known diets, (bats, monitor lizards and crocodilians, including insectivorous, piscivorous and carnivorous species). This allowed for robust testing of previous pterosaur dietary hypotheses. Microwear from *Dimorphodon* for example, previously hypothesised as a piscivore, indicates a diet of vertebrates and invertebrates. Microwear from basal monofenestratans, previously hypothesised as carnivores, provides evidence of piscivory in these pterosaurs. Dietary evidence from microwear therefore provides novel insights into the ecological roles of respective pterosaurs and pterosaur dietary evolution.

Integrating genomic and fossil evidence to date the tree of life

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Establishing a timescale for the tree of life is a task that has long been approached via a literal interpretation of the fossil record. However, fossils come with caveats such as difficulties in establishing biogenicity, establishing a correct age constraint, and assigning affinities. We chose to approach the question with a combined molecular clock analysis, attempting a reappraisal of the fossil material and integrating it with molecular sequences to estimate a timescale for the tree of life. Our timescale is robust to parameter variations within the analysis and finds that the last universal common ancestor originated prior to the late heavy bombardment. The major clades diverged some time later: crown Archaeabacteria ~3178 Ma; crown Eubacteria ~3454 Ma; and crown Eukarya ~1524 Ma. These dates place the earliest potential fossils into the bracket of total life, with crown group domains not appearing until around the Strelley Pool Formation. In our timescale, crown group cyanobacteria originate significantly after the Great Oxidation Event, rejecting the view that they were its primary driver. Additionally, we show a concurrent evolution of the alphaproteobacteria and the crown eukaryotes, both of which originate in the Mesoproterozoic, suggesting a symbiotic acquisition of the mitochondria between 1579-1209 Ma.

Insights into the taphonomy of *Weichselia reticulata*

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The tree fern *Weichselia reticulata* (Stokes et Webb) Fontaine had a wide palaeogeographic distribution in Laurasia and Gondwana during the Jurassic and Cretaceous periods. In particular, leaf fragments of a few centimetres are very abundant from the upper Barremian of Las Hoyas (Cuenca, Spain) and the Barremian of Beare Green Pit (Surrey, England). Both localities are interpreted as freshwater habitats. The plant fossils are mostly charred (i.e., preserved as charcoals), and more rarely consist of impressions and permineralizations covered by calcite or iron oxide. The maximum lengths of a total of 1381 fragments of *W. reticulata* were measured. Our results show that: (1) the mean size of impressions is larger than that of compressions and permineralizations; (2) the mean size of the fragments from Beare Green Pit is smaller (8 mm) than those from Las Hoyas (26 mm); and (3) when the remains are found associated in the same layer, the Beare Green Pit fossils show less variation in size. These differences may be explained by differences in the necrobiosis (e.g., higher fragmentation during burning) and biostratinomy (e.g., higher selection during water transportation).

The end-Ordovician Anji Biota (Zhejiang, China) and a wider Hirnantian sponge mega-community

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The recently-discovered Anji Biota of Zhejiang preserves an unprecedented deep-water Hirnantian fossil assemblage, preserved by pyritisation in black mudstone of the post-extinction *Metabolograptus persculptus* Biozone. The community was dominated by a hyper-diverse assemblage of sponges, representing both early-branching and modern groups, and preserved with detailed skeletal remains and soft tissues. Aside from abundant graptolites, associated fossils are limited to occasional orthocone nautiloids, and rare examples of other exceptionally preserved taxa such as echinoderms, eurypterids and other arthropods. One site also shows a depth transect from a shallow-water *Aegiromenella* Fauna into the sponge community, with an intermediate-depth assemblage between them.

Additional collections have increased the sponge diversity to over 100 species, with many new taxa expected from further collecting. Additional work elsewhere in South China has revealed similar diverse, abundant sponge faunas from the *M. persculptus* Biozone in several provinces, across 2000 km, despite differences in the sedimentary successions. The preservation of the sponges appears to be related to an interval of rapid suspended sediment input during transgression. We encourage investigations of Ordovician–Silurian boundary sections globally to assess whether the offshore sponge proliferation in South China was a global phenomenon, and what its implications might be for post-extinction recovery.

Geobiology and palaeogenomics: genes that make rocks

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The combination of geobiology and palaeogenomic studies is a powerful approach which leads to a more fundamental understanding of how Earth and life have changed through time in building the sedimentary rock record. For example, linking palaeogenomic studies of biomineralization genes for modern organisms and when they first evolved in the Cambrian with geobiological studies of the impact this had on the production of carbonate sedimentary facies and the development of the Neritan Ocean, provides a unique perspective on how genes have shaped formation of the sedimentary record. Another component of the Cambrian explosion, the evolution of vertical bioturbation at the start of the Cambrian, has had significant effects on biogeochemical cycling and sediment production, and provides an inviting target for future genomic studies. The remaining Phanerozoic includes a broad variety of evolutionary innovations which within a joint geobiological and palaeogenomic

context can also be profitably studied. These include evolution of the coccolithophore exoskeleton as they have strongly contributed to widespread deposition of carbonate sediment in deep settings and development in the Mesozoic of the Cretan Ocean. Such work will ultimately provide a history of how genomic changes shaped the development of the sedimentary rock record.

Accounting for differences in species frequency distributions when calculating beta diversity in the fossil record

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Beta diversity is a measure of the taxonomic differentiation between habitats/localities within an assemblage, and is normally calculated as a set of pairwise taxonomic "distances". It has long been understood that, due to the incompleteness of the fossil record, beta diversity estimates for fossil assemblages will always be higher than the true value. However, the difference between the observed and true distances will vary greatly depending on differences in the shape of the relative abundance distribution. Using simulations, it is shown that incomplete sampling of a homogenous fauna with more even relative abundances of taxa produces higher beta diversity than one with very few extremely common taxa. A new procedure is proposed for calculating beta diversity in the fossil record, whereby the observed distances are compared to the distances obtained by making random samplings from a homogenous fauna with the same abundance distribution. This method is applied to an empirical dataset: Permian-Triassic tetrapods from the Karoo Supergroup of South Africa. A homogenous fauna is observed in the Guadalupian, but during the Lopingian increased provinciality is observed. No change is found across the Permian-Triassic boundary, but during the Middle Triassic beta diversity again decreases.

Scotland's Jurassic Park: new dinosaurs, crocodylomorphs, pterosaurs, and fishes from the Middle Jurassic of Skye

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The Isle of Skye is one of the rare localities worldwide that preserves vertebrate fossils from the Middle Jurassic (ca. 174-163 million years ago), a critical time when several major dinosaur groups were diversifying and more modern-style mammals, lizards, and amphibians radiated. The PalAlba consortium of Scottish-based palaeontologists has launched several expeditions to Skye over the last five years to collect Middle Jurassic fossils in the lagoonal and fluvial rocks of the Great Estuarine Group, and we report our key findings here. Several new dinosaur tracksites—including the first sauropod tracks and first ornithopod trackway from Scotland—indicate that sauropods preferred nearshore lagoonal settings while other dinosaurs preferentially left their tracks on mudflats. New crocodylomorph material reveals a high diversity of dog-sized species, the recent discovery of a pterosaur skeleton demonstrates the presence of a rhamphorhynchoid-grade taxon that may fill an important gap in pterosaur evolution, and a bounty of new fish beds contains a diversity of pycnodont species with intriguing biogeographic affinities to Gondwanan forms. These and other finds provide a unique window into whole ecosystems of the Middle Jurassic, and suggest that much remains to be discovered on Skye.

The "push of the past": an important bias in the fossil record

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Homogeneous “birth-death” models for speciation and extinction may be used to model patterns of diversification, but survivorship biases can create remarkable and counter-intuitive effects through time. Here we consider the “push of the past”, the effect that occurs by imposing the condition that clades survive until the present (which of course, some have). Such clades tend to begin with high bursts of diversification and an early origin of the first crown group, an effect that becomes more pronounced as extinction rates increase: similar effects occur after mass extinctions. An extra effect increasing rates in early lineages is also seen in very large living clades. These effects are also likely to affect rates of phenotypic change and may even distort molecular clock estimates of clade origins. Understanding this and other biases that emerge from the “null hypothesis” of clade diversification is thus essential before causal mechanisms for major macroevolutionary patterns are sought. It may be that many traditional major features of the fossil record turn out to be the inevitable consequence of our own perspective – looking back in time from within a large clade that has survived over half a billion years.

Evolution or revolution at the J/K boundary: The case of the Ammonoidea

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The original conception of the Tithonian and Berriasian Stages was entirely ammonite based, and ammonite biostratigraphy still has much to contribute to the definition of a J/K boundary. The database of Ammonoidea occurrences is substantial, with reference sections in SE France, SE Spain, Bulgaria, Ukraine (Crimea), Turkmenistan, Iraq, the Himalayas, Yemen, Morocco, Tunisia, Mexico, Argentina, the United Kingdom and Russia (Volga Region and Siberia).
Over the past 10 years these faunas have been re-investigated as part of a team study of the Berriasian Working Group (ISCS/IUGS). New primary data on the taxonomy, stratigraphic ranges and palaeobiogeographic distributions were obtained.
Besides the reappraisal of the high endemism of the faunas, the new picture of the ammonoid evolution accross the J/K boundary points out salient issues regarding the tempo of the “so-called” turnovers that affect the ammonite faunas during the Late Tithonian and Early Berriasian. All new evidences strongly suggest that the picture formerly obtained from the Ammonitico Rosso successions of SE Spain is oversimplistic.

Phylogenomic analysis of Brachiopoda and Phoronida: implications for morphological evolution, biomineralization, and the Cambrian radiation

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Brachiopods are among the first appearing biomineralised Cambrian metazoans and represent a major component of the early animal fossil record. While their fossil record is ultimately key to determining character homology and polarity during evolution of the brachiopod body plan, reading this pattern has been clouded by phylogenetic uncertainty among the crown clades; specifically, monophyly of brachiopods with respect to phoronids, and the relationships of the calcitic to phosphatic brachiopods. Much of this phylogenetic uncertainty stems from difficulties in rooting the tree of brachiopods within Lophotrochozoa. Phylogenomics—the analysis of hundreds to thousands of orthologous genes—has been instrumental in resolving difficult phylogenetic relationships in diverse metazoan clades through reduction of random error in combination with careful evolutionary model selection. We have conducted the first extensive phylogenomic investigation of Brachiopoda/Phoronida with analyses that combine novel sequence data with all publicly available transcriptomes and a broad range of protostome outgroups. Analyses were run under best fitting evolutionary models (LG and gamma) utilising a published 106-gene lophotrochozoan ortholog set. Preliminary results strongly support a monophyletic

Brachiopoda with Phoronida as sister group within Lophotrochozoa, with weak support found for Inarticulata, thus constraining possible scenarios for the evolution of brachiopod biomineralisation.

Decoupled morphological and phylogenetic diversification during the rise of the ruling reptiles and their kin

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One of the key faunal transitions in terrestrial ecosystems occurred after the Permo-Triassic mass extinction (PTME; ~252.2 Ma), when the previously obscure archosauromorphs (crocodylians, dinosaurs, birds, pterosaurs and stem-species) become the dominant terrestrial vertebrates. This transition set the scene for the dinosaur-dominated ecosystems of the Jurassic and Cretaceous, but its pattern and processes remain poorly understood. Here, we place all known late Permian–early Late Triassic archosauromorph species into an explicit phylogenetic context, and use this dataset and topology to quantify changes in species richness, disparity and evolutionary rates through this interval. Our results indicate the following sequence of diversification: (1) a morphologically conservative and globally distributed post-extinction 'disaster fauna' in the earliest Early Triassic; (2) a major phylogenetic diversification with significantly elevated evolutionary rates in the later Early Triassic; and (3) a marked increase in species richness, abundance, and disparity occurring around the Early–Middle Triassic boundary. This final diversification phase is contemporaneous with global ecosystem stabilization, as indicated by the end of intense carbon perturbations, a global cooling event, and the return of conifer-dominated forests. Our results show the fundamental role of the PTME in reshaping terrestrial ecosystems, and its far-reaching impact on Mesozoic and modern faunas.

The first functional analysis of the lateral line system in fossil fish

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The lateral line is a mechanosensory system used by fish for predator evasion, prey detection, shoaling and navigating their environment. Fish display an extremely diverse range of lateral line morphologies ranging from simple grooves on the surface of the body to elaborate and complex ramifying tubes enclosed in dermal tissue and bone. Whereas the lateral line has been recognised in fossil fish for well over a centrury, the function of the lateral line is only recently beginning to be understood in modern taxa. Recent work has demonstrated that the degree of complexity of ramifying lateral line tubes may behave as a signal filter, the effects of which are dependent on the dimensions of the canal system. Here we employ a simple fluid mechanics model using Hagen–Poiseuille flow to calculate the mean flow and pressure inside lateral line canal segments for a given pressure acting on the pore openings in a fossil lateral line system. The solution describes the pressure and velocity that motion-sensitive neuromast cells within the canal experience. The technique offers great potential for investigating function of fish lineages in different environments and how sensory systems diversify and change during key evolutionary events.

A total-evidence approach to resolving pancrustacean phylogeny

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Many aspects of arthropod biology are intently researched, and their phylogenetic interrelationships are no exception. Recent studies have converged in favor of the Pancrustacea hypothesis of arthropod phylogeny, which describes a topology in which taxa traditionally grouped together as "crustaceans" form a paraphyletic group with

respect to hexapods (insects and their close relatives). However, the relationships within Pancrustacea are more controversial, especially regarding the affinities of Hexapoda to other pancrustaceans. In an effort to resolve the remaining uncertainties in pancrustacean phylogeny, the present study uses a total-evidence framework, incorporating both molecular and morphological characters for inference of phylogenetic topology. A phylogenetic matrix was assembled including 753 morphological characters and 56,504 amino acid positions scored for a total of 259 crown-arthropod taxa, of which 86 were fossil taxa, and analyzed under both Bayesian and maximum likelihood models. This matrix then underwent several modifications that were intended to improve phylogenetic resolution. Excepting the positions of a few fossil taxa, preliminary results were largely congruent with each other and with previous research on pancrustacean phylogeny. The best-resolved iterations of the analysis had highly reduced taxon sampling including only extant taxa coded for both molecular and morphological data, as well as fossil taxa.

Helcionelloid molluscs from Cambrian Series 2, Stages 3-4 of East Antarctica and outline morphometric approaches to problematic taxonomy

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New problematic helcionelloid molluscs from the Shackleton Limestone (Cambrian Series 2, Stages 3-4) outcropping in the Transantarctic Mountains can be reliably identified to the new *Dailyatia odyssei* Zone of South Australia. Keystone taxa such as the Zone's eponym, *Pojetaia runnegari* and *Mackinnonia rostrata* also allow for increased correlation of East Antarctica to other rock units in East Gondwana as well as Laurentia. Most taxa are represented by relatively poorly preserved steinkerns (internal moulds), reflected in their open nomenclature.
Presented are results of elliptical Fourier analysis of the outlines of steinkerns of *Mackinnonia rostrata* from the Shackleton Limestone and Ajax Limestone (Cambrian Series 2, Stages 3-4, South Australia) and *Mackinnonia taconica* from the Bastion Limestone (Cambrian Series 2, Stages 3-4, North-East Greenland). Principal component analysis of the protoconchs and supra-apical field is capable of reliably ($p<0.05$) distinguishing the three groups. The intraspecific variation uncovered between the *M. rostrata* assemblages is interpreted as incipient speciation.
Problems with helcionelloid identification and taxonomy which hinder reliable biostratigraphy may be solved by techniques such as elliptical Fourier analysis which is sensitive to subtle morphological variation.

Sampling biases constrain interpretation of the fossil records of non-marine lepidosaurs and turtles

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Fossil record quality is a popular topic, with many studies on a variety of vertebrates and invertebrates. Particularly prominent are attempts to 'correct' curves of taxic diversity through time via the use of subsampling techniques, in order to eliminate biases caused by under- or oversampling of the record in space or time. I used Shareholder Quorum Subsampling (SQS) to estimate non-marine lepidosaur and turtle diversity for the Triassic–Paleogene (252–23 Ma). In addition, generalized least-squares regressions (GLS) were used to examine the relationships between diversity and varied combinations of sampling and environmental proxies. The lepidosaur record is more poorly sampled than the turtle record, but both reveal a similar pattern of under-sampling in the southern hemisphere, affecting observed 'global' patterns. At the K–Pg boundary, global lepidosaur diversity decreases, whereas in turtles the transition is negligible. The diversity of both groups fluctuates similarly in response to changing Paleogene climates, and undergoes a global decrease across the Eocene-Oligocene boundary during the Grande Coupure. GLS analyses compared using Akaike weights indicate sampling biases (particularly collection

counts per bin) best explain long-term diversity fluctuations. More work must be done to alleviate geographic sampling biases in both records.

Rotten livers, muscles and guts: controls on exceptional preservation of internal organs

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Exceptionally preserved soft tissues are found in many Lagerstätten and are invaluable in reconstructing ancient life. The most important control on the replacement of organics by authigenic minerals is the generation of suitable geochemical conditions, especially pH, during decay. Studies based on fossil material have concluded that localised organ specific 'microenvironments' must occur within a carcass during decay for exceptional preservation to occur.
Experiments investigating this phenomenon have relied on external conditions around a carcass as a proxy for whether internal conditions are suitable for mineral precipitation. We have designed a novel experiment to investigate the formation of microenvironments inside a carcass in real time. Our experiments demonstrate that (i) internal chemical gradients are more pronounced than immediately around the carcass, (ii) microenvironments are predominantly controlled by the body cavity and not individual organs, and (iii) decaying organs, such as the stomach, have little influence on surrounding tissues and do not cause 'pH-cascades' during integrity failure. Our data also indicate that organ histology is the dominate factor in preferential preservation, explaining the biases seen throughout the fossil record.

Asymmetry of paired endites on frontal appendages in Amplectobeluidae (Radiodonta: stem Euarthropoda) and its taxonomic significance

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The frontal appendage is the main feeding structure and the most well-known part of radiodontans, and thus has been used as the main source of characters in the classification of these putative stem-group euarthropods. The endites (or ventral/inner spines), normally considered as paired on each podomere, are of particular value in taxonomy and autecology. Here we show that, in all known taxa of Amplecotobeluidae, the paired endites on each podomere are conspicuously different in size, contradicting the traditional idea that they are always of the same size. Such asymmetry between the paired endites suggests that the frontal appendage might have had the ability to rotate to some degree. We further argue that the paired endites were particularly differentiated in most taxa of Hurdiidae, forming one row of comb-like endites and one row of 'lateral spines'. This is in contrast to Anomalocarididae, where paired endites were ventral, symmetrical, and equal in shape and size. This differentiation in the size of paired endites in different clades indicates divergence of feeding strategy in early radiodontans, which was accompanied by the differentiation of other feeding structures (such as mouthparts and gnathobase-like structures). Such discoveries offer new characters for discerning the main clades of radiodontans.

Naked chancelloriids from the lower Cambrian of China: evidence for sponge-type growth

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Fossils with extinct character combinations can help reconstruct the origins of modern body plans. Some Cambrian animals, however, have defied phylogenetic placement because of their seemingly irreconcilable anatomies. Chancelloriids are an extinct group of animals with an overall sponge-like habit, but with sclerites that suggest a close relationship to halkieriids and other motile bilaterians, posing a phylogenetic conundrum. Here, we describe new chancelloriid specimens from the lower Cambrian (Stage 3) Chengjiang Lagerstätte that are notable for their weak or even absent spination. A single apical orifice leads to a simple body cavity, in keeping with their sponge-like external anatomy, and the apex bears a tuft of differentiated sclerites, in common with recently described chancelloriids from the Burgess Shale. By considering the microstructure of the sclerites and their distribution across the body, we propose a new model of chancelloriid growth featuring a sub-apical growth zone. Among comparably shaped organisms, this mechanism is shared with particular calcarean sponges. We suggest that chancelloriids are most parsimoniously interpreted as sponges, albeit with convergent spicule-like structures and an unusually robust epidermis. Chancelloriids could therefore shed light on the disparity, development and tissue complexity of early sponges, which occupy a pivotal position in the metazoan tree.

Faunal response to sea level and environmental change in the Jurassic Sundance Seaway, western United States: a stratigraphic palaeobiological approach

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A stratigraphic palaeobiological approach is essential to understand how regional ecosystems respond to sea level and environmental perturbations, a main challenge in palaeoecology. Here we use quantitative abundance estimates, integrated within a sequence stratigraphic and environmental framework, to reconstruct benthic community changes through the 13 myr history of the Jurassic Sundance Seaway. We observe a turnover event at the Middle–Upper Jurassic transition, which coincided with a shift from carbonate to siliciclastic deposition. Turnover was not uniform across the onshore–offshore gradient, but was higher in offshore environments in both carbonate and siliciclastic settings. The higher resilience of onshore communities to third-order sea-level fluctuations and to the change from a carbonate to a siliciclastic system was driven by a few abundant eurytopic species that persisted from the opening to the closing of the Seaway and were not restricted to single depositional environments or sequences. Lower stability in offshore facies was instead controlled by the presence of more volatile stenotopic species. This pattern is consistent with previous observations that shallow-water settings are dominated by abundant, geographically widespread, and environmentally tolerant species. Numerical models suggest that such selection is caused by wide variations in the area of shallow-marine habitat during sea-level change.

The evolution of acellular bone in teleosts: structure-function relationship in fish bone histology

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The skeleton of most teleost fishes shows a peculiar type of acellular bone, in which the main bone cells (osteocytes) are missing entirely. In the literature, acellular bone is considered to be a character of the highly-diverse clade Neoteleostei. However, it is also found in other teleosts, such as pikes (Esocidae), while some neoteleosts such as tunas (Scombridae) have cellular bone. The evolutionary history of the character is therefore complex. We address two main questions: 1) What is the phylogenetic distribution of acellular bone in deep time? 2) Is there a functional explanation to this distribution? We use a dataset of more than 500 fossil and extant taxa, mapped on a time-calibrated tree built from recent molecular topologies to reconstruct the history of acellular bone in teleosts. Acellular bone appeared several times independently, with a main occurrence in Euteleostei

(including Neoteleostei). Tunas are confirmed to have reacquired cellular bone secondarily, possibly due to their endothermic metabolism. We study bone histology for the first time in the opah, another endothermic teleost. It also shows secondary cellularity, with features strikingly similar to those of tuna bone. Thus, functional parameters such as endothermy appear to be linked with histological features in teleost fishes.

The search for physical sedimentary-stratigraphic signatures of ancient life

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Animal, plant and microbial life all influence modern geomorphological landforms through the mediation of rates and scales of processes such as erosion, deposition and sediment transport. The known preservation of relict landforms, translated into the sedimentary-stratigraphic archive as particular combinations of sediment type, bedforms and stratal architecture, implies that there may be a long-term sedimentological record of such interactions, which extends beyond the body or trace fossil record. Here we systematically consider the extent to which the evolution of major groups of organisms may have manifested influences on landscapes throughout Earth history. Particular emphasis is placed on alluvial settings, where the internal stratigraphic architecture of particular geomorphic features is better understood, and frequently occurs at scales that are readily recognised in geological outcrops. The paucity of unmistakably 'biotic' landscape components at this scale presents challenges to the identification of indirect life signatures from individual examples, but is sometimes possible. A more holistic view of the long-term geologic record has the potential to elucidate signatures of life, recorded as the frequency distribution and scale of certain sedimentary associations wax and wane in close stratigraphic synchrony with the evolutionary history of different organism groups.

New insights on the correlation of Permo-Triassic terrestrial faunas of South Africa with those of European Russia

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The mid-Permian to the mid-Triassic is a fascinating period in tetrapod evolution, witnessing the transition from primitive to modern ecological structures and the rise of archosaurs following the apogee of Palaeozoic therapsid faunas. It also encompasses two major extinction events, of differing magnitude, that are evident in both terrestrial and marine environments. This time period is best known from the fossiliferous sequences of the South African Main Karoo Basin and the sedimentary basins of European Russia. Palaeontological studies over the past 15 years have resulted in numerous discoveries that have refined the biostratigraphic framework of both regions, and independent dating methods have been employed that have further clarified the relationship of the two faunal successions. We present a new regional correlation between the faunal assemblages of these high latitude regions, incorporating this new data. Both are defined by mid-Permian faunas dominated by dinocephalian therapsids, after which tetrapods of Gondwanan origin enter Eurasia in the aftermath of the Capitanian mass extinction event, particularly dicynodonts and theriodont therapsids. Following the end-Permian mass extinction temnospondyls diversified in both regions and archosaurs became more common but, by the mid-Triassic, cynodonts were evolving complex postcanine occlusion in Gondwana but had become extirpated from European Russia.

A chondrichthyan-like shoulder girdle in an "acanthodian" helps tease apart early chondrichthyan relationships.

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There is a growing consensus that acanthodians – a collection of prodigiously fin-spined, Palaeozoic fishes – are in fact some of the very earliest relatives of living chondrichthyans (sharks, rays, and elephant sharks). This places acanthodian anatomy in a uniquely important position to inform our understanding of jawed vertebrate evolution. While this phylogenetic status is now well supported, uncertainty about stem-chondrichthyan intrarelationships leave questions of stepwise character evolution poorly resolved. Here we present new information on the Lochkovian (Early Devonian) acanthodian *Vernicomacanthus uncinatus*. We show that the shoulder girdle of *V. uncinatus* is unique among acanthodians in the possession of a prominent posterolateral angle—a character previously known only in Palaeozoic "sharks". Alongside this are a number of chondrichthyan and gyracanth-like aspects of the dermal anatomy. Using this information, as well as novel information on the shoulder girdles of the acanthodians *Ptomacanthus* and *Diplacanthus*, we reassess the morphology of the acanthodian shoulder girdle and build a new phylogenetic dataset spanning the chondrichthyan total-group. Using this we test possible schemes of relationships amongst stem-chondrichthyans and assess the resulting implications for stepwise character evolution in chondrichthyans.

A model for marine reptile taphonomy in the Late Jurassic Slottsmøya Member Lagerstätte

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The completeness of the fossil record has received renewed interest in the last years, with amongst others large-scale models for dinosaur and marine reptile diversity and preservation through the Mesozoic. To make these globally applied algorithms more accurate, the preservation and biases of the fossil record need to be addressed also on a local scale: How can the preservation of each specimen be explained and how does taphonomical history vary through time? How is the vertebrate record coupled to the preservation potential of remainders of the ecosystem?
To do so, excavations needs to be undertaken with detailed stratigraphic control and a holistic approach. In the Late Jurassic Slottsmøya Member Lagerstätte, Spitsbergen, the taphonomy and ecosystem evolution can be studied through 12 million years in one site. 60 plesiosaurian and ichthyosaur specimens are described with respect to articulation, landing mode, preservation, predation and scavenging. Their stratigraphic distribution is analyzed and a correlation is found between high TOC, low oxygen levels, low benthic invertebrate density and optimal skeletal preservation. Marine reptile elements are broken and brittled, but surprisingly three-dimensional for the known compaction rate. In the proposed taphonomical model the thoroughly described methane seep communities is one key factor for this result

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Differences in extinction rates explain contrasting regional diversity patterns in modern tropical bryozoans

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Marine biodiversity surrounding the Indonesian Archipelago is several times higher than anywhere else but why this is true is unknown because of poor historical data. To address this, we compared the fossil records of cheilostome bryozoans from Indonesia versus the Caribbean, regions that differ several-fold in species richness today. Cheilostome diversity was strikingly similar in the two regions until the end of the Miocene 5.3 Ma, so that the modern disparity must have developed more recently. However, the Miocene faunas were ecologically very different, with a greater proportion of erect and free-living species in the Caribbean. Our results support the

hypothesis that modern differences in diversity arose primarily from differential extinction of Caribbean erect and free-living species due to oceanographic changes associated with uplift of the Isthmus of Panama, rather than exceptional rates of diversification in the Indo-Pacific.

Long-term mammalian stable isotope record across the Great American Biotic Interchange

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The South American late Cenozoic fossil record provides a unique natural laboratory for the study of mammalian paleoecology in the context of changing biotic and abiotic forces. South America remained largely isolated from other continents for more than 50 Myr. First, the presence of emerging land and then, the permanent establishment of the Isthmus of Panama (~3.1–2.7 Ma) triggered an interchange of terrestrial taxa with North America, an event known as the Great American Biotic Interchange (GABI). We investigate resource use through stable isotope analysis of mammals from a long-term fossil record from the Pampean Region (La Pampa and Buenos Aires provinces, Argentina) spanning from ~9 Ma to ~12 Ka. Our analyses point to a major shift in resource use by most of endemic herbivorous taxa, as they switched from a pure C_3 diet to a mixed C_3-C_4 diet at the Late Miocene-Early Pliocene. Carnivorous taxa mirrored this shift, with endemic Sparassodonta consuming prey from pure C_3 environments, whereas immigrant Felidae preferred prey from mixed C_3-C_4 areas. Flexible dietary behavior (e.g., gomphotheres, equids), as indicated by our stable isotope data, may have facilitated the successful settlement of some immigrant groups in the Pampean area.

Skull development and biomechanics in the coelacanth *Latimeria*; implication for fossil coelacanths and fossil lobe-finned fishes

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The coelacanth *Latimeria* is the only living vertebrate that retains an intracranial joint (IJ), which enhances the biting force during feeding. In adults, the brain represents 1% of the endocranial volume (EV), and lies posterior to the IJ. By contrast, the brain spans the IJ in younger individuals and represents a more substantial EV. We investigated whether the dramatic changes in the position and relative size of the brain during *Latimeria* growth allow for protecting the brain from higher loadings generated by the IJ during biting in adults. We simulated muscle activity and joint-reaction forces during biting using Multibody Dynamics Analysis, and calculated the stresses and strains in the skull and brain with Finite Element Analysis (FEA). Stresses and strains are low in the adult brain, but clearly higher when it is replaced by the juvenile brain that has been scaled to the EV of the adult, and spans the IJ. Our results hence suggest that the evolution of a biting-enhancing mechanism involving the IJ in fossil coelacanths, and potentially in other sarcopterygian "fishes", could have imposed major constraints on brain evolution.

An enigmatic amphibian from the Early Cretaceous of Japan

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Albanerpetontids are small enigmatic salamander-like amphibians with a fossil record extending from the Middle Jurassic to the Pleistocene. Although there are a few articulated (but crushed) specimens from the Early Cretaceous

of Spain and Italy, most of the record is based on 3-D microfossils representing a few characteristic elements. Consequently the anatomy, and thus phylogenetic position, of these amphibians remains poorly understood, as does their palaeobiogeographic history. The first and last records are from Europe, but albanerpetontids are a consistent presence in North American microvertebrate deposits from the latest Early Cretaceous until the Palaeocene. Given their apparent absence in Asia prior to the Late Cretaceous, it has been suggested that albanerpetontids dispersed from North America into Asia with the opening of the Bering land bridge.

New material from the Early Cretaceous Kuwajima Formation of Japan offers new perspectives. High resolution micro-CT scanning of a key specimen has revealed an association of exquisitely preserved skull and postcranial elements, many of which were previously unknown. Moreover, phylogenetic analysis places the Japanese taxon as a relatively derived albanerpetontid. Its presence in Asia in the Early Cretaceous, prior to the first appearance of the group in North America, falsifies the America-first hypothesis.

Mosiacism, development, and the early evolution of birds

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The discovery of *Archaeopteryx*, the first bird, inspired the term "mosaic evolution," describing the presence of ancestral and derived characteristics within a single organism. This requires that traits evolve semi-independently, responding to selection at different rates. Mosaic evolution has been influential in shaping avian evolution. For example, the early adaptive radiation of birds has been attributed to the dissociation of the forelimb, hind limb, and tail, which allowed for independent ecomorphological specialization of each of these regions. Here, we use high-dimensional geometric morphometric data to examine the degree to which the avian skull can be divided into semi-autonomous regions (modules) and the tempo and mode of evolution in each module. We show that that the skull is highly modular and that each module exhibits unique punctuated bursts of evolution occurring in different lineages. Evolutionary rate and disparity in each cranial module is found to be associated with embryonic development: modules with complex developmental origins (multiple cell populations) have higher rates and disparity. Finally, we reconstruct a 3D model of the cranial phenotype at the root of crown birds, generating a hypothesis of the ancestor of all modern birds. These results demonstrate the importance of intrinsic factors in shaping large-scale evolutionary patterns.

Newly discovered complete skull of *Ichthyornis* reveals unforeseen mosaicism late in the dinosaur-bird transition

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The Late Cretaceous toothed avialan *Ichthyornis dispar* represents one of the closest Mesozoic relatives to crown-group birds, and since its initial description in 1872 has provided critical information on the biology of birds preceding the evolutionary radiation of crown clade Aves. Despite continued work affirming its evolutionary importance, no substantial new cranial material of *I. dispar* has been reported since the 19th Century. Furthermore, Jurassic and Cretaceous lagerstätten that have yielded the most evolutionarily informative Mesozoic bird fossils typically preserve crushed and distorted skulls, severely limiting our understanding of non-avian ornithuromorph cranial morphology. Here we report four new specimens of *I. dispar* bearing cranial remains, including a new, extraordinarily complete skull and two previously unrecognized elements from the holotype. We found that *I. dispar* exhibited a transitional beak – small, lacking a palatal shelf, and restricted to the tip of the jaws – coupled with a crown-like kinetic system. The brain was relatively modern but the temporal region, poorly known in most non-avian avialans, was surprisingly archaic and deinonychosaur-like, bearing a large adductor chamber bounded dorsally by substantial bony remnants of the upper temporal fenestra. The far-crownward persistence of this temporal configuration demonstrates unforeseen complexity during the modernization of the avian skull.

Earthquakes and palaeontology. A case of shallow and deeper marine environment mixing from Crete (Greece)

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The latest Zanclean eastern Mediterranean molluscan record is revealed through the study of a 60m thick stratigraphic sequence near the village Voutes (Heraklion Basin, Crete, Greece). Forty-two species of bivalves and gastropods have been identified, 31.7% of which are no longer present in the Mediterranean. Bathyal zone deposits were recognized by the macrofaunal analysis. Strong mass-wastings were found to have formed a series of sand lenses on the lower part of the section. These lenses have distinctive sedimentological attributes and contain a fauna typical of coastal zone. The origin of these mass-wasting deposits has long been enigmatic but could be related to an uplift which started in Crete as early as ca 5 Ma (latest Zanclean). These possibly earthquake-triggered sandy slides indicate the transportation of material from the coastal zone to the upper bathyal zone.
Sand lenses contained molluscs indicate the infra to circalittoral zone, as biocoenoses of vegetated and gravelly bottoms were recognized. Some of the most characteristic bivalves of bathyal zone as Leda clavata, Ledella nicotrae, Yoldia nitida, Bathyarca philippiana, Limea strigilata and Kelliella ruggierri are reported in the Pliocene of Greece for the first time.

A new ray-finned fish from the late Devonian: fresh insights into the rise of actinopterygians

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Actinopterygians comprise 50% of living vertebrate diversity, with an evolutionary history extending back nearly half a billion years. However, fundamental issues preclude a robust understanding of their early history. Specifically, issues abound regarding the origin of the living radiations, as well as the effects of the end-Devonian mass extinction on the group as a whole. Here we present a new articulated actinopterygian from the Late Devonian 'Chemung facies' of Warren, Pennsylvania, USA. First reported by Eastman as *Rhadinichthys* sp. in the early 20th century, this small (ca. 60 mm total length) individual is largely complete, but critical anatomical details, especially of the head, remain obscured by matrix. MicroCT scanning reveals suprising anatomical detail, including a nearly intact cranium. This taxon displays surprisingly derived features for a Devonian actinopterygian, including an unfused dermohyal, multiple suborbitals and an opening in the aortic canal along its ventral midline. Phylogenetic analysis places the Warren actinopterygian among post-Devonian forms, and implies the divergence of many lineages prior to the Devonian-Carboniferous boundary. These results have important implications for patterns of evolution early in actinopterygian history, and the impact of the Hangenberg mass extinction on ray-finned fishes.

The positive influence of continuous characters and extended implied weighting on phylogenetic reconstruction: a crocodylian case study

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Morphological characters have traditionally been coded into discrete categories for phylogenetic reconstruction. Recently, however, the use of continuous characters such as ratios and angular measurements has become more

prevalent, although it remains rare. Here we used the crocodylomorph clade Neosuchia to test the impact of continuous data on fossil and extant phylogenies. With their complex evolutionary history and widespread homoplasy in several longirostrine (long-snouted) groups, neosuchians offer an excellent opportunity for studying the influence of new characters on phylogenetic reconstruction. We created a new data set of 84 continuous and 487 discrete characters scored for 106 neosuchian and outgroup taxa, which was analysed using Maximum Likelihood with and without extended implied weighting (EIW) in TNT and Bayesian Inference in MrBayes for a rediscretised data set. Both methods exhibited no notable differences when using rediscretised data without EIW, providing lower overall tree resolution than continuous character analyses and no separation of longirostrine clades. In contrast, our results show that use of continuous data and EIW successfully separates longirostrine clades in Neosuchia, improving overall tree resolution. This study demonstrates the usefulness of continuous data and EIW not only in phylogenetic reconstruction but also in successfully dealing with rampant convergence in morphological evolution.

Oxygen minimum zones in the early Cambrian ocean

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The relationship between the evolution of early animal communities and oceanic oxygen levels remains unclear. In particular, uncertainty persists in reconstructions of redox conditions during the pivotal early Cambrian (541-510 million years ago, Ma), where conflicting datasets from deeper marine settings suggest either ocean anoxia or fully oxygenated conditions. By coupling geochemical palaeoredox proxies with a record of organic-walled fossils from exceptionally well-defined successions of the early Cambrian Baltic Basin, we provide evidence for the early establishment of modern-type oxygen minimum zones (OMZs). Both inner- and outer-shelf environments were pervasively oxygenated, whereas mid-depth settings were characterized by spatially oscillating anoxia, within zones of higher productivity and correspondingly higher oxygen demand. This picture of a spatially restricted anoxic wedge contrasts with prevailing models of globally stratified oceans, offering a more nuanced and realistic account of the Proterozoic-Phanerozoic ocean transition, which bears importantly on models of early Earth oxygenation.

Jurassic onychites (arm hooks from squid-like cephalopods) associated with the statolith occurrences in the Wessex Basin, southern England

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Modern coleoid (squid-like) cephalopods have arms that carry arrays of both suckers and hardened, organic hooks. Fossil arm hooks have been known since the work of Sternberg in 1823, but it was Kulicki & Szaniawski in1972 who described 22 hook parataxa from the Jurassic of Poland. Exceptional soft-bodied preservation of species such as *Belemnotheutis antiquus* from the Callovian-Oxfordian of the United Kingdom has allowed the identification of the host animal of some parataxa, though the majority remain un-attributable. In the Christian Malford lagerstätte (Upper Callovian) of Wiltshire large numbers of hooks (including forms described as *Acanthuncus*, *Arites*, *Deinuncus*, *Falcuncus*, *Longuncus* and *Paraglycerites*) are found associated with an abundance of statoliths (cephalopod 'ear bones') and macrofossil evidence of both belemnites and teuthids, some of which includes exceptional soft-bodied preservation. Using reference material in various museum collections it is possible to document the variation in hooks in both single species and between species, and this has enabled isolated hooks found in microfossil residues to be used to determine the presence of species in the absence of body fossils.

The Downton Bonebed: insights into a lost world

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The Downton Bonebed is a multitaxic Fossil Concentration-Lagerstätte located in the Platyschisma Shale Member of the Downton Castle Sandstone Formation c. 1.5 m above the Ludlow Bonebed. The Downton Bonebed has received little direct study since its discovery over a century ago. The aims of this study were to catalogue for the first time the fossil contents of the Downton Bonebed, and to look at the sedimentology to define the depositional environment that the bonebed formed in, as well as its wider global context. The bonebed is rich in fossils with a broad diversity of vertebrates, invertebrates, plants and allies; however with each group the diversity is low, suggesting that the Downton Bonebed was formed in a restricted environment. The sedimentology reveals evidence of two energy conditions shifting between quiet low energy setting with trace fossils present and periods of rapid burial in which all of the other fossils are found associated with swaley and hummocky cross laminations suggesting large storms. The environmental setting for the Downton Bonebed is a quiet hyposaline inlet/lagoon in close proximity to a terrestrial freshwater source, cut off from the Downton Sea by a barrier or barrier beach.

Coupling palaeoclimate data and numerical climate models to constrain Cambrian palaeogeography

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The Proterozoic/Phanerozoic transition was characterised by major biological changes, including increasing metazoan mineralization and mobility, with profound consequences for geochemical cycles and the physical environment. However, our understanding of the co-evolution of the environment and the biosphere throughout the Cambrian radiation is hampered by loose constraints on the global palaeogeographic context. Here we couple palaeoclimate models and proxy data to evaluate the viability of contrasting Cambrian continental reconstructions proposed in the literature. We focus on two configurations that may be considered 'end-members' on the spectrum of Cambrian palaeogeographies, with Gondwana either spanning the full range of Southern palaeolatitudes or lying along the equator. We simulate potential climatic conditions associated with each reconstruction by running a general circulation model under a wide range of greenhouse gas levels and orbital configurations. We compare model outputs to a new database of early Cambrian palaeoenvironmental data. Scoring of the model agreement with geological data allows us to determine which continental configuration most plausibly represents the Cambrian world, and also identify regions where improvements to palaeogeographic reconstructions or model simulations are needed. This study reaffirms the coupling between numerical climate models and geological climatic data as a fundamental tool to refine deep time palaeogeographic reconstructions.

What were the Ediacaran biota? Answers from the Chengjiang Lagerstätte

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Since the Lower Cambrian, frondose fossil *Stromatoveris psygmoglena* was described from eight specimens (Shu, Conway Morris and Han 2006), more than two hundred new fossils have been discovered from the Chengjiang Lagerstätte by researchers at Northwest University, China. These specimens reveal exceptionally preserved

anatomical details, which enable phylogenetic reconstruction of the relationships between *Stromatoveris*, iconic Ediacaran taxa and the extant phyla. Further to this, chemical analysis of exceptionally preserved *Stromatoveris* body tissue forms an independent line of evidence on original composition, affinities and modes of preservation. These results provide insights into the nature of hitherto enigmatic Ediacaran macro-biota, linking them to the more familiar taxa and ecology of the Cambrian.

An Early Ordovician somasteroid from Morocco reveals the origin of crown-group Echinodermata

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The early evolution of asterozoans remains uncertain given the difficulty of comparing the ossicle organization of the endoskeleton in diverse groups of Lower Palaeozoic ancestors. The Extraxial-Axial Theory proposes the homology of the biserial ambulacral ossicles based on embryonic and ontogenetic data, but its broader implications for informing the deep origin of crown-group Echinodermata have not been tested under a comprehensive phylogenetic framework. We describe an early asterozoan from the Ordovician Fezouata biota, Morocco. Despite the presence of typical somasteroid features, such as offset ambulacrals, a virgal series composed of simple ossicles, it is unique in the absence of an axially-oriented ossicle series along the body margins. Bayesian and parsimony-based phylogenetic analyses resolve this specimen in a basal position within total-group Asterozoa, illuminating the ancestral morphology of this clade. Somasteroids comprise a paraphyletic grade with stem-group Asteroidea, whereas stenuroids are paraphyletic within stem-group Ophiuroidea. Asterozoa and Crinoidea are united by the synapomorphic extension of the body wall into the free appendages. These findings clarify the contentious phylogenetic relationships between crown-group Echinodermata and its Cambrian stem lineage, which includes sessile forms with incipient pentarradial symmetry. Pelmatozoan monophyly is not supported and instead blastozoans represent the most likely sister-taxon to crown-group Echinodermata.

The murky history of Cenozoic coral reefs in the Coral Triangle

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The Coral Triangle region of Southeast Asia contains the most diverse marine ecosystems on Earth. To date most of the mechanisms proposed to explain this hotspot remain untested due to a lack of paleontological data. However, new large-scale studies of Late Cenozoic reef corals from Eastern Borneo reveal that the first coral assemblages that occurred in the region were mainly low-relief patch reefs that developed in environmental conditions of low light and high sediment inputs. These shallow turbid habitats hosted a high coral diversity with 100 species of 55 genera in the Oligocene and 234 species of 79 genera in the Miocene. We found no significant faunal turnover at generic level within the studied time interval as 85% of extant genera were already present by the early Miocene. Preliminary comparisons of coral faunas from ancient turbid reefs with analogous modern habitats of Eastern Borneo show similarities. Our observations suggest that turbid reefs have played an important role during the origination and maintenance of coral diversity in the Coral Triangle. Most importantly, there is increasing evidence that these so-called 'marginal' habitats may act as crucial ecological refugia as Coral Triangle ecosystems respond to ongoing anthropogenic environmental change.

Phylogenetic position of a new Late Cretaceous duck-billed dinosaur (Hadrosauroidea) from the Dorotea Formation, Chilean Southern Patagonia

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A new species of a hadrosauroid dinosaur has been discovered in the Dorotea Formation (Maastrichtian) in Southern Chile, representing the first non-Argentinian hadrosauroid. In order to establish its phylogenetic relationships we use the matrix of Xing *et al* (2014) for the Parsimony and Bayesian Inference analyses. The new taxon is unique in having: (1) a prominent mediolaterally extended sacral ridge, projecting medioventrally from the medial face of the preacetabular process, extending across the entire dorsal margin of the iliac plate and covering the entire medial face of the preacetabular process. It reaches a maximum depth of approximately half the height of the ilium, level with the transition from the preacetabular process to the iliac plate; (2) craniolaterally a strongly deflected preacetabular process is, reaching an angle of 62° with the longitudinal axis of the supraacetabular process. The phylogenetic results suggest that the new species is a hadrosauroid no-hadrosaurid, increasing the diversity of South American hadrosauroids and it is the southernmost record for this group in South America. The specimen represents one the latest occurrences of hadrosaurian dinosaurs in South America and provides additional evidence for the discussion of the paleobiogeographical events that explain the existence of contemporary hadrosaurs in Antarctica.

Is parsimony dead? Bayesian and parsimony phylogenies tested using both empirical and simulated morphological data

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All evolutionary inferences require reliable phylogenies. Morphological data has traditionally been analysed using parsimony methods, whilst likelihood methods are more commonly applied to molecular data. Recent simulation studies have suggested, however, that the Bayesian Mk-model is more accurate for morphology analyses. This is potentially problematic as very different trees can be derived using these methods. Here we simulate data under two distinct models. The first uses the fossilised birth-death process to build trees and matrices. The second uses selection of digital organisms in a mutating fitness landscape. In addition to these simulated data, 31 independent empirical datasets were used to compare trees derived from molecular data (using a priori specified models) with trees derived from morphological data through Bayesian and parsimony searches (including both equal and implied weighting). For all comparisons we used both Robinson-Foulds and SPR tree distance metrics. The results of these independent analyses are in conflict: simulation studies suggest that parsimony outperforms Bayesian, whereas empirical data finds higher congruence between molecules and morphology analysed under Bayesian inference. How these results are applied to tests of evolutionary hypotheses depends upon the confidence placed in the realism of simulations versus the reliability of empirical molecular data.

Three-dimensional priapulid trace fossils from the early Cambrian (Series 2, Stage 4) of Sweden

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Of the few occasions that Cambrian ecosystems can be reconstructed with a certain amount of fidelity, fossil scalidophoran worms have constituted a dominant component. Their role is widely recognized as key actors in these ecosystems as prolific burrower-bioturbators and predators. The lower Cambrian Mickwitzia Sandstone Member from southern Sweden contains one of the most diverse and well preserved Cambrian (Stage 4) shallow marine ichnofacies representing a diverse faunal assemblage. The fine scale fidelity of preservation of traces in these rocks is of considerable significance often recording sub-millimetre scale impressions of the producer's external anatomy and burrowing toolkit. Moulded impressions of worms found in outcrops of the Mickwitzia Sandstone that preserve a remarkable amount of anatomical detail of the producer permit assignment of traces to much lower taxonomic ranks. Comparisons with the morphology and architecture of extinct priapulids, as well as the locomotory and burrowing behaviour of extant priapulids demonstrates that these traces are assignable to stem-priapulid, or at least scalidophoran producers. This indicates that priapulids where ubiquitous in Cambrian marine environments and present in diverse ecosystems. They occupied a variety of niches including well oxygenated subtidal ecosystems and were only later displaced to their current range possibly through competition.

Evidence for a rapid recovery of snakes following the Cretaceous-Paleogene mass extinction

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The Cretaceous-Paleogene (K-Pg) mass extinction event saw the demise of non-avian dinosaurs, pterosaurs, and mosasaurs, amongst numerous other groups, but its aftermath also stimulated major radiations in multiple vertebrate clades. Rapid post-extinction radiations have been documented in mammals, birds, frogs, and teleosts, however the influence of the K-Pg on the evolution of snakes is poorly understood. We investigated this using a molecular clock approach, and demonstrate that all snakes descend from five boundary-crossing lineages, and Alethinophidia, the clade comprising the majority of modern snake diversity and disparity, underwent a rapid diversification in the early Paleogene. We used a novel supermatrix representing 169 species coded for up to 52 loci, with numerous outgroup taxa included to control for rate heterogeneity within the ingroup. Divergence time analyses were performed under a variety of parameterisations, outgroup topologies, and calibration sets, using both Bayesian and Maximum Likelihood methods. Our inferred association between the K-Pg event and the subsequent diversification of Alethinophidia provides evidence of the importance of this mass extinction in shaping Earth's modern vertebrate faunas. Additional analyses of the disparity of Cretaceous and Paleogene snakes, and ancestral state reconstructions, suggest that fossoriality and small size contributed to snake survival across the K-Pg boundary.

Breathing life into an extinct sea scorpion: revealing the gill structure of a three-dimensionally preserved eurypterid through MicroCT scanning

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Exceptionally preserved fossils provide unique windows into the lives of extinct organisms, revealing interactions between species, behaviours frozen in time, and parts of animals that were previously unseen. These fossils allow us to reconstruct long-dead animals as living creatures and place them on the tree of life. Eurypterids were important members of Palaeozoic ecosystems, filling a wide variety of ecological roles. While the external morphology of eurypterids is well-understood, we know very little about their internal anatomy, largely due to the fact that most specimens are compressed into flattened impressions. We use MicroCT to reconstruct the internal structures of an exceptional eurypterid fossil from the Hunterian Museum in Glasgow, preserved inside a concretion, and showing unique three-dimensional preservation of internal structures. Most notably, the Glasgow specimen preserves the gills, which can provide information about whether eurypterids were active predators like

scorpions or scavengers like modern horseshoe crabs. The gills may also hold the key to discovering whether eurypterids are more closely related to horseshoe crabs or arachnids. Our preliminary results indicate that eurypterids had horizontally oriented book gills similar to xiphosurans and that their gills had a surface area equivalent to that of modern active marine organisms.

Re-evaluating the function of cephalopod septa

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Ammonoids are an extinct group of cephalopods whose shells have been used to reconstruct palaeoecology, macroevolutionary trends, and interpret geochemical data. However some fundamental aspects of their palaeobiology, such as habitat depth and mode of life, are poorly understood. One traditional method to estimate habitat depth is using the complex morphology of the highly curved, multi-lobate septa. Hypotheses state the increased complexity of these structures increase the resistance of the shell to implosion from hydrostatic pressure, thus forms with more complex sutures inhabit deeper waters. Evidence of this mechanical function is limited to theoretical mechanical models, the results of which directly have contradicted each other. We circumvent these problems by combining high-resolution computed tomography and finite element analysis to test different septal morphologies against a constant hydrostatic pressure. Based on the tested morphologies, septal complexity does not strengthen the shell against water pressure; furthermore, increasing the amplitude of septal folds increases the stress developed within the septa rather than decreasing it. More complex septa do show decreased stress under point loading compared to simpler septa. These results challenge the traditional interpretation of the function of septal complexity in ammonoids and the indices developed to calculate habitat depth from septal geometry.

A 3.77 (or possibly 4.28) billion year history of microbial communities associated with marine hydrothermal vents

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Modern hydrothermal vents provide diverse environments for microorganisms. Here there is a large phylogenetic and physiological diversity of bacteria and archaea, occurring in a wide range of habitats. An assumption is that similar communities of microorganisms have been present on Earth for an extremely long time, given that there is direct evidence of marine hydrothermal activity going back to the Archaean eon (which began 4 billion years ago), and the hypothesis that life may have originated in these environments. In this presentation I will review the fossil record of microorganisms at hydrothermal vents, which comes from two different rock types: volcanogenic massive sulfides (VMS), which formed at high temperature vents, and jaspers (iron-silica rocks), which formed at low-temperature, sulfide-poor vents. Occurrences of microorganisms in VMS go back to the Paleo-archaean era (3.235 billion years ago) and in jaspers to the Eo-archaean (3.770, or possibly 4.280, billion years ago), with the latter being the oldest organisms yet discovered on Earth. These very dates suggest that life may have been possible on Mars during its equivalent aged warmer period, and that life may be found at putative hydrothermal sites on the icy moons with liquid oceans (e.g. Europa and Enceladus).

Colonies, clones and modularity: a new view of Ediacaran fronds

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The Rangeomorpha and Arboreomorpha include some of the oldest large, macroscopic organisms in the fossil record, with specimens capable of attaining lengths approaching two metres. The seemingly rapid acquisition of large size in these groups has been widely assumed to stem from an underlying morphogenetic simplicity. However, the detailed morphology of many of these organisms remains poorly constrained, rendering assumptions about morphogenesis and phylogenetic placement premature.We here present morphological, morphogenetic and palaeoecological evidence to suggest that Ediacaran frondose taxa may variously have had modular, colonial and, perhaps, clonal body plans. Reassessment of Arborea from South Australia reveals a distinctive arrangement of internal anatomical structures that connect individual external branch units to the interior of the organism, consistent with a colonial construction. Filamentous structures amongst frond-bearing fossil assemblages worldwide reveal that rangeomorphs could be physically interconnected to other individuals of the same species by enduring stolon-like structures, over distances of tens of centimetres to metres. Furthermore, new morphogenetic data from several multifoliate rangeomorphs reveal potential evidence for biological modularity. Taken together, this information enables us to offer an alternative colonial hypothesis to explain the rapid transition to large body size in the middle Ediacaran.

High diversity of small dinosaurs preceding the Cretaceous-Paleogene (K-Pg) mass extinction

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Dinosaurs dominated terrestrial ecosystems for over 100 million years, before disappearing at the end of the Cretaceous. It is thought that latest Cretaceous faunas were low in diversity and dominated by large species, suggesting a decline in dinosaur diversity preceding the K-Pg boundary. However, small dinosaurs are undersampled and understudied, and so their apparent low diversity could be an artefact of sampling and study biases. Here, it is shown that alongside the giant *T. rex* and *Triceratops*, a diverse fauna of small dinosaurs thrived in the Maastrichtian, including previously unrecognized taxa of Dromaeosauridae, Troodontidae, Caenagnathidae, Alvarezsauridae, Thescelosauridae and Leptoceratopsidae. Total diversity includes roughly 40 species ranging from 2 kg to 50,000 kg, occupying carnivorous, herbivorous, insectivorous, and piscivorous niches. An analysis of functional diversity shows that ecological niche occupation increased rather than decreased from the Late Campanian to the Late Maastrichtian in the Western Interior, driven by the immigration of new taxa such as alvarezsaurids and titanosaurians. These patterns reject a diversity decline, and suggest that dinosaurs remained ecologically diverse until the end of the Cretaceous. These findings are consistent with a catastrophic extinction at the end of the Maastrichtian coinciding with, and driven by, the Chicxulub asteroid impact.

Molecular clocks on Chelicerata recover monophyly of mites and arachnids and suggest an early colonization of land

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Animal life has marine origins, with only few phyla completing their entire life cycle outside water. The process through which organisms adapt to life on land is known as terrestrialisation, and it is one of the most extreme cases of adaptation. The chelicerates (pycnogonids, horseshoe crabs, spiders) are an ancient group of arthropods, with an astonishing fossil record dating back to the Cambrian, and includes the second largest clade of fully terrestrial organisms, the arachnids. Whereas morphological phylogenies support a single land colonization, phylogenomic studies support multiples by nesting marine horseshoe crabs within terrestrial arachnids. Here, we present a timescale for Chelicerata aiming to test how many times and when arachnids adapted to life on land. We used an expanded multigene dataset covering most chelicerate diversity and the largest set of fossil calibrations to date. Our results recover monophyly of Chelicerata, Euchelicerata and Arachnida, suggesting a single terrestrialization event. Furthermore, we found Acari as monophyletic (Parasitiformes+Acariformes) and recover Tetrapulmonata (Araneae+Pedipalpi) in alliance to Scorpiones (Arachnopulmonata) or allied to a clade composed

by Scorpiones+Pseudoscorpiones. Our results reconcile previous results based on morphology and molecular evidence, and suggest a Cambrian-Ordovician colonization of land by arachnids, substantially predating trace or body fossil evidence.

Increased disparity in Therapsida coincides with emergence of novel ecologies, Cistecephalidae (Therapsida: Anomodontia) as a case study

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Synapsid evolution can be characterized by three successive radiations: the Permo-Carboniferous pelycosaurs, the Permo-Triassic Therapsida, and finally the Late Triassic Mammaliaformes. While descriptive studies suggest increased morphological disparity concurrent with the rise of therapsids, no work has compared disparity across the entire interval. We present detailed analysis of shape disparity in synapsid humeral elements of the majority of pelycosaur and therapsid groups, and a selection of Triassic cynodonts. Clades were analyzed for Procrustes variance, in 5 million year time bins from 305 - 235 Ma (Carboniferous - Triassic). We found that pelycosaurs show lower disparity than therapsids, and increased disparity coincides with the emergence of Therapsida. Macroevolutionary changes observed in Therapsida have historically been associated with ecological diversification. To confirm associations between clade-wide dynamics and novel ecomorphologies, we conducted comparative geometric and linear morphometric analyses on pelycosaurs, therapsids, and extant tetrapods, with emphasis on the therapsid family Cistecephalidae - small arguably fossorial dicynodonts. We found that Cistecephalidae morphospace is unoccupied by any known pelycosaur group, and the expansion of therapsid morphospace is associated with novel synapsid ecomorphologies such as that of Cistecephalidae. This provides evidence that increased disparity associated with novel ecomorphologies may have been critical to the evolutionary success of early Synapsida.

The earliest evidence of metazoan symbiosis

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The Cambrian Explosion represents a major metazoan radiation event, which is reflected in the dramatic increase of both taxonomic and ecological diversity. In light of recent fossil discoveries from exceptionally preserved Cambrian lagerstätten, the ecological complexity and trophic structures of these Cambrian marine communities has been further revealed. Here we will present the newly discovered worm species, *Inquicus fellatus* gen. et sp. nov, which infested the Cambrian scalidophoran worms *Cricocosmia* and *Mafangscolex*, representing the earliest examples of aggregate infestation, host specificity and host shift in metazoans. The exact taxonomic affinity of *I. fellatus* and the nature of its symbiotic relationship with *Cricocosmia* and *Mafangscolex* will be further discussed. Other examples of metazoan symbiosis from Cambrian communities and their ecological and evolutionary implications will also be further explored.

The ‘pliable’ nature of the phylogenetic relationships within early ornithopods

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Neornithischians were a major clade of herbivorous dinosaurs that existed from the earliest Jurassic to the latest Maastrichtian. During their long evolutionary history, neornithischians diverged into several highly distinctive clades, including ceratopsians, pachycephalosaurs, and hadrosaurids. However, the origin and the early evolution of Neornithischia, and the phylogenetic relationships of the taxa situated near the base of the clade, remain somewhat elusive. This especially applies for those taxa traditionally placed at the base of Ornithopoda. Recent recognition of a new basal ornithopod from the Cenomanian of the Czech Republic prompted a re-evaluation of the phylogenetic relationships among neornithischians situated outside of Marginocephalia and Ankylopollexia. A phylogenetic analysis reconstructed a diverse Elasmaria as a basal clade within Ornithopoda. At the same time, it inferred *Hypsilophodon foxii* outside of Ornithopoda as the sister taxon to Cerapoda. These results continue an ongoing trend of the removal of subsets of taxa traditionally dubbed as 'hypsilophodontids' from the base of the ornithopod branch of the Neornithischia to outside of Cerapoda. However, the position of these former 'hypsilophodontids' remains highly pliable between analyses depending on the data sampling, and the tree-search strategies used. Therefore, the changing positions should be viewed cautiously until a consensus is reached.

Sporadic sampling not climatic forcing drives early hominin diversity

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The role of climate in the origin and diversification of early hominins is hotly debated. Much of this debate has centred on whether change in the early hominin fossil record is continuous or pulsed, and whether diversification is causally linked to directional shifts in climate or climatic instability. Yet, in all previous studies, fluctuations in the number of hominin taxa are accepted as genuine changes in diversity, even though it is possible that such fluctuations reflect changes in the quality of their fossil record. We present a detailed examination of early hominin diversity dynamics through time, including both taxic and phylogenetically corrected diversity estimates, and compare these estimates to sampling metrics for rock availability and collection effort. Taxic diversity, primate-bearing formations, and collection effort strongly correlate, suggesting some features of hominin diversity may represent sampling biases rather than a genuine evolutionary signal. Peak diversity at 1.8 Ma is a sampling artefact, reflecting maximal rock availability and collection effort. Phylogenetic diversity estimates imply peak diversity at 2.4 Ma, and show little relation to sampling. We find no evidence of pulsed turnover in the early hominin fossil record and conclude that the appearance of pulsed change is an artefact of uneven sampling.

Stomata, carbon isotopes and past CO_2 reconstruction: a critical comparison of fossil plant based CO_2 proxy models and methods

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Over the past decade new stomatal proxy methods and models have been developed to estimate palaeo-amospheric carbon dioxide concentration (pCO_2) from fossil plants. These include mechanistic models which are founded on existing knowledge of plant photosynthetic and stomatal conductance responses to pCO_2 and empirical models of plant stable carbon isotope discrimination and pCO_2 derived from experimentation with the model angiosperm taxon *Arabidopsis*. Few experimental tests have been conducted on the efficacy of these novel pCO_2 proxy methods using multiple species of varied phylogenetic origin. Fewer still have undertaken cross comparison studies through the application of multiple CO_2 proxy methods to the same experimental plant material growing in known CO_2 concentrations. This presentation will briefly review all new stomatal and plant stable carbon isotope based proxy CO_2 methods and present new results on a cross comparison test of their accuracy when applied to 10 different plant taxa that are representatives from the four major vascular plant groups (lycophyte,

monilophytes, gymnosperms and angiosperms) growing in controlled elevated CO_2 chambers. The impact of exposure to varying oxygen and carbon dioxide levels on model accuracy will also be assessed.

The central nervous system of Trilobitomorpha – taphonomy, morphology and evolutionary implications

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The discovery of exceptionally preserved neurological tissues in early and middle Cambrian total-group euarthropods has clarified major controversies regarding the segmental origin of specific cephalic appendages, and illuminated the evolution of the central nervous system (CNS) in the evolutionary context of Panarthropoda. Different aspects of the CNS, such as the condensed dorsal brain and the ventral nerve cord, have so far been reported for radiodontans, fuxianhuiids, megacheirans, and bivalved euarthropods. However, data on the neurological organization of Trilobitomorpha – a diverse clade of Palaeozoic euarthropods that includes trilobites as its most familiar representatives – remains more elusive. New investigations of the Burgess Shale mollisoniid *Houghtonites gracilis* (Walcott) reveal details of the CNS in exceptional detail, including optic nerves, putative optic neuropils, a condensed dorsal brain, and the entire ventral nerve cord; the latter consists of condensed ganglia with segmental nerves, linked together by longitudinal connectives throughout the body. Elemental analyses reveal that the CNS of Houghtonites is replicated in graphitized organic carbon films, and thus is in agreement with the classical model of Burgess Shale-type preservation. In a broader context, *Houghtonites* provides new insights on the CNS of Trilobitomorpha, and casts new light on the ancestral neurological organization of crown-group Euarthropoda.

A bizarre early tetrapod from the Early Permian of Kansas, USA, provides further support for radical polyphyly of 'lepospondyls'

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Two decades of phylogenetic analyses have supported a monophyletic Lepospondyli, but this was recently challenged by a study that placed two groups, the Recumbirostra and Aïstopoda, in distinct parts of the tetrapod tree. Other lepospondyl groups, such as Nectridea, remain untested. We report a new nectridean-like lepospondyl from the Permian of Manhattan, Kansas, preserving 3D morphology of the posterior skull, anterior axial skeleton, pectoral girdle, and limbs. The specimen possesses a mosaic of derived nectridean (holospondylous vertebrae with elongate transverse processes) and primitive features similar to colosteid and 'whatcheeriid' stem tetrapods. Cervical and anterior thoracic ribs flare distally, with the distal edge of the first thoracic rib articulating directly with the scapulocoracoid, which is low, broad, and fully-ossified with a flat, posteriorly-directed glenoid. The humerus is short and robust, with a straplike humeral head and a well-developed preaxial plate. Phylogenetic analysis resolves Urocordylidae, comprised here of the Manhattan lepospondyl plus *Urocordylus* and *Crossotelos*, as the sister taxon of the colosteid *Greererpeton*, well within the tetrapod stem but distinct from aïstopods, further eroding support for a traditional Lepospondyli. 'Lepospondyli' may represent diverse experiments in ecomorphology throughout early tetrapod phylogeny, in which case early tetrapod evolvability may be underestimated.

Get low: the evolution of the baleen whale auditory pathway

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Living baleen whales (Cetacea: Mysticeti) are the largest animals to have ever lived, using baleen to filter vast amounts of small prey in a single feeding event. They also hear the lowest frequency sounds of any mammal. This is achieved using bone conduction, where skull vibrations are transmitted to the inner ear (cochlea), which is adapted for detecting low-frequency sounds. Conversely, the earliest mysticetes were small-bodied animals that possessed teeth and fed raptorially or via suction. Whether these toothed mysticetes possessed similar auditory abilities to their leviathan descendants is one of the least-explored aspects of cetacean evolution.
Here, we detail how the mysticete auditory pathway has evolved, resulting in extant mysticetes detecting infrasonic sounds. Stem mysticetes retain the plesiomorphic basicranial morphology seen in basilosaurids with sounds entering via acoustic fat pads in the mandibles. In contrast, crown mysticetes display substantial changes indicative of the skull becoming the entry point of the auditory pathway and the use of bone conduction. Cochlear morphology is essentially unchanged, with the exception of an increase in absolute dimensions. These data suggest that although toothed mysticetes were specialised for hearing low frequencies, it was not until the appearance of crown mysticetes that infrasonic hearing became possible.

The Estuary Effect and the origin of lake faunas: critical linkages between global tectonic, sea level and biodiversity

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The timing and mechanisms of how faunas established themselves on land is critical to our understanding of clade origination, radiation and derivation through time. In addition, determining the conditions and physiological traits necessary for clades to invade continents allows us to better characterize the nature of these invasions and understand the requirements for survival in non-marine environments as well as informing on the possible cause of diversity disparity across the tree of life. The early history of lake faunas is one of opportunity and amelioration. Feedback loops created by the establishment of vascular land plants altered the terrestrial nutrient cycle and impacted lacustrine regimes by increasing the nutrient availability and loading, allowing more complex trophic interactions to develop. Clades invading the continents via the "estuary effect" did so numerous times via the episodic establishment of marine-freshwater connections along continental margins. The invasion occurrences and subsequent diversification demonstrates a dramatically different diversification pattern on continents than in the marine realm. The global tectonic and geochemical cycling that has occurred throughout the Phanerozoic may have influenced continental colonization and subsequent diversification of those clades through time.

Burgess Shale fossils reveal the ancestral state of annelid nervous systems

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Despite the expectation that nervous tissues have limited preservation potential, rare occurrences of nerve cords and brains have been documented from Cambrian Burgess Shale-type Lagerstätten. Nervous tissues have been reported from euarthropods and early chordates, but are yet to be described in fossil spiralians. We report the brain, palp nerves, circumoral nerve ring, segmental ganglia and parapodial nerves of the stem group annelid *Canadia spinosa*, an iconic polychaete from the Burgess Shale. The nervous system of extant annelids is a highly variable organ system, ranging from ganglionated and cephalised in errant animals to the total loss of discrete segmental ganglia in sessile taxa. The earliest diverging annelids are Oweniidae and Magelonidae according to phylogenomics, which is controversial, but congruent with some morphological characters. In these animals the nervous system is simply organized and lacks ganglia with the brain possibly consisting of a simple loop. As a result of their deeply branching position and simple morphology, these taxa have been argued to possess nervous system morphologies that are annelid plesiomorphies. *Canadia* reveals that a complex nervous system was present

in the annelid stem group and that annelid evolution is punctuated by multiple independent losses of complexity in this important organ system.

Diversity and disparity of USA Radiodonta

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Radiodonta, large Cambrian pelagic predators, are often preserved as disarticulated elements of their body plan: frontal appendages, circular mouthparts made of radial plates, lateral flaps, or carapace elements, although they are rarely found as complete specimens. These animals are best known from the Chengjiang, Haiku, Emu Bay Shale and Burgess Shale Lagerstätten. A study of radiodontan material from Cambrian deposits from the Great Basin (Utah, Nevada, and California) and Kinzers Formation (Pennsylvania) offered the opportunity to study the evolution and distribution of radiodontans at a local and regional level and at high temporal resolution, and also increased our knowledge of radiodontan diversity. Here we report the oldest *Amplectobelua* from Laurentia, the youngest representatives of *Stanleycaris*, *Caryosyntrips* and *Tamisiocaris* worldwide, and a new genus of hurdiid – all only known from USA deposits. The frontal appendages of radiodontans were used in feeding, with different morphologies indicating different feeding styles. The disparity of frontal appendage morphologies was quantified using a character-based morphospace, separating radiodontan frontal appendages into 5 major groups: two-appendage durophages, one-appendage durophages, filter feeders, sediment sifters and raptorial predators. USA Lagerstätten contain radiodontans with the full range of radiodontan ecologies, and rival more famous Cambrian Lagerstätten in radiodontan disparity and diversity.

The ecological consequences of extinctions: from giant sharks to small mollusks

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The end of the Pliocene marked the beginning of a period of great climatic variability and sea-level oscillations. Although it has been proposed that these environmental changes triggered the extinction of benthic communities in the Caribbean, large marine vertebrates are usually assumed to have remained globally resistant. We overturn this assumption by reporting a previously unrecognized extinction event in the Pliocene, in which 36% of the marine megafauna genera were lost. We used a functional diversity approach to evaluate the potential impacts of this extinction for ecosystem functioning, and found that seven out of 49 (14%) functional groups (unique trait combinations) disappeared, along with 17% of functional richness (volume of the functional space). This contrasts with previous studies that have reported negligible functional changes after the extinction of marine invertebrates. We further compared the functional diversity loss after the newly reported marine megafauna extinction and the well-known Caribbean mollusks extinction. We found that small, speciose mollusks are functionally redundant (large number of taxa filling functional groups), and consequently resilient, whereas large megafaunal taxa are functionally unique and their communities highly vulnerable. Our results suggest that functional redundancy is a key determinant of the consequences of extinctions for marine ecosystems.

The multiple origins of powered flight among paravian theropod dinosaurs: constraints from new phylogenetic, aerodynamic and anatomical data

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The evolution of birds (Avialae) from paravian theropods is a textbook evolutionary radiation. Our understanding of this transition has been frustrated, however, by lack of consensus on the relationships between birds and their closest relatives. This lack of consensus has made it difficult to understand the timing and sequence of evolutionary changes along the line of descent to modern birds, particularly those involved with flight. We have addressed this issue through a larger, more resolved evolutionary hypothesis produced by analysing a revised dataset using an automated pipeline of analysis tailored to large morphological datasets. The grouping of dromaeosaurids and troodontids (Deinonychosauria) as the sister taxon to birds is corroborated, and we recover the Chinese 'Jianchang' paravians (e.g. *Anchiornis*) as the basalmost avialans, instead of troodontids. Wing loading and specific lift (theoretical and in vivo based criteria devised to discern volant from flightless avians) calculated for taxa with vanned feathers and interpreted in the context of the improved phylogeny provide upper and lower bounds for flapping-based locomotor evolution, especially powered flight. Powered flight appears to be limited to paravians and originated multiple times, with the strongest non-avialan candidates for this behaviour being the dromaeosaurids *Microraptor* and *Rahonavis*.

Gymnosperm–insect pollination relationships in Early Cretaceous amber from Spain

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Amber from Spain, ca. 105 Ma in age, currently provides the soundest evidence for insect pollination during the Early Cretaceous, with three known instances of insects vectoring gymnosperm pollen. The three modes of pollination are: (1) two melanthripid thrips species with bodily attached pollen clusters of cycadalean or ginkgoalean affinity; (2) a zhangsolvid long-proboscid fly with a clump of abdominally adherent bennettitalean pollen; and (3) an oedemerid beetle with several bennettitalean or cycadalean pollen grains clinging to its body, followed by a trail of additional grains resulting from insect movement before complete resin entombment. Each of these gymnosperm-pollinating lineages spotlights a distinctive evolutionary-ecological pathway, respectively. First, there were lineages that survived to the present that still pollinate gymnosperms; second, other lineages became extinct; and third, some lineages shifted to angiosperm hosts. Curiously, Cretaceous records of insects vectoring angiosperm pollen are lacking. Current evidence suggests that insect pollination was generalised among Early Cretaceous gymnosperms, specifically during the Albian–Aptian interval when angiosperm lineages were rapidly proliferating. During that time, there was considerable lineage extinction, origination, and host-plant shifts. Nevertheless, the role of insect pollination during the early evolution and radiation of angiosperms requires further assessment.

Evaluating bite marks and predation of fossil jawless fish during the rise of jawed vertebrates

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The extinction of diverse clades of armoured jawless vertebrates (ostracoderms) during the radiation of jawed vertebrates in the Devonian is a major evolutionary event. Here we use fossil evidence to directly test the hypothesis that the demise of jawless vertebrates was a result of predation by jawed vertebrates. A survey of heterostracan ostracoderm fossils finds predation traces in 37 specimens. They are interpreted as predation traces due to their 1) regular geometric shape, 2) complementary traces on both sides of the animal, 3) a distinct pattern, and 4) evidence of sub-lethal (repair) attacks. Occurrences of these attacks dramatically rise during the Early Devonian (Emsian), which coincides with an increase in jawed vertebrate diversity. Our results demonstrate that the occurrence of no single jawed vertebrate group correlates with predation trace occurrences, but faunal assemblages containing predation traces were found to contain significantly different jawed vertebrate fauna to those without any predation evidence. Results therefore indicate that specific jawed taxa were likely predators in Silurian and Devonian vertebrate assemblages, but that predation did not increase through time.

The influence of cranial biomechanics on the evolution of the mammalian jaw joint and definitive mammalian middle ear

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The evolution of the mammalian dentary-squamosal jaw joint and the corresponding definite mammalian middle ear is a key event in vertebrate evolutionary history. Fossils spanning the cynodont-crown Mammalia transition document osteological modifications to the jaw and cranial bones. Theoretical biomechanical models have postulated that these osteological changes result in a shift in adductor muscle orientation, reducing load at the jaw hinge and concurrently amplifying bite force production, coupled with consolidation of cranial bones and supposed reduction in feeding-induced stress. Despite persisting in the literature for many years, these ideas remain to be tested. Here we assemble six digital reconstructions of key fossil taxa across the transition. Using multibody dynamics analysis (MDA) and finite element analysis (FEA) we test the proposed biomechanical hypotheses. Despite a slight decrease in cranial stress and strain we find no evidence for an increase in cranial strength across the transition. There is no reduction in load at the jaw hinge or increase in bite magnitude. Our results suggest that modification to load regime did not trigger the emergence of a novel jaw joint. We propose that miniaturization provided a small-size, low load environment where modifications to auditory and feeding function were possible without compromising cranial performance.

The Tournaisian recovery of terrestrial vegetation following the end Devonian mass extinction

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To understand how terrestrial vegetation was impacted by and recovered from the End Devonian Mass Extinction, a quantitative record of Tournaisian plant spores has been acquired from a 500 m borehole through the Ballagan Formation and related outcrop sections in the Scottish Borders. This is part of the NERC TW:eed project – an integrated study of the earliest Carboniferous tetrapods and their world. The immediate post-extinction vegetation was simple and then progressively increased in diversity, including inceptions and the return of some Devonian plant groups. After this initial reestablishment, the creeping lycopod *Oxroadia* (*Anaplanisporites baccatus* with its abundant megaspore *Lagenicula subpilosa*) became dominant, forming dense thickets on the floodplain. These

thickets were repeatedly interspersed, on the tens of meters scale, by *Prolycospora claytonii*-dominated assemblages. Although not known *in situ*, a strong association with fragments of *Genomosperma kidstoni* indicates a seed plant affinity. Additionally, a marked increase in abundance of *Spelaeotriletes crustatus* in the late Tournaisian suggests an increasing abundance of progymnosperms. Quantitative abundance of selected spores correlates with palaeosol distribution, highlighting repeated climatic fluctuations between wetter and drier episodes. CONISS analysis reveals eight distinct assemblages that can be mapped onto long Milankovitch cycles, identified in marginal marine sections.

Get across the wood: exceptional preservation of Cretaceous soft-bodied xylophagous mollusks

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Teredinidae are obligate xylophagous bivalves colonizing drifted woods and displaying a specialized anatomy with a shell highly reduced in size, so that the vast majority of their anatomy consists in soft-tissues. Therefore, their fossil occurrences mostly correspond to burrows, isolated shell valves or small terminal aragonitic structures called "pallets". Here, we report exceptionally preserved shipworms from the Late Cretaceous of the Envigne Valley (Vienne, France) with soft-parts which are frozen by silicification emerging out of the wood. This preservation led us to investigate the inner content of the inhabited wood pieces using computed tomography to document the anatomical preservation of the animals and their organisation inside the wood. The 3D-reconstructions evidence that rare and fragile soft-tissues are preserved inside (mantle, respiratory siphons) but also surprisingly that the mineralized pallets, which are a key-feature of the Teredinidae anatomy, are here absent. On the basis of this finding, we analyzed the different tissue mineralogy to conclude on the evolutive of taphonomic absence of these structures and further suggest an explanation to their up to date variable fossil record. The selection of the colonized woody pieces and the local environment of the Envigne Valley are also inferred from the study of these shipworms.

Tooth replacement and tooth resorption mechanisms in Osteichthyes

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Mechanisms of tooth replacement are characterized in Chondrichthyes with tooth families resembling a conveyor belt and intraosseus tooth replacement in Tetrapoda. Tooth replacement in Osteichthyes is linked with resorption before shedding, whereas in Chondrichthyes teeth are shed without resorption. Basal conditions and the origin of tooth replacement and resorption in Osteichthyes are debated. Comparative data on tooth replacement and resorption of fossil and recent taxa are rare. We use digital, non-destructive Synchrotron microscopy (SRXTM) to identify lines of arrested growth and resorption lines as evidence to reconstruct sclerochronology. Detailed 3D segmentation in submicron scale of articulated undebated jaws and teeth of recent and fossil osteichthyans allows an identification of replacement mechanisms in teeth and oral denticle morphotypes. Resorption lines in *Polypterus* and *Moythomasia* are continuous proximal to the replacement teeth and can erode deeply, erasing parts of initial teeth completely or only partially. Oral denticles e.g. in *Moythomasia* are not replaced, but added appositionally. Although dental morphologies in *Moythomasia* are different their replacement and resorption are similar in contrast to oral denticles that differ in morphology and replacement. These results facilitate an interpretation of mechanisms in fragmentary material and evolution of tooth resorption in Osteichthyes.

Approaching sexual dimorphism in non-avian dinosaurs and other extinct taxa

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Sexual dimorphism, exhibited in most extant vertebrates, including Aves, has been proposed for various extinct taxa. Such claims in non-avian dinosaurs have been received skeptically, with rates of dimorphism claims underrepresented compared to other fossil groups. Alternative explanations regarding dinosaur ornaments/armaments either misrepresent sexual selection theory (e.g., 'species recognition hypothesis') or ascribe relatively rare socio-sexual systems broadly across Dinosauria (e.g., 'mutual sexual selection hypothesis'). We propose a different approach to testing for dimorphism in extinct taxa. Under game theory, the null hypothesis for anisogamic species is that dimorphism is present. Previous studies rely on low-power statistical approaches and fail to test for the actual signal of dimorphism (demonstrated here through statistical modeling). Contrary to how these studies frame the problem, the goal should be to constrain the plausible range of the magnitude of sexual dimorphism. Rather than testing for two distinct morphs, our approach looks for divergence in a trait through growth combined with testing specific alternate hypotheses (e.g., ontogenetic, interspecific, non-sex-based individual variation) using histological and taphonomic methods and focusing on traits typically involved in sexual selection (e.g., body mass, coloration, ornaments/armaments). Many dinosaur taxa show patterns in bizarre structures consistent with sexual selection and are therefore likely dimorphic.

The other old red continent: ichnological signatures of arthropod terrestrialization throughout the Silurian of Australia

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The terrestrialization of arthropods is a key event in the history of Earth; its timing, estimated through ichnological evidence, suggests Cambro-Ordovician excursions were followed by Siluro-Devonian colonization of fully non-marine habitats. Much of this evidence comes from Euramerica, leading to potential bias in our understanding of terrestrialization towards the 'Old Red Continent'.
Here we present field results of a holistic ichnological survey across much of the Silurian-Devonian sedimentary record of Australia (Grampians Group, VIC, Mereenie Sandstone, NT, Tumblagooda Sandstone, WA). We find high ichnological diversity in the shallow marine record of the Grampians Group, but fluvial parts of the succession are barren. This contrasts to the classic aeolian deposits of the Mereenie Sandstone, where a limited ichnofauna is dominated by *Diplichnites* and *Polarichnus*. Both areas differ from the high ichnodiversity Tumblagooda Sandstone, from which we present new sedimentological evidence demonstrating tidal deposition, rather than a fluvial-aeolian setting as previously interpreted.
Australian ichnological data is compared with Euramerican data to show that, worldwide, Silurian non-marine environments appear to have had limited ichnodiversity, suggesting this interval records the initial phases of full colonization.

Closing the gap between palaeontological and neontological speciation and extinction rate estimates

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Speciation and extinction drive changes in biodiversity, therefore defining and quantifying the rates of species origination and extinction has wide-reaching implications in macroevolution. Neontologists use phylogenies of extant species to estimate diversification rates, while palaeontologists infer them using the fossil record. Although living and extinct species are samples of the same underlying evolutionary process, large discrepancies between speciation and extinction rates inferred using fossils and phylogenies have been widely documented for empirical data, but the theoretical reasons for this discrepancy remain unknown. Here, we demonstrate that the discrepancies are driven by differences in implicit assumptions about the process of speciation in neontological and palaeontological models. We present the birth-death "chronospecies" model that clarifies the definition of diversification rates in a joint palaeontological and phylogenetic framework. Using simulations and empirical datasets, we show that the model can explain much of the apparent incongruences between rates estimated using fossils versus phylogenies. Our new model will play an important role in the future integration of palaeontology and phylogenetics.

Incorporating inapplicable data in phylogenetic analysis

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Morphological cladistic analysis is a central tool in bringing palaeontological data to bear on biological and evolutionary questions. One impediment to reliable phylogenetic analysis arises where morphological observations are translated into discrete, computer-readable characters. There is presently no satisfactory way to account for 'ontogenetically dependent' characters that are cannot logically be applied to all taxa: for example, 'tail colour' where some taxa lack a tail. Existing algorithms treat such 'inapplicable' data points as either ambiguous ('missing') data, or as an extra state. Both of these approaches introduce systemic error in tree length calculations, causing suboptimal trees to be recognized as the shortest and thus jeopardizing phylogenetic conclusions. We resolve this issue with a new approach that enumerates occurrences of homoplasy, rather than transformations between character states. A modified four-pass version of the Fitch algorithm generates accurate length counts for all character configurations, which allows the safe inclusion of inapplicable data without the introduction of bias. Inapplicable data are particularly common in larger datasets, and 'combined' datasets incorporating observations from multiple taxa. Our new method enables robust phylogenetic analysis of datasets with broader taxonomic scope.

Towards more accurate inference of phylogeny from morphology: a case study in extant crocodilians

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DNA is generally used to infer phylogeny for modern taxa, and its use is increasingly reliable, but for fossils we must rely on morphology. For groups where phylogenies have been inferred using DNA and morphology separately, the two often disagree. There are grounds to consider DNA-based phylogenies to be more reliable, including biogeographic consistency and lower homoplasy, indicating that morphology-based phylogenies for fossils may be far from correct. Better ways to to infer phylogenies from morphology must be developed. In order to begin to address this, the consistency of a matrix of morphological characters with a DNA-based phylogeny for modern crocodilians is assessed. Groups of characters are compared used a Mann-Witney U test and three consistency indices, and all characters were reassessed first hand and documented. Postcranial characters were significantly more homoplastic ($p < 0.05$) than cranial characters, perhaps due to the lower functional load and greater complexity of the cranium. Characters which were clearly homologous within each state and where state delimitation was clear were significantly less homoplastic ($p < 0.05$) than other characters. Focus on character quality, rather than quantity and/or skeletal coverage is thus tentatively recommended, but further work examining different methodologies and taxa is required.

A minimum population extinction time driven by stochastic environmental forcing

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The number of individuals within a population, or number of species within a lineage, changes with time in an inherently stochastic manner. Fluctuations within such a stochastic trajectory have long been recognized as a pathway by which extinction occurs, particularly within small populations. However, it is less well understood how external sources of stochastic forcing, such as environmental variability, interact with a population's intrinsic stochasticity. In this work, we develop a model from which the typical time to extinction of a population is computed, subject to forcing from an environment that switches randomly between two states with differing death rates. We find that there exists a frequency of environmental fluctuations that minimizes the mean time to extinction. This "worst" switching rate scales with the population's generation turnover timescale, indicating that extinction risk varies across species with differing per capita birth rates. We discuss the implications of this timescale-sensitivity for extinction selectivity during past extinction events within the geological record. Furthermore, we show that the rate of evolution may be dependent critically upon the timescale of environmental perturbations.

The environmental context of early animal evolution

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Animals originated and evolved during one of the most unique times in Earth history—the Neoproterozoic Era. A large dataset of >10,000 Neoproterozoic-Paleozoic shale samples compiled by the Sedimentary Geochemistry and Paleoenvironments Project is interrogated here to better understand the landscape early animals inhabited. Using a space-for-time translation, animal ecosystems along modern natural gradients of oxygen and primary productivity are then used to conceptualize Neoproterozoic ecosystems. Analyses of redox-sensitive trace metals demonstrate that animals evolved in a relatively low-oxygen ocean, although perhaps not considerably less oxygenated than the Paleozoic. Anoxic water columns were generally ferruginous (iron-rich) rather than euxinic (sulfide-rich, as in the modern ocean), and sulfide stress was likely limited. Habitats suitable for chemosymbiotic lifestyles based on sulfide oxidation were also likely rare. Analyses of sedimentary total organic carbon suggest that early animals lived in an ocean with lower primary productivity compared to the preceding Mesoproterozoic or following Paleozoic. Combined with an inability to inhabit productive regions in this low-oxygen ocean—where aerobic respiration would quickly draw down oxygen to lethal levels— Neoproterozoic animal communities would have likely been more food limited than generally appreciated, leading to important impacts on ecosystem structure and organismal behavior.

Fossil plant cuticles may track SO_2 pollution during LIP volcanisms - implications for understanding mass extinctions

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Flood basalt volcanism and large igneous provinces (LIP) have been implicated in several of the major Phanerozoic mass extinctions, principally through global warming caused by highly elevated pCO_2. The Triassic-

Jurassic boundary (Tr-J) and the associated end-Triassic mass extinction, is one such event. However, the patterns of Tr-J biodiversity loss observed are sometimes difficult to reconcile with the effects of global warming alone. Recently attention has therefore turned to additional volcanic products as potentially aggravating factors - in particular sulfur dioxide (SO_2), but so far it has been difficult to detect SO_2 in the geological record. Here, we present new data showing that fossil plant cuticles may indicate the presence of SO_2 at the Tr-J. Plant cuticles are highly resistant, often persisting as fragments in sediments even when macrofossils are not available. We show that damaged and distorted cuticle surfaces across the Tr-J are consistent with modern and experimental SO_2-caused cuticle damage and with leaf-shape changes across Tr-J, providing more detailed information about the Tr-J environmental degradation and ecosystem response. These results identify fossil cuticle distortion as a useful proxy for past SO_2 emissions and with it the potential to improve our understanding of the Earth system.

Climate change and rates of crocodylomorph body size evolution

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The Crocodylomorpha are an extremely ancient group, but unlike other vertebrate groups of similar antiquity they have an extensive crown-group. The Crocodylomorpha have therefore been subjected to dramatic environmental changes and multiple extinction events throughout their history. The Crocodylomorpha frequently exhibit an aquatic mode of life, robust skeletons and tough osteoderms, improving their preservation potential. As such, the Crocodylomorpha have a good fossil record relative to other vertebrate clades. Their long history and good preservation makes them excellent subjects for studying the effects of environmental change on vertebrate evolution. Here we present a study of crocodylomorph body size evolution using comparative phylogenetic approaches. Rates of crocodylomorph body size evolution is highly heterogeneous, with generally low rates interrupted by brief periods of rapid diversification. Crocodylomorph diversity, body size and rate of body size evolution is found to be strongly correlated with temperature. Diversity is constrained by cooling, but can recover quickly in periods of climate stability. Body size and rates of body size evolution increase with cooling. Punctuational evolution and sensitivity to temperature lends support to the Court Jester hypothesis. A relationship between body size and temperature has is a cause for concern in the light of anthropogenic climate change.

The importance of microenvironment in determining the roles of early diverging fungi in early terrestrial ecosystems

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Fungi are thought to have been important in early terrestrial ecosystems as saprotrophs, mutualists and parasites of plants and animals. Fossil fungi are abundant, but determining their roles can be difficult. Environmental context is important, so we are investigating fungal diversity in different microenvironments using high resolution photographic mapping of substrates in thin sections to plot fungal distribution in relation to organic matter. Fossils of interest are targeted for more detailed study using Confocal Laser Scanning Microscopy. We examined a thin section of the 407-million-year-old Rhynie Chert (Scotland). We observed layering of the vegetation and corresponding variation in preservation on a millimetre scale, which reflects fossilisation in a time series under different environmental conditions. Colonization of plants by fungi varies significantly through the section in terms of abundance. Taken together the environmental context, state of preservation of the plants and the morphology of the fungal bodies indicate predominantly saprotrophic interactions by early diverging fungi operating in litter vegetation under drying conditions. This approach, which considers the microenvironment of the fossils, is essential to developing a deeper understanding of the roles of fungi in early terrestrial ecosystems.

Species discovery and changing taxon concepts in Cenozoic molluscs - after 50+ years what does revision of a popular handbook tell us?

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Over the past 30 years it's been established that many common and widespread ('traditional') morphologically-based species of benthic marine invertebrates fall into more narrowly distributed allopatric and genotypic clusters. These DNA clusters typically correspond with more narrowly defined morphological species – so-called cryptic species - that are considered by almost all taxonomists to be species. Because invertebrate palaeontology pays little attention to species concepts, does this mean that that species (=taxon) concepts are diverging between zoological and palaeontological communities? Until now this has not been examined. Updating a handbook of common British Cenozoic fossils for a new 2017 edition involved fully revising identification, taxonomy and stratigraphic range data for 266 molluscan species. This small but highly vetted data set allows insight to whether taxon inclusiveness has changed over the past 56 years since the first edition. I will examine how current views of the morphological inclusiveness of species has changed in response to; improved taxonomy and nomenclature, increased sampling, improved stratigraphic resolution, and novel discoveries. I will examine how these changes have led to stratigraphic or geographic range changes and how newly established species durations compare to data derived from other taxonomic and geographic studies of Cenozoic molluscs.

Carbon characterization in the Sirius Passet Biota and a geothermal gradient through Cambrian Lagerstätten

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Mechanisms that delay the degradation or destruction of organisms are viewed as one of the most important taphonomic factors that lead to the exquisite preservation seen in Lagerstätten deposits. However, perhaps of equal importance, yet rarely explored, is the subsequent metamorphic history and peak thermal paleotemperature of Lagerstätten deposits. Raman spectroscopy is a non-destructive technique that allows the investigation of the organic and inorganic chemical structure of samples. The structure and the degree of disorder of the organic matter in that sample can then also be used to estimate peak metamorphic temperature. Here we investigate the structure of the carbonaceous matter in the exceptionally preserved early Cambrian Sirius Passet Lagerstätte using Raman spectroscopy. The spectral characteristics are indicative of moderately ordered kerogenous matter and indicate that the transitional Buen Formation that hosts the Sirius Passet biota was thermally altered at a peak temperature of 409 °C (±50°C). How does this palaeotemperature compare with other prominent Cambrian Lagerstätten (such as the Burgess Shale) and is there a relationship between the morphological fidelity of fossils in Lagerstätten deposits and the thermal maturity of the host strata?

A 'reptilian' mode of reproduction in pterosaurs and its implications for pterosaur palaeobiology

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Determining the biology of pterosaurs has proven challenging and key aspects such as their reproductive biology are still much debated. Over the last decade a spectacular series of fossil finds, including eggs, embryos, neonates and several complete postnatal growth series have provided critical new evidence. Interpreted using current knowledge of reproduction in extant amniotes these fossils present a remarkably detailed picture of pterosaur reproduction. Females had paired ovaries and laid relatively small, oval, pliable-shelled eggs that were incubated at ambient temperatures in vegetation or a loose substrate. Neonates were well developed with extensive flight membranes and likely superprecocial, able to fly at, or soon after, hatching. Young pterosaurs required little or no

parental care and grew slowly at rates a magnitude lower than that of extant birds or bats. This reproductive mode, which is strikingly different from that of extant fliers, but fully compatible with that of basal amniotes, has important implications for other aspects of pterosaur biology. Embryonic development at ambient temperatures is more consistent with heterothermy than homeothermy which, in turn, is consistent with relatively slow post-natal growth rates. The ability to grow and fly may help explain pterosaur gigantism and also has profound implications for pterosaur ecology.

Reconciling the commonality of long-term stasis in the fossil record and the rare detectability of stabilizing selection in extant biota

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Rapid evolutionary changes are common in many extant species, whereas fossil species regularly display morphological stasis for millions of years. Hence, evolutionary biologists from different disciplines can carry drastically different expectations on rates of evolutionary change. Here I dissect these apparent discrepancies in expectations by constructing models of expected trait change under various micro-evolutionary processes (genetic drift, directional and stabilizing selection) and by comparing these models with observed morphological change in a fossil species lineage that displayed stasis in all examined traits for over 5,000 years, and that was sampled at a resolution bridging ecological and evolutionary timescales. On ecological timescales the expected magnitude of trait change is very similar for all models of micro-evolutionary processes, and observed magnitudes of trait change broadly overlap with all of these models. Stasis-associated rates of morphological change in the fossil species lineage fall largely, but not exclusively, within the range of genetic drift. On evolutionary timescales, however, change is more constrained than predicted by neutral evolution. In short, the absence of evidence for stabilizing selection from studies of morphological changes over ecological periods even applies to high-resolution studies of paleontological stasis and it does not imply that the process is rare in extant natural populations.

Cambrian weird wonders and the origin of ctenophores

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Ctenophores have in the last decade figured in a sometime acrimonious debate regarding their systematic position in the metazoan tree—are they the sister group to all other animals, or are they immediately stemward of bilaterians, perhaps together with cnidarians? Molecular phylogenetic studies have recovered both and a wide consensus is still lacking. Here we describe a remarkable new specimen of Dinomischus from Chengjiang, China. It preserves rows of compound cilia on tentacles, resembling comb row structures that together with a number of other Cambrian fossils demonstrate an evolutionary origin of ctenophores from a sessile polyp-like suspension feeder. Dinomischus furthermore preserves internal mesenteries, like cnidarians. Morphological phylogenetics firmly recovers cnidarians and ctenophores as a clade (Coelenterata) based in part on this new evidence, together with several anatomical and embryological features. Furthermore, the development of ctenophores is echoed by the Cambrian stem groups introduced here, including the scleroctenophores, Siphusauctum (the “tulip animal”), and Xianguangia, which shifts from the cnidarian stem to the ctenophore stem. Our findings simplify some aspects of the early evolution of metazoan body plans compared to the “ctenophores first” scenario.

High-dimensional geometric morphometric approach to understanding skull shape evolution in squamates

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Squamata, with ~10,000 extant species, exhibits remarkable diversity in cranial morphology that mirrors its incredible range in ecological modes. With such wide variation, elucidating how and why certain skull configurations evolved in squamates has enormous potential to formulate general principles underlying skull evolution. Achieving this task, however, requires a systematic and robust characterization of cranial morphology and a comprehensive taxonomic sampling of extant and fossil groups. Here, we harness 3-D reconstructions from micro-CT and surface scans of ~150 taxa to generate a dense geometric morphometric characterization of skull morphology. With a suite of computational tools, we test the tempo, mode, pattern of modularity, and potential drivers of cranial shape evolution. The dataset, capturing the morphological and ecological breadth of squamates, shows a strong ecological signal, namely among fossorial groups, elevated disparity and morphological evolutionary rates in the early history of the clade, and distinct highly modular rostral and integrated posterior parts of the skull. As phenomic data accumulate rapidly in paleontology, this study demonstrates an emerging class of evolutionary analyses that synthesizes high-dimensional phenotypic data with a deep time perspective—one with incredible potential for understanding the morphological evolution of major vertebrate clades.

Tracking genome size variation in a 407 milion year old plant

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Asteroxylon mackiei is a 407 Ma clubmoss from the Rhynie Chert, but its exceptional preservation creates an opportunity to study a phenomenon important for all living plants – changes in genome size (GS). Changes in GS played a major role in plant evolution with evidence from comparative genomics of repeated cycles of ancient whole genome duplication followed by diploidization. Because GS is related to stomata guard cell length (GCL) it can be investigated in fossils (GCL is greater in plants with bigger genomes). Previous research based on small samples of published GCL values concluded that early land plants possessed exceptionally large genomes. *A. mackiei* stomata were measured directly from slides in the collections of The Natural History Museum (London), The Hunterian (Glasgow) and The University of Münster (Germany). These were compared to GCL of living clubmosses of known GS. GCL of *A. mackiei* falls within the larger range of modern Lycopodiaceae, indicating that its GS is not exceptionally large but comparable to that of living *Huperzia selago*. These fossils also showed a very broad range of GCL values (39-92 µm), which we interpret as providing the earliest direct evidence of genome size variation in plants at the species level.

High-resolution virtual histology in 3D for understanding development in living and fossil birds

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Determination of developmental age and life history traits of fossils is crucial for accurate taxonomy and understanding evolution and biology of extinct animals. However, the exceptionally rapid growth of extant birds means ageing methods based on incremental growth lines (e.g. LAGs), used in other vertebrates, are largely inapplicable and robust alternative ageing methods remain to be established. Analysis of avian intracortical bone microstructure provides a promising approach but, to date, most microstructural studies in avian bone are qualitative, 2D, involving a limited range of living species, and applying destructive thin-section-based histology. We aim to use minimally-destructive high-resolution 3D imaging to identify and quantify microstructural

phenotypes in extant species to help estimate developmental age and life history in fossil birds. We assessed the 3D microstructure of cortical bone from the midshaft of the femur, tibiotarsus, and humerus in a growth series of domestic ducks (*Anas platyrhynchos*) using high-resolution synchrotron-based computed tomography and found qualitative changes in pore diameter and heterogeneity throughout development. While volumetric bone measures allow distinguishing juvenile from adult birds, further analysis is ongoing to interpret age more specifically. Future work will test how variation in microstructure relates to body mass, life history, and phylogeny, by comparing extant species.

Hidden diversity of small theropods from the Bathonian (Middle Jurassic) of the UK

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Theropod dinosaurs are well represented in the British Middle Jurassic. The record is dominated by large-bodied tetanuran theropods including: *Magnosaurus nethercombensis* and *Duriavenator hesperis* from the Bajocian Inferior Oolite of Dorset; the historically important taxon *Megalosaurus bucklandii* from the Taynton Limestone Formation of Oxfordshire; *Cruxicheiros newmanorum* from Cross Hands Quarry, Warwickshire; and *Eustreptospondylus oxoniensis* from the Oxford Clay of Oxfordshire. With the exception of *Proceratosaurus bradleyi* and other fragmentary remains, small-bodied taxa are less well known. In order to investigate the diversity of these small-bodied taxa more thoroughly, a dataset was built on the basis of 250 small theropod teeth recovered from microvertebrate sites throughout the UK Bathonian. Tooth shape was quantified and analysed using multivariate statistical methods, including Principle Component Analysis and Pairwise Discriminant Function Analysis to test if these isolated teeth overlap with, or are quantifiably distinct from, the morphologies of approximately coeval taxa from similar geographic areas. Results demonstrate that there are at least four quantifiably distinct theropod tooth morphotypes that do not overlap those of named taxa. The Bathonian record of the UK therefore contains a much higher theropod diversity than previously recognised, with these new records including a dromaeosaurid-like taxon and an early troodontid.

New record of an abundant ammonite assemblage from the latest Cretaceous Corsicana Formation, Brazos River, Texas. Implications for the Cretaceous–Paleogene (K–Pg) mass extinction event in the Gulf of Mexico

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Outcrops along the Brazos River, Texas, containing the Cretaceous-Paleogene (K–Pg) boundary provide critical insight into the timing and nature of the mass extinction event 66 million years ago. Investigations of the Corsicana Formation at two sites (Darting Minnow and Cottonmouth Creek) have resulted in the discovery of an abundant ammonite assemblage directly below the K–Pg boundary. Findings of *Discoscaphites iris* confirm the presence of the highest Maastrichtian ammonite range zone in North America, corroborated by dating from calcareous nannofossil biostratigraphy. The Brazos ammonite fauna is characterized by high abundance but low diversity, dominated by the genera *Eubaculites* and *Discoscaphites*, with rare *Sphenodiscus* and gaudryceratids – first record of this group in the Maastrichtian of the United States. Jaws and juvenile specimens are present, indicating a living community. Well-preserved shell material allows for determination of water temperatures during the latest Cretaceous, which can be compared with sedimentary geochemistry to explore climate trends and the effects of volcanism leading up to the mass extinction and Chicxulub bolide impact. Ammonites thrived during the latest Maastrichtian in the western Gulf Coast, contradicting hypotheses for an early disappearance of the group at low latitudes prior to the K–Pg extinction.

Evolution of complex life: Late Neoproterozoic co-divergence of bilaterians and their gut microbiota

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The seemingly simultaneous appearance of animal crown group fossils in the early Cambrian, while reliable Neoproterozoic fossils remain limited, is known as Darwin's Dilemma. Recent work has combined geological age data with molecular sequences from living species to establish a timescale for the Tree of Life, with increasing evidence for bilaterian divergence in the Cryogenian and/or Ediacaran periods. Meanwhile, microbiota associated with animals play a pivotal role in their development (e.g. nutrient processing, immune system activation), but bacteria lack a fossil record entirely. Here I show that bacterial clades significant to the animal gut microbiota have estimated divergence times during the Cryogenian-Ediacaran, coincident with the inferred evolution of bilaterian gut morphology. New strategies are introduced to constrain bacterial divergences, including the horizontal transfer of genes into fossiliferous clades, and the cospeciation of bacterial symbionts with their fossiliferous animal hosts. 18 calibrations are derived from fossils which meet phylogenetic and straigraphic criteria comparable to the level of scrutiny in high-quality divergence time analyses of animals. Prior calibrations do not circularly invoke the Neoproterozoic, implying this result is genuine. I suggest that bacterial diversification was sparked by the opening of new niches in the form of bilaterian tissue differentiation.

Substrate relationships and biomineralisation of an Ediacaran encrusting poriferan

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Benthic metazoans encrust in order to secure and maintain growth on a substrate, a key competitive innovation. Here we describe the substrate relationships, mode of biomineralisation and possible affinity of *Namapoikia rietoogensis*, a large (<1 m), robustly skeletal, and modular Ediacaran metazoan which colonised the walls of synsedimentary fissures within microbial-metazoan reefs. *Namapoikia* had an internal structure of open tubules and transverse elements, and a non-deterministic growth form which could encrust both lithified, and living microbial substrates, the latter via modified skeletal holdfasts. *Namapoikia* shows growth interactions and substrate competition with contemporary living microbial mats, including the production of plate-like dissepiments which elevated living tissue above the microbial surface. *Namapoikia* could also recover from partial mortality caused by microbial overgrowth. We infer that initial skeletal growth involved the rapid formation of an organic scaffold via a basal pinacoderm prior to calcification. This may be an ancient mode of biomineralisation similar to the living calcified demosponge *Vaceletia*. Possible skeletal growth banding, combined with large size, also implies individual longevity. The open tubular internal structure, non-deterministic skeletal organisation, and inferred biomineralisation style of *Namapoikia* suggest affinity within total-group poriferans.

A Triassic-Jurassic window into the early evolution of Lepidoptera

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Based on an assemblage of fossilized wing scales encountered in latest Triassic and earliest Jurassic sediments from northern Germany, we here present the so far earliest evidence for Lepidoptera (moths and butterflies). The diverse scales confirm a (late) Triassic radiation of lepidopteran lineages, including the divergence of the Glossata,

the clade that comprises the vast multitude of extant moths and butterflies that have a sucking proboscis. The microfossils extend the minimum calibrated age of glossatan moths by ca. 70 million years, refuting ancestral association of the group with flowering plants. Development of the proboscis may be regarded as an adaptive innovation to sucking free liquids for maintaining the insect's water balance under arid conditions. Pollination drops secreted by a variety of Mesozoic gymnosperms may have been non-mutualistically exploited as a high-energy liquid source. The early evolution of the Lepidoptera was probably not severely interrupted by the end-Triassic biotic crisis.

ABSTRACTS: POSTERS – GROUP A (MONDAY)

* Candidates for the Council Poster Prize are marked with an asterisk.
Underlined author denotes the primary presenter.

The stresses of the Cenozoic rat race: functional support for competitive exclusion of multituberculates by rodents?

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Multituberculate mammals thrived during the Mesozoic, but their diversity declined from the mid-late Paleocene onwards, with last occurrences known from the late Eocene. The radiation of superficially similar eutherian rodents has been linked to multituberculate extinction through competitive exclusion. However, characteristics providing rodents with a supposed competitive advantage are currently unknown and comparative functional tests between the two groups are lacking. Here, a multifaceted approach to craniomandibular biomechanics was taken to test the hypothesis that superior skull function made rodents more effective competitors. Digital models of the skulls of four extant rodents and the Upper Cretaceous multituberculate *Kryptobaatar* were constructed and used (i) in finite element analysis to study feeding-induced stresses, (ii) to calculate metrics of bite force production, and (iii) to determine mechanical resistances to bending and torsional forces. Results suggest that most rodents experienced higher craniomandibular stresses and some had lower resistances to bending and torsion than the multituberculate, apparently refuting the competitive exclusion hypothesis. However, rodents optimize bite force production at the expense of higher skull stress and this may have been more functionally and selectively important. Our results therefore provide a first step to understanding the decline of multituberculates in the changing environments of the Paleogene.

Microfossils from the Late Neoproterozoic glacial-interglacial succession on Digermulen Peninsula, Arctic Norway

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The late Neoproterozoic strata exposed on the Digermulen Peninsula (Arctic Norway) provide a good sedimentary record of Neoproterozoic glaciations on the Baltica palaeocontinent. The lower Vestertana Group contains two glaciogenic units, the Smalfjord and Mortensnes formations which have been correlated with the Marinoan (650 to 635 Ma) and Gaskiers glaciations (c. 579 Ma), respectively. The diamictites are bracketing the shales and siltstones of the Nyborg Formation. Samples from the Nyborg-Mortensnes succession in Guvssájohka valley were collected in 2016 by the Digermulen Early Life Research Group. Acetolysis yielded well-preserved organic-walled microfossils (OWM). Importantly, OWM were also recovered from the fine-grained diamictite matrix in Mortensnes Middle Member. The interglacial Nyborg assemblage includes various leiosphaerids, *Synsphaeridium*-type cell aggregates, *Pterospermopsimorpha*, *Simia*, *Stictosphaeridium*, and rare sculptured and ornamented acritarchs (?*Ceratosphaeridium*). Unusual microfossils, meshworks of aggregated tubes, occur in Member D of the Nyborg Formation. The glacial assemblage within the Mortensnes Formation is expectedly more depauperate and contains abundant unbranched bacterial filaments, small-sized leiosphaerids, and a toroidal

morphotype very similar to the Tonian taxon *Squamosphaera*. These occurrences extend the fossil record on the Digermulen Peninsula below the levels bearing Ediacara-type macrofossils, and add to the OWM record during the end-Neoproterozoic low-to-mid latitude glaciations.

Archosauromorph extinction during the Triassic-Jurassic mass extinction was not related to body size

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Previous mass extinctions destroyed swathes of standing diversity but many of the evolutionary patterns during these events are not known. Currently, it is not clear whether species' traits or lifestyle made them more vulnerable to extinction during these events, or if mass extinctions were random killers that did not act according to the rules of background selection. Most evidence indicates previous mass extinction did not act on body size, but in modern vertebrates larger species have greater extinction risk. Here, we investigate whether body size selectivity played a role in the survival and extinction of Archosauromorpha during the Triassic-Jurassic mass extinction. Using a novel approach, we estimated a new archosauromorph maximum likelihood supertree that incorporates phylogenetic uncertainty. We used phylogenetic comparative methods to test if more closely-related species were more likely to go extinct during the Triassic-Jurassic event, and if larger species were more prone to extinction. We found that there was a significant phylogenetic signal in extinction during the Triassic-Jurassic mass extinction, but there is no correlation between body size and extinction. Previous mass extinctions did not act under body size selectivity, and current extinction risks may differ from those in deep time.

Submitted by: Miss Bethany Allen (eebja@leeds.ac.uk)
Is PalAss Member? Yes
Spoken Before: Never previously presented
Career Stage: MSc or first year of PhD
Permission to Stream/Recording/Photograph: Yes
Comments: None

Lilliputians and Brobdingnagians: Body size changes in Lower Jurassic bivalve molluscs

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Within the Blue Lias Formation (Lower Jurassic) of Britain several bivalve molluscs are seen to undergo a within-species shell size increase. This trend is seen across multiple ecological guilds and occurs in tandem with biotic recovery from the end-Triassic mass extinction event (ca. 201 Ma). The most striking example of body size increase is seen within the species *Plagiostoma giganteum*, which undergoes a 170% mean body size increase relative to specimens measured from its first common occurrence. Although this size increase has been noted within published literature for over 50 years, this study is the first to investigate this and other coeval body size trends in detail. Analysis of growth lines shows gigantism was achieved by a combination of increased longevity and more rapid growth. To record these trends Rhaetic and Lower Jurassic exposures were sampled in South-West Britain, Northern Ireland and North Yorkshire and supplemented with measurements of specimens housed within museum collections. This study now comprises body size data on over 100 bivalve species that provides an understanding on how Lower Jurassic ecosystems responded during the recovery from the end-Triassic mass extinction event.

Phylogeny, ecology, and time: 2D outline analysis of anuran skulls from the Early Cretaceous to Recent.

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Anura have a long fossil record. However, specimens are often severely flattened, limiting their inclusion in quantitative analyses of morphological evolution. Here we perform a 2D morphometric analysis of anuran skull outlines, incorporating 42 Early Cretaceous to Miocene species and 93 extant species across 32 families. Outlines were traced in tpsDig2 and analysed with elliptical Fourier analysis. Fourier coefficients were used in MANOVAs and disparity analyses across multiple ecological and life history groupings. As skull outlines showed significant phylogenetic signal (k=0.53, p=0.006), phylogenetic MANOVAs were also conducted. Ecological niche was a significant discriminator of skull shape (F=1.44, p=0.004), but not after phylogenetic correction. The Neotropical realm showed highest disparity. Developmental strategy had a weak effect on skull shape (R2=0.02, p=0.039), and disparity was similar in metamorphosing and direct developing frogs. Body size was associated with differences in skull shape in fossil frogs (R2=0.44, p=0.017) and extant taxa (R2=0.10, p=0.049), and this effect was only partly due to allometry, which was weak but significant in both fossil (R2=0.11, p=0.002) and extant frogs (R2=0.09, p=0.001). Finally, the shift of morphospace occupation for fossil and extant frog skull outlines appears largely phylogenetically structured, as phylogenetic correction removed any temporal shift of morphospace.

Skeletal and character completeness of the Triassic marine reptile fossil record

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The marine fossil record has been traditionally considered more complete than the terrestrial. Previous work has shown that skeletons of some marine reptiles, such as ichthyosaurs and plesiosaurs, are more completely preserved than those of contemporary terrestrial animals. Here we study both the skeletal and character completeness of several Triassic groups of marine reptiles, including placodonts, nothosaurs, pachypleurosaurs, pistosaurs and thalattosaurs. These groups typically have smaller body sizes than ichthyosaurs and plesiosaurs and have distinct ecological preferences, offering a contrast to these previously studied groups. We calculated the skeletal completeness metric (SCM) and the character completeness metric (CCM) for all valid species of these groups. Provisional results show that while on average marine fossil record is more complete than the terrestrial record, this pattern is not maintained across all studied groups. Comparison between character and skeletal completeness indicates that there is not a strong correlation between both metrics and that most characters are concentrated in the most usually preserved or described skeletal regions, like the skull. No significant correlations are found between completeness and other metrics, such as diversity, size or lithology. A significant correlation was found between the completeness of a holotype and the year the species was named.

Worms on acid: how pH affects burrowing behaviour of *Nereis diversicolor* and its bearing on mass extinction scenarios

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Mass extinctions are often characterised by a loss of bioturbators. The Early Triassic interval is dominated by laminated facies defined by the ichnofabric index (II) as having no bioturbation (II1). The Permian-Triassic is the crisis in which ocean acidification (OA) is most widely implicated, but this remains controversial. Does a relationship exist between pH and ichnofabric index? We tested the effects of altered pH on the rag worm *Nereis diversicolor*. Aquarium tanks were filled with coloured sand and mud and 20 individuals of *N. diversicolor* each. Tanks were filled with distilled water with salinity 16‰ adjusted to pH 7.0, 7.5, and 8.0 (5 replicates of each) and kept at 16°C for 5 weeks. Aquaria were photographed weekly to permit classification of their ichnofabric index.

After 5 weeks, tanks at pHs 7.0, 7.5 and 8.0 had mean II of 2.6, 3.2 and 2.4 respectively. No tanks exhibited the near-total loss of bioturbation seen at the Permian-Triassic boundary, but acidification stress during that event persisted over much longer timescales than we can replicate. Nevertheless, our experiments show that altered pH reduces bioturbation activity, lending tentative support for a role for OA in extinction crises that record a drop in ichnofabric index.

What were they thinking? Exploring ceratopsian braincase morphology and palaeoneurology through ontogeny.

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Since the 19th Century palaeontologists have been examining whether endocasts can provide a good estimate of brain size and morphology and, if so, what this can tell us about the sensory capacity of these long dead organisms. Ceratopsians were one of the most diverse dinosaur clades of the Late Cretaceous. Ceratopsian palaeontology currently lacks comprehensive neuroanatomical studies which can illuminate how neurology might predict behaviours that have been suggested by previous research.
Braincases are often neglected in contemporary palaeontological studies due to the high level of fusion and consequent obscurity of sutures. In the case of near sutural obliteration, landmarks on the braincase such as nerve exits and tubera can be used to map bone extent and thus allows for approximate yet reliable braincase segmentation.
Ceratopsian skulls were imaged using high resolution micro-CT scanners and were then reconstructed in Avizo (3D visualisation software). The first project, described here, investigates changes in neurocranial architecture through ontogeny of one species (*Psittacosaurus*). This has been a rare chance to acquire detailed 3D information on numerous ontogenetic stages of a single dinosaur species, from hatchling through juvenile to adult, and to link the various allometric and morphometric deviations from isometry to wider function.

Callovian ammonite and brachiopod faunas from the Essaouira-Agadir Basin (Morocco). Palaeogeographic implications.

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New fieldwork in the Middle and Upper Jurassic of the Essaouira-Agadir Basin of Atlantic Morocco was undertaken in the past two years. Extensive collections of ammonites and brachiopods were made bed by bed at three reference sections in the Imouzzer Ida Ou Tanane area and at Jebel Amsitene. In addition,. a revision of the historical collections stored at the MEM in Rabat allowed us to complement the new field data.
The ammonite faunas collected allowed us to recognize the late early to early late Callovian ammonite biozones of the standard Mediterranean scale. The fauna is dominated by species of *Reineckeinae, Grossouvriinae* and *Peltoceratinae* that characterise the mediterranean successions of the northern margin of the Tethys with special reference to the standard succession of western France (Poitou).
Brachiopod assemblages span a slightly longer time interval and may already be present in the Late Bathonian. The faunas are dominated by members of the genera *Kutchithyris*, *Bihenithyris*, *Kutchithyrinchia* and *Somalirynchia*. Similar faunas are known from the horn of Africa, southern Arabia, and the Indian subcontinent and are characteristic of the Jurassic Ethiopian Province. Distribution of the assemblages in time and space will be discussed.

Bird-hipped, but bird-brained? Sensorineural trends within Neornithischia and the evolution of ornithopod social signalling structures.

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Numerous species of ornithischian dinosaurs, most notably hadrosaurian ornithopods, exhibited elaborate cranial crests. These crests functioned in visual and acoustic signalling, providing osteological correlates of social activity and a rare opportunity to investigate sensorineural trends associated with the evolution of complex intraspecific interactions. Reconstruction of hadrosaur endocasts has demonstrated relatively large cerebrum volumes, suggesting increased cognition associated with these social behaviours. However, sampling of endocasts from earlier diverging neornithischian lineages has been sparse, frustrating efforts to clarify trends in neurological evolution within the clade.
To address this, the endocranial space and inner ear morphology of the non-ornithopod neornithischian Thescelosaurus and an unnamed, early-diverging ornithopod from the Cedar Mountain Formation were digitally reconstructed from CT scan data, and compared to those of other ornithopod taxa in an explicit phylogenetic context. *Thescelosaurus* is plesiomorphic in brain morphology, with an encephalisation quotient (EQ) value intermediate between thyreophoran and ornithopod taxa. Expansion of the cerebrum and increasing EQ values are then seen through Ornithopoda, culminating in the highest observed values in hadrosaurs. This suggests that the expanded forebrains of these taxa may be the result of longer-term processes as opposed to a correlative of the evolution of elaborate crests within Hadrosauria.

Trematode traces on Recent bivalve shells

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Parasitic digenean trematodes have a complicated life cycle with one or two intermediate hosts before they enter their terminal vertebrate host (bird, fish). They have a very low fossilization potential. They are mainly studied by biologists. Some digenean trematodes belonging to the Gymnophallidae use bivalve molluscs as their last intermediate host: they encapsulate themselves as cysts (metacercaria) between mantle and shell and leave their traces. Not all these infected bivalves are consumed: intact shells can be found with traces of these cysts such as the pits first reported in fossil shells by Ruiz & Lindberg (1967). Different trematode cyst traces exist. Whether these traces are really made by metacercaria can only be studied in living bivalves. Studying life cycles and the role of parasites in food-webs is still a growing field of research. I present pictures of trematode traces in Recent bivalve shells from the North- and Wadden Sea coast of the Island of Texel, the Netherlands. Interest in trace fossil evidence of trematode-bivalve interactions in the past is increasing (Huntley & De Baets, 2016).

The phylogenetic performance of morphological partitions in birds and squamate reptiles

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Despite increased use of genomic data in phylogenetics, morphological information remains important for resolving evolutionary relationships, particularly for fossil species for which molecular data is unavailable. An important issue with molecular data, however, is the nature of the morphological characters themselves. Selection and evolutionary lability can make some sets of characters more prone to homoplasy than others. Moreover, when these characters evolve in semi-autonomous modules, they have the potential to overwhelm genuine phylogenetic signal contained within the data. Here we use meta-analysis of 29 published datasets to compare osteological and soft-character partitions in birds and squamate reptiles and test for different levels of homoplasy relative to molecular phylogenies. We demonstrate that non-osteological characters are marginally less consistent with

molecular data in general in birds ($p<0.001$), but are more consistent with this phylogeny in a single, large morphological dataset. This may partly reflect different evolutionary rates or evolutionary constraints at different taxonomic levels, but in general osteological data appear to track evolutionary history better than soft characters in birds. This finding offers reassurance to palaeontologists building phylogenies of birds, dinosaurs and other reptiles, as the more readily fossilizable characters are the ones found to be more consistent with molecular trees.

Microstructural and chemical characterization of medullary bone across the bird phylogeny

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Medullary bone (MB) is a specialized tissue produced by female birds during the egg-laying cycle. It is commonly described as a highly vascularized and strictly woven bone tissue, endosteally deposited in the medullary cavity of hindlimb elements. Using these criteria, MB-like tissues have been identified in non-avian dinosaur specimens. However, MB's definition mostly results from its study in domestic bird species that are not representative of bird diversity. Moreover, some avian pathological bone tissues meet these criteria, thus casting doubt on previous observations of MB in the fossil record.
With a sample of 40 bird species, the present work constitutes the first taxonomically comprehensive study of MB. Using micro-CT and histochemical techniques, our study assesses the skeletal distribution and extent of microstructural and chemical variation of MB across birds.
Our preliminary results reveal that the distribution of MB in the postcranial skeleton varies interspecifically. MB is uniformly present in the femur and tibiotarsus and consistently absent in the pes. Only few species exhibit MB in the humerus. Its chemistry is diagnostically different from pathological bone. Finally, MB presents a lamellar component in some specimens.
These new data will be used to reassess previously published identifications of MB in fossil archosaurs.

The Chris King collection - a data goldmine buried in the clay?

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The Natural History Museum, London, has been bequeathed a unique fossil collection of benthic macro- and microfauna of Paleocene/early Eocene age. Collected over forty years in southern England and north-west Belgium, this major assemblage comprises 80,000 specimens, mainly molluscs. It is currently being curated and digitized to allow us to extend research beyond its original purpose of improving stratigraphic dating and correlation. A clear research opportunity lies in analysis of the biotic response to global temperature change during the uppermost Paleocene-lower Eocene. The collection finely samples coastal sediments deposited across the southern margin of the North Sea Basin, a key area preserving excellent sedimentary records across a short duration spike in global temperatures, the Paleocene-Eocene Thermal Maximum (PETM: 55.8-60.0 Ma). During this period warming of 5-8°C occurred within just 10 kyr. The detailed response of coastal macrofauna to this episode remains largely unknown. It is anticipated that quantitative studies on this collection could substantially increase our understanding of shallow marine palaeoenviroments and taxonomic and ecological responses of their biota across the PETM. Additionally, integration of isotopic analysis with macrofaunal analysis may reveal the possible role of hyposalinity and permit characterization of biotic change at ecologically valuable stratigraphically fine scales.

Acritarchs, cryptospores: why almost all palaeontology text-books got it wrong

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Evitt (1963, PNAS 49 : 298–302) defined the acritarchs as an informal group of organic-walled microfossils with unknown biological affinities (that could not be attributed to a known group of phytoplankton, such as the

dinoflagellates or any other biological group). Richardson et al. (1984, J. Micropal. 3:109-124) proposed the diagnosis of another informal grouping, the 'anteturma Cryptosporites' in order to classify primitive spore-like palynomorphs (that could not be attributed with certainty to the spores of land-plants). Since the original description of the terms 'acritarchs' and 'cryptospores,' many other definitions have been proposed for both informal groupings, creating a debate between specialists that is mainly based on the confusion between the definition (based on morphologies) and the (speculative) biological interpretation of both terms. Consequently, almost no current palaeontological text-book or website cites correctly the original definition of the 'acritarchs' and the 'cryptospores'. We advocate that, as long as the exact biological affinity of most of the individual morphotypes remains unknown, the informal groupings of the acritarchs and the cryptospores are still valuable and the original definitions should be retained, based solely on morphological criteria.

Character completeness of the temnospondyl amphibian fossil record

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Changes in fossil specimen completeness can alter the amount of observable character states per species, and, therefore, affect macroevolutionary interpretations. The quality of the tetrapod fossil record has been quantified as the proportion of phylogenetic characters that can be scored for an individual species. Here, we calculate this character completeness metric (CCM) for temnospondyl amphibians using all previously published phylogenetic matrices focused solely on the group. We also use an alternate implementation of the CCM which calculates how completely known individual characters are through time. Variation in completeness across different partitions of cladistic characters may offer a potential explanation for poorly constrained areas of temnospondyl interrelationships.
The most character-rich matrices show that mean temnospondyl character completeness is consistently very high (~75–95%) for both species and characters, with little relative fluctuation through time. Completeness does not correlate with changes in diversity, which suggests that it is unlikely to be limiting our understanding of temnospondyl macroevolution; however, completeness is likely inflated due to the exclusion of poorly known taxa in phylogenetic analyses. There are also significant differences in completeness between different portions of the temnospondyl skeleton, which may be explained by preferential preservation bias of the skull.

Jurassic fish from Scotland – new finds from the calm before the teleost storm.

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Middle Jurassic fish assemblages provide an important and exciting insight into a time immediately before the establishment, in the Upper Jurassic, of the largest extant fish group, the crown-group teleosts. New finds from the Middle Jurassic of the Isles of Skye and Eigg, Scotland, reveal a diverse assemblage comprising chondrichthyans, new species of pycnodonts, pachycormids, stem-group teleosts but also possible perleidiforms. Additionally, specimens from the Upper Jurassic of northeast Scotland record hybodont sharks and members of the Caturidae, Furidae and Aspidorhynchidae but only one record of a pycnodont. Palaeobiogeographic analysis of the pycnodont assemblage indicates that founder event speciation and dispersal from the epicontinental seas of Europe are shown to govern pycnodont evolution similar to the dispersal pattern of Pachycormiformes. The Skye *Pachycormus* is contemporary with, and likely identical to, those from Strawberry Bank, Gloucester. In addition to phosphatic body fossils, three different morphotypes of otolith have been recovered including some attributable

to *Leptolepis*. These new finds demonstrate the importance of Jurassic deposits of Scotland as a potential source of new and important taxa that will help to provide important insights immediately before the origination of the largest vertebrate group currently in existence – teleost fish.

Constraining the timing of whole genome duplication in plant evoltionary history

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Whole genome duplication (WGD) has occurred in many lineages within the tree of life and is invariably invoked as causal to evolutionary innovation, increased diversity, and extinction resistance. Testing such hypotheses is problematic, not least since the timing of WGD events has proven hard to constrain. Here we show that WGD events can be dated through molecular clock analysis of concatenated gene families, calibrated using fossil evidence for the ages of species divergences that bracket WGD events. We apply this approach to dating the two major genome duplication events shared by all seed plants (ζ) and flowering plants (ε), estimating the seed plant WGD event at 399-381 Ma, and the angiosperm WGD event at 319-297 Ma. These events thus took place early in the stem of both lineages, precluding hypotheses of WGD conferring extinction resistance, driving dramatic increases in innovation and diversity, but corroborating and qualifying the more permissive hypothesis of a 'lag-time' in realising the effects of WGD in plant evolution.

Rooting the tree and investigating the evolutionary history of Bacteria

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A rooted tree of Bacteria is essential to reconstruct the evolutionary history of Bacteria, including ancestral gene content, metabolism and physiology. Many current ideas pertaining to the nature of bacterial evolution are informed by hypotheses of prokaryotic phylogeny. However, rooting the tree of Bacteria has proven difficult. Recent discoveries of a huge diversity of new uncultured phyla further complicate matters, and the relationships between the major bacterial phyla still have little resolution. We attempt to construct a rooted tree of bacteria using probabilistic gene tree-species tree reconciliation methods. These are hierarchical models in which horizontal gene transfers (HGTs), gene duplications and gene losses are integrated into an overall model of genome evolution using amalgamated likelihood estimation (ALE), where patterns of gene family evolution contain information about the root of the tree. Using these methods, we may produce a rooted tree and reconstruct ancestral gene content and metabolism for the internal nodes, including the last bacterial common ancestor (LBCA), and can infer information about the early evolution of life. We also investigate HGTs through time, and look at the evolution of membrane lipids across the tree of Bacteria to ascertain whether the so-called 'lipid divide' between Bacteria and Archaea exists.

Initial steps in ordering events of the Late Ordovician mass extinction: chitinozoan contributions to Maquoketa Group holostratigraphy (Upper Katian, Wisconsin, USA).

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The Maquoketa Group contains a series of carbonate carbon isotope excursions that record ocean-geochemical disturbances during the run-up to the Late Ordovician mass extinction and glacial maximum. To enhance understanding of the processes active during these times of severe climatic, oceanic and biospheric change,

ordering the regional stratigraphic succession to the global chronostratigraphic scheme is crucial. Preliminary chemostratigraphy and facies analysis shows significant regional differences within the Maquoketa Group along a continental interior to margin transect. We hypothesize that this variability reflects a diachronous succession that in total captures one of the most complete and well-preserved records of the Upper Ordovician in the world. Here, to test this hypothesis, we develop a chitinozoan biostratigraphy for the Gardner Kiln core (Wisconsin, USA), which penetrates the entire Maquoketa Group. Thirty-two samples yield rich and well-preserved assemblages with 6084 chitinozoan specimens assigned to 47 species. Preliminary correlations are drawn with sections across North America for which chitinozoan biostratigraphy is available (i.e., Oklahoma, Kentucky, and Québec). The exceptionally well-preserved palynomorphs from the Maquoketa Group illustrate the potential for this group to become a key biostratigraphic tool in high-resolution integrated stratigraphy of the Upper Ordovician in the US Midcontinent region.

Chitinozoans from the Rheidol Gorge Section, Central Wales, UK: a GSSP replacement candidate for the Rhuddanian/Aeronian boundary

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As part of an effort to evaluate potential replacement sections for the existing Aeronian base stratotype, 28 samples from the Rhuddanian/Aeronian boundary interval of the Rheidol Gorge section (central Wales, UK) were studied for chitinozoans. Famously known through the work of Jones (1909) and Sudbury (1958), the sampled succession comprises a graptolite-bearing sequence of laminated black shales alternated with thinner, sparsely graptolitic grey mudstone intervals, deposited under anoxic and oxic-to-dysoxic seafloor conditions, respectively. The exposed section of approximately twenty meters spans the middle part of the upper Rhuddanian *Monograptus* (*Coronograptus*) *cyphus* Zone through the lower Aeronian *Monograptus* (*Demirastrites*) *triangulatus* Zone of the mid-Llandovery Series. Despite our increased sampling viz-à-vis preliminary reports and the presence of numerous and moderately well-preserved specimens, the chitinozoan analysis demonstrates a species assemblage that remains more-or-less uniform throughout the entire exposed succession. The assemblage is characteristic of that of the *Spinachitina maennili* Biozone, which is globally recognised around the base of the Aeronian. Chitinozoans from the Rheidol gorge section can thus be directly correlated to the original type Llandovery area and to many lower Silurian Rhuddanian/Aeronian boundary successions in other parts of the world.

Testing the link between beak shape and functional performance in birds

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Bird beaks are often a cited example of the tight relationship between morphological form and function. Despite this, recent work has suggested that skull and beak morphology is a surprisingly weak predictor of dietary ecology, and instead beak shape is constrained by size, phylogeny and integration with the braincase. While these studies have tested the link between shape and ecology, the link between shape and function remains largely unexplored. The aim of this study was therefore to test how variation in bird beak shape relates to mechanical function. Beginning with a 2D morphospace of skull shape in 227 passeriform taxa, we created 25 3D hypothetical beak shapes that capture the variation in form across axes 1 and 2 of the morphospace, capturing 77% of skull shape variation. Finite element analysis (FEA) was used to estimate beak stress in response to a load at the beak tip. Our results show a significant exponential relationship between axes 1 and 2 of the morphospace and the ability of the shape to dissipate stress. Some underpopulated regions of the morphospace perform just as well as some of the more populated areas, suggesting other links between shape and function are yet to be quantified.

The apparatus composition and architecture of *Erismodus quadridactylus* and its implications for the prioniodinin apparatus bauplan

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The apparatus composition and architecture of prioniodinin conodonts is poorly understood, largely because few prioniodinin taxa are represented by articulated 'natural assemblages', but also due to the highly variable gradational morphology of their constituent elements that makes apparatus reconstruction problematic. We describe a natural assemblage of *Erismodus quadridactylus* (Stauffer, 1935), a basal prioniodinin conodont, from the Sandbian (Late Ordovician) of North Dakota, USA. The assemblage demonstrates that the apparatus architecture of *Erismodus* is similar to those of Late Palaeozoic prioniodinins, namely, *Kladognathus* Rexroad and *Hibbardella* Bassler, but also has similarities with ozarkodinin apparatuses. There is evidence to suggest that *E. quadridactylus* also shared topological similarities to 'prioniodontid' architecture, with respect to the position of its inferred P elements. This apparatus reconstruction suggests, at least with respect to the M-S array, an 'ozarkodinin-type' bauplan is likely more widely representative across ozarkodinids. Furthermore, element morphotypes traditionally considered to lie within the S array are M elements, whereas others traditionally interpreted as P elements are found in the S array. These observations are used as a basis for revising the prioniodinin apparatus bauplan and for refining concepts of element homology among other prioniodinin conodonts and their closest relatives.

Cranial osteology of *Martillichthys renwickae* [Neopterygii; Pachycormiformes], and ecological implications for suspension-feeding pachycormids

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Pachycormids are a modestly diverse family of putative stem teleosts, ranging in age from the Early Jurassic to the Late Cretaceous, and found in marine deposits across the globe. While some members of the group are well represented in the fossil record, the most famous pachycormids — the giant suspension feeders including the enigmatic *Leedsichthys* — are almost exclusively known from crushed, disarticulated material, and have been largely characterised by fragments, limiting understanding of their ecology and evolution. Here, we use CT scanning to re-describe an articulated, though flattened, cranium of *Martillichthys renwickae* from the Middle Jurassic (Callovian) Oxford Clay of the UK. This scan reveals internal details of perhaps the most complete suspension feeding pachycormid skull known, and revises several details of the anatomy of *Martillichthys*. Most significantly, *Martillichthys* shows specialized characters with an apparently restricted distribution among suspension-feeding pachycormids, including gill rakers with elongated 'needle teeth' and a greatly extended occipital stalk. Our virtual models of *Martillichthys* reinforce past systematic interpretations of the interrelationships of suspension feeding pachycormids, and provide a model for interpreting the less complete remains of other members of this enigmatic but long-lived group of fishes.

Radiological study of the sequence of dental mineralization, eruption and replacement in hipparionine horses from the Miocene of Spain

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Hipparionine horses are ubiquitous in Neogene continental fossil sites of Eurasia, Africa and North America so they have been the object of iconic biostratigraphical, evolutionary and palaeoecological studies. Cerro de los Batallones palaeontological complex (Madrid Basin, Spain) is composed of 9 fossil sites that contain a massive amount of remains belonging to a diverse Late Miocene mammalian fauna. Among these sites, Batallones-10 stands out for containing exceptionally well-preserved remains of herbivores, with the equid *Hipparion* sp. being the best represented taxon. *Hipparion* sp. maxilla and mandibles with teeth in place are very abundant at Batallones-10, contrary to what is usual in most of the mammalian fossil sites, where teeth are commonly found in isolation. This fact allowed us to analyse mandibles of 27 *Hipparion* sp. individuals from Batallones-10 with radiological techniques (X-ray and CT scan) with the aim of: 1) describing the sequence of mineralization, eruption and replacement of teeth in a complete hipparionine horse ontogenetic series that includes an abundant representation of juvenile individuals for the first time and 2) inferring whether the *Hipparion* sp. individuals from Batallones-10 died as a consequence of a gradual (attritional) process or a catastrophic event.

The exceptional diversity of trilobite moult configurations from the Emu Bay Shale, South Australia

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The Emu Bay Shale (EBS) is a Cambrian Stage 2 Konservat-Lagerstätte dominated by preserved carcasses and moulted exoskeletons of two extremely numerous trilobite species, *Estaingia bilobata* and *Redlichia takooensis*. Moult configurations of these species capture the movement of the trilobite and pattern of sclerite disarticulation, therefore allowing an unparalleled detailed interpretation of behaviour during moulting events. This exceptional in-situ preservation results from a lack of disruptive abiotic and biotic processes (currents, bioturbation), and rapid burial at the EBS.
The extensive collections of *E. bilobata* and *R. takooensis* housed in the South Australian Museum, Adelaide, were surveyed, and a number of specimens displaying the full observable range of variation in moulting behaviour chosen for closer examination. Rare moulting events utilising unusual movements (such as disarticulation of the entire cephalon), which are often not preserved at localities with greater disruption, are discernable. Several new moult configurations were named on the basis of these specimens, and other names resurrected from the literature. These will be used as a tool to interpret trilobite moulting at other Palaeozoic Konservat-Lagerstätte. The EBS results demonstrate hitherto undescribed intraspecific moulting behaviour flexibility, particularly during early trilobite evolution. Fieldwork is planned to quantify this moulting variability.

A new myriacanthid holocephalian from the Early Jurassic of Bornholm, Denmark

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A new myriacanthid holocephalian is described from the Hasle Formation (probably *Uptonia jamesoni* subzone to *Acanthopleuroceras valdani* subzone, Early Pliensbachian, Early Jurassic) of Bornholm (Denmark) on the basis of isolated upper posterior (palatine) and lower posterior (mandibular) tooth plates. *Oblidens bornholmensis* gen. et sp. nov. differs from all other myriacanthids for which the same dental elements are known, in the distribution of the hypermineralised tissue covering the occlusal surfaces of the tooth plates, and the arrangement of the ridges transecting the tooth plate surface and so varying their surface relief. *Oblidens* is the first myriacanthid holocephalian to be recorded both from the Pliensbachian and from Denmark. The presence of a further, undetermined myriacanthid tooth plate is noted from the same locality.

The frondose Ediacaran macrofossil *Arborea arborea* is a eumetazoan

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The Ediacaran frond *Arborea arborea* from South Australia is an iconic member of the soft-bodied Ediacaran macrobioa. Largely recognised from fragmentary remains, *Aborea* possesses a distinctive frondose body plan, and could reach almost three metres in size. However, it has been little studied when compared to the other main frondose component of the Ediacaran biota, the rangeomorphs.
Examination of multiple *Arborea* specimens from the Ediacara Member of South Australia reveals a previously unrecognised suite of morphological characters. These include an inflatable holdfast disc, front-back differentiation, and a stem that exhibits considerable variation in its length within populations. Exceptionally preserved specimens reveal features that we interpret as preserved internal anatomical structures. These reveal differentiation of tissues, and a network of bundled linear tubular structures that raise the possibility that *Arborea* was a colonial organism. In conjunction with previously recognised features including apico-basal differentiation, we propose that to the exclusion of all non-metazoan possibilities, *Arborea* was a total-group eumetazoan.

The Late Triassic latitudinal biodiversity gradient

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The latitudinal biodiversity gradient (LBG), the increase in species richness towards the equator, is one of the most widely recognised patterns in macroecology. This gradient has been extensively documented in modern terrestrial vertebrate faunas, yet the evolution and drivers of this pattern through time remain uncertain. The fossil record offers a deep time perspective on the LBG; however, previous studies have been hampered by uneven spatial and temporal sampling, particularly very poor sampling of low-latitude regions. The Late Triassic tetrapod fossil record provides a unique opportunity to study the LBG in deep time, as sampling in low- and mid-latitude regions during this interval has been extensive, and the climate and continental configuration were very different from today's. Here, we explore the relationships between Late Triassic tetrapod diversity, palaeolatitude, and climate using data from the Paleobiology Database, sampling standardisation, and tree-based biogeographic and character-mapping approaches. Results suggest that Late Triassic tetrapods do not conform to a modern-type LBD; instead diversity is higher at mid-latitudes than at low-latitudes. We also examine the distribution of major Late Triassic tetrapod groups (e.g. dinosaurs, temnospondyls, and pseudosuchians) and how this relates to global climate to uncover the drivers of spatial variation in global tetrapod diversity.

Decreasing influence of calcite – aragonite seas on marine calcifiers in the Phanerozoic

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Aragonite-calcite sea conditions describe Phanerozoic fluctuations of abiotic marine aragonite vs calcite precipitation, which is thought to be driven by oscillations in seawater Mg:Ca ratio, temperature, and pCO_2. Despite many examples of groups of marine calcifiers originating or diversifying when aragonite-calcite sea conditions favoured their skeletal mineralogy, no convincing quantitative evidence currently supports these inferences at Phanerozoic time scales. Here, we apply Summed Common species Occurrence Rate (SCOR) to

fossil occurrence data from the Paleobiology Database (PBDB) to assess the relative success of marine aragonite-shelled organisms in the context of fluctuating aragonite-calcite sea conditions. We find that covariation between aragonite-calcite sea conditions and skeletal composition is time dependent with the Ordovician – Carboniferous showing the best correlation, followed by the Permian, but becomes insignificant for the remainder of the Phanerozoic. We propose a combination of changes in the taxonomic composition and $CaCO_3$ saturation state to explain the observed patterns.

Evolutionary tempo in Permo-Triassic terrestrial amniotes

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Simpson's ground-breaking "Tempo and Mode in Evolution" laid the foundation for modern phylogenetic comparative analyses. Many studies based on palaeontological datasets focused on the "mode" of evolution, neglecting the equally important "tempo". Furthermore, most analyses assumed homogeneous evolutionary rates and did not account for potentially variable evolutionary rates.
Here we present the first comprehensive analysis of rates of body size evolution in Permo-Triassic terrestrial amniotes. We show that heterogeneous evolutionary rates are ubiquitous in the fossil record of early amniotes. Exceptionally high rates can be found in various clades of parareptiles and therapsids. Both Parareptilia and Therapsida experience an increase in evolutionary rates through time. Archosauromorphs, on the other hand, follow a homogeneous rate model, even when accounting for different postulated topologies. Elevated evolutionary rates appear to be associated with drastic changes in body size, diet and short-term diversification events. High rates of body size evolution do not seem to confer long-term advantages over competing clades, and might in fact indicate stress in the respective groups. Comparisons with published analyses that did not account for variable rates indicate that those inferences of evolutionary mode might have been biased for various amniote clades (e.g. Anomodontia).

The function of colouration in *Confuciusornis*

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Techniques using the morphology of fossilized melanosomes make it possible to reconstruct the colours of melanin-based integumentary patterns and thus provide insight into the ecology and behaviour of extinct organisms. We studied a well-preserved specimen of the Cretaceous bird *Confuciusornis* to shed light on its palaeobiology. Using data taken from preserved melanosomes, we identified different melanin-based colours of the head, chest, coverts, remiges, and rectrices. Our analyses indicate that *Confuciusornis* wore grey on most of its body. Our data have implications for signalling. The streamer-like rectrices found on some specimens of *Confuciusornis* have been hypothesized to play a role in sexual signalling. However, as the rectrices present in the specimen we sampled were grey, our data do not support that pigmentation augmented this purported function. Despite the inferences made here, definitive conclusions on the ecology and behaviour of *Confuciusornis* cannot be made without a comparison of more specimens. As this taxon potentially exhibits dimorphism in the presence or absence of long rectrices, there is potential for sexual dichromatism. This could be tested in the future by analysing additional specimens.

The Natural History Museum's Fossil ExplorerApp: A Smartphone application to help non-specialists identify common UK fossils

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Fossil Explorer is a Cordova/Phonegap hybrid mobile application, written in Javascript, HTML and Google's AngularJS Javascript app framework published in April 2017 for Android and IOS operating systems. It aims to help non-specialists identify common UK fossils based on where they were found. The app returns illustrated lists of common fossils for any location either through user selection or geolocation functionality, where the fossil age range corresponds to the outcropping rock. Data webservices provided by Google Maps and the British Geological Survey were used for geolocation and plotting the distriution of rock ranges. Fossil data and images were compiled from the NHM's British Fossils range of books.
As of September 2017, the app has 6000+ users making 100,000 screen visits. The app has high return usage and average usage times demonstrating market appetite and practical use. Simple design and user journeys have contributed to its success.

Size change in Chalk Sea echinoids from southern England during the Cenomanian-Turonian extinction event.

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The Cenomanian/Turonian boundary (CTB) was a time of global change, with mid-latitude seawater temperatures exceeding 27°C, elevated primary productivity, widespread marine anoxia and marine extinctions. Approximately 7% of marine families and 27% of marine genera are thought to have become extinct at this time. Given these climatic and biotic changes, we would expect body sizes of marine animals to become temporarily smaller due to elevated temperatures, lower levels of dissolved oxygen and the post-extinction Lilliput effect. To test this hypothesis, we measured 1659 individuals, representing 6 echinoid orders, spanning the upper Albian to Santonian from sites in southern England, UK. Significant reductions in body size across the CTB were recorded in Saleniidae (Salenioida), *Camerogalerus* (Discoididae, Holectypoida) and Hemiasteridae (Spatangoida). The Holasteroida also reduced in size, but not significantly. Unexpectedly, *Conulus* (Conulidae, Echinoneoida) and Cidaroida both increased in size, although this change was not significant in the Cidaroida due to a paucity of Turonian samples. The within-lineage size increase in *Conulus* is associated with a change in inferred feeding and tiering. Size reductions at family and ordinal level were associated with shifts in taxonomic composition, with apparent loss of larger genera and replacement by smaller genera through time.

The affinity of some peculiar macrofossils from Sirius Passet, North Greenland

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Reflective patches are commonly found in the early Cambrian Sirius Passet Lagerstätte, North Greenland. A very distinct morphotype is characterised by having a prominent ridge and a specific growth trajectory. Analysing specimens ranging from 3.2mm to 180.3mm in length allows classification of the fossils into three morphogroups: oval / quasi-oval, extended and irregular, due to differences in geometry. Due to their peculiar anatomy, we review their likely biogenic status and affinity, including: microbially induced sedimentary structures, rip-up clasts from microbial mats, sponges, placozoans as well as colonial and multicellular cyanobacteria. Some specimens preserve articulated arrays of spicules, suggesting affinities with sponges, while others lack such features. We can reject a fungal, biofilm, or stromatolite affinity as we cannot demonstrate that the adjacent sediments were deformed or sediment was agglutinated, and a placozoan affinity as we observe possible amalgamation in the larger forms. Although these fossils currently have no obvious affinity, they are very distinct, which suggest that these organisms are a new group of organisms with an, as yet, unclear affinity.

Seagrass and the history of cuttlefish

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Cuttlefish possibly had an origin in the late Cretaceous and subsequently radiated globally. By the Middle Eocene cuttlefish may have evolved into Sepia s.l. The record of cuttlefish in the New World ceased by the end of the Eocene possibly as a result of climate cooling. The lack of cuttlefish in the New World continues to the present day. Later fossil records are mostly from Europe. Cuttlefish are currently found in seagrass and other environments globally, except for the New World and Antarctica. Rare fossil forms belonging to Belosaepiidae s.l. and Sepiidae are recorded in faunal collections that may have come from the proximity of past seagrass environments. This relationship may have been formed in the late Cretaceous and continues to the present day. The fidelity exhibited may be due to cuttlefish behaviours in seagrass including feeding, protection and reproduction. In particular seagrass acting as a nursery may be important.

British Zechstein palynomorphs suggests a wetter Late Permian environment

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The Late Permian Zechstein Sea was a semi-isolated inland sea occupying the Southern Permian Basin at equatorial latitudes. The sea endured for 5 to 7 million years during which time it underwent five cycles of evaporation. In the context of an increasingly arid Late Permian climate, classic Zechstein reconstructions show cyclic regressions accompanied by evaporative down draw leading to hypersaline conditions. This resulted in dramatic short term reductions in biotic abundance and diversity in both the marine and terrestrial realms. However, it is hypothesised that transgression phases experienced sufficient precipitation to allow ecosystem recovery in both marine and terrestrial environments.
Palynological investigation of borehole material from northeast Yorkshire has yielded unexpected palynomorph abundance from the Carnallitic Marl Formation in the fourth cycle. The palynomorph assemblage is dominated by taeniate and striate bisaccate pollen accompanied by monosaccates and trisaccates. Typical Late Permian taxa *Lueckisporites*, *Protohaploxypinus*, *Nuskoisporites*, *Perisaccus*, *Klausipollenites*, *Vittatina*, *Labiisporites*, *Vestigisporites* and *Illenites* have been identified and lend support to a transient gymnosperm-dominated late Zechstein vegetation.
The presence of such an abundance of palynomorphs questions previous assumptions that Late Permian equatorial climates were continuously arid. These findings suggest the climate was at times damp enough to support extensive gymnosperm forests.

Ostracod fauna of the Aras Valley section (NW-Iran) indicates sustained oxygenated conditions during the end-Permian mass extinction

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Several drivers, such as global temperature rise, marine deoxygenation and ocean acidification have been suspected to explain the end-Permian mass extinction. Although supportive evidence exists for all three scenarios (e.g. geochemical, sedimentological and palaeontological data), environmental parameters accompanying the extinction are still a matter of debate.
In our study, the exceptionally high ostracod content of the Aras Valley (NW-Iran) section was investigated to examine environmental conditions during the extinction and the recovery phase. The “Boundary Clay” of this

section shows a continuous sedimentary succession, deposited after the extinction event in an outer shelf setting. Its investigation yielded a high species richness of 70, belonging to 23 genera, mainly including typical Palaeozoic taxa, such as Palaeocopids, Platycopids of the genera *Cavellina* and *Sulcella*, as well as Bairdiidae. Mass occurrences of *Praezabythocypris ottomanensis* in the upper part of the "Boundary Clay", correlated to a persistent temperature rise and marking a replacement within the assemblage by Podocopids suggest a changing environment. However, the generally high species richness and high abundance of Bairdioidea, which indicate normal marine conditions, lead to the assumption that anoxic conditions were not significantly affecting the Aras Valley section.

Microbial communities and decay: how their diversity and succession affects the fossil record.

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Understanding decay is fundamental to the correct interpretation of fossils, especially exceptionally preserved soft bodied remains. Decay influences the preservation potential of characters, and it has been shown that patterns of character loss are conserved between related taxa, even under different conditions. These patterns undoubtedly reflect both the nature of soft tissues and the results of microbial decomposition, yet little is known about the latter. Previous work has investigated the formation of bacterial biofilms, how clays affect microbial communities, and patterns of microbial succession in terrestrial vertebrates (in a forensic context), but how the diversity and succession of microbial communities during decay relates to rates and sequences of character loss in unknown. Here we present the first investigation of this problem, documenting the diversity and abundance of whole microbial communities (bacteria, archaea, and fungi) during controlled decay of amphioxus under a range of experimental conditions. Our study addresses important questions regarding both the design of experiments to investigate exceptional preservation, and the degree to which variation in microbial succession controls the sequence and rate of character loss through decay.

Quantitative assessment of evolutionary trends in a late Triassic conodont lineage

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A debate still remains about the origin of form in evolutive biology, whether it is driven 'externally' by environmental factors and natural selection, or 'internally' by developmental constraints. Owing to their long and rich fossil record, conodonts have a great potential for shedding light on this debate. Some recent studies (Jones et al. 2012, Martínez-Pérez et al. 2016) have highlighted how some conodont morphologies/traits might have constituted the basis for functional adaptation to weaker or harder food. Nevertheless, too little is currently known about potential developmental constraints in conodont elements.
Here we scanned and analyzed about 160 P1 elements of three phylogenetic related genera originating from a GSSP candidate Carnian-Norian Boundary located in Sicily. This material has been the focus of an array of recent interesting studies by Mazza and coworkers (Mazza et al. 2012, 2015, 2016). In particular they performed cladistics analyses, and qualitatively described evolutionary trends. Moreover, the material preservation is usually pristine, so its good quality allows such quantitative analyses. Using both Elliptic Fourier contour analysis and landmark or sliding-landmark-based geometric morphometrics, we quantitatively test the suggested evolutionary trends, and identified patterns of covariation through the phylogeny that may reflect underlying developmental rules.

The palaeobiology of Ediacaran *Palaeopascichnus*: new insights from morphometric and geochemical analysis

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The Palaeopascichnida are a relatively understudied component of the enigmatic Ediacaran biota. The structure is comprised of series of mm-scale, oval-shaped elements previously interpreted as: evidence of movement; feeding traces; and alternatively as body fossils of various affinities. *Palaeopascichnus* has been compared to the Xenophyophora, an extant group of large, benthic protists found in deep marine habitats that are characterized by their large size and possession of stercomata within their cells.
The biological construction and test interpretations of phylogenetic affinity for *Palaeopascichnus* was assessed using material from the Ediacaran of Newfoundland, Canada. Quantitative morphological analysis of 125 well-preserved specimens shows complex branching and well-constrained growth patterns, and multivariate statistical and cluster analysis both identifies natural groupings within that dataset, allowing quantification of similarities with extant taxa. Petrographic analysis combined with SEM backscatter imaging and elemental mapping also revealed enrichment of metallic elements (Ti, Ba, Fe) within the oval-shaped walls that, with morphometric analysis, supports a foraminiferan affinity.

Palaeoclimate analysis of the flora of the latest Eocene Insect Limestone of the Isle of Wight, southern England

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The latest Eocene flora from the Insect Limestone, Isle of Wight, is an important representative of British Paleogene vegetation, indicative of European environmental conditions near the onset of global change. New collections, and those in the Natural History Museum, the Dinosaur Isle Museum and made by Andy Yule, have been studied. Plant remains occur in concentrations of debris within a horizon of very fine micrite near the base of the Bembridge Marls Member, Bouldnor Formation, Solent Group. Nearest living relatives of the most abundant fossils are wetland herbs, e.g. *Azolla*, *Sabrenia*, and most commonly, *Typha*. Less common trees and shrubs include representatives of the Juglandaceae, Lauraceae and other flowering plants, with some conifers. Despite fairly poor preservation, detailed drawings of angiosperm leaf architecture combined with multivariate statistics has enabled the recognition of distinct morphotypes. Palaeoclimate inferences are based on physiognomic features of the angiosperm leaves in combination with nearest living relatives. Angiosperm leaf taxa with toothed margins are comparatively rare, suggesting a warm climate. Small leaf size points to low rainfall. Plants such as *Acrostichum*, *Daphnogene*, *Neolitsea*, *Palaeocarya*, *Hooleya* are characteristic of warm temperate to subtropical mixed mesophytic vegetation today, whilst sclerophyllous elements (e.g. *Zizyphus*) suggest drier conditions.

Digital Devonian Dipnomorpha: 3D morphometrics and the phylogenetic impact of endocast characters in dipnomorph fish

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The Dipnomorpha include the extinct Porolepiformes and the extant Dipnoi (lungfish) and, being sister to tetrapodomorphs, are important to our understanding of early sarcopterygian evolution. Cranial endocasts are now known from most stem-sarcopterygian groups including actinistians and tetrapodomorphs, which phylogenetically bracket the Dipnomorpha, and this proliferation of digital endocasts presents a wealth of data that can contribute to resolving phylogenies. Until the polarity of endocast characters can be reliably identified,

however, the efficacy of the information they carry remains unclear. Notably, the first digital endocast of a porolepiform, *Glyptolepis paucidens*, presents difficult questions surrounding the polarity of endocast characters. Recent Devonian lungfish endocasts, alongside *Glyptolepis*, present an opportunity to conduct 3D geometric morphometrics on a sample spanning the Dipnomorpha to identify informative endocast characters unambiguously and define their polarity. The endocast of *Glyptolepis* occupies an area of morphospace between that of primitive and derived lungfish, though aligns more closely with derived taxa. With this information, and concerns about the validity of endocast characters in mind, the impact of inclusion of these characters in phylogenetic analyses, and resultant differences in taxonomic resolution, are presented and discussed.

A taxonomic review and phylogenetic analysis of *Clevosaurus latidens* Fraser, 1993

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The Rhynchocephalia is a group of reptiles that had a high diversity and morphological disparity in the early Mesozoic. Among Mesozoic rhynchocephalians, one of the most diverse and widely distributed taxa was the genus *Clevosaurus*; this genus is currently represented by nine species: *C. bairdi*, *C. brasiliensis*, *C. convallis*, *C. latidens*, *C. minor*, *C. mcgilli*, *C. petilus*, *C. sectumsemper* and *C. wangi*. However, during recent years some taxonomic and phylogenetic studies have highly questioned the validity of a number of *Clevosaurus* species, particular attention has been focused on the three Chinese species as well as the poorly known *C. latidens* from the fissure deposits of Cromhall Quarry, England. In order to clarify the taxonomic identity of *C. latidens* and its possible relationships with herbivorous taxa, we reexamined and recoded characters of type specimens and other associated material. Additionally, we performed a phylogenetic analysis using parsimony and Bayesian approaches. Our results demonstrate that taxonomically *C. latidens* is not related to *Clevosaurus*, which is also supported by our phylogenetic analyses that recovered similar topologies for both parsimony and Bayesian approaches that suggests that *C. latidens* represents a new genus of an early diverging opisthodontian.

Downtown, deeper and down: Aspidella and the bathymetry of Ediacaran taxa

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The palaeoenvironments in which Ediacaran organisms lived, in particular the bathymetry of these settings, is critical to interpretations of their ecological preferences and biological affinities. A sample of muddy sandstone from the Fermeuse Formation is described here from downtown St John's, Newfoundland, Canada, which bears specimens of Aspidella terranovica. Sedimentological analysis indicates that the muds and sands were deposited by a mixture of tidal and wave-driven processes in a shallow marine environment. The affinities of Aspidella have long been debated, but the potential that it lived in nearshore settings, in the photic zone, raises broader questions about the ecology and biology of Ediacaran taxa.

Impact of Eocene-Oligocene global cooling on the size of lamniform sharks

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Body size is a key attribute in organisms, as it reflects interactions between life history, developmental, physiological and ecological processes. Bergmann's rule states that body size increases with increasing latitude or decreasing temperatures. The Eocene-Oligocene transition saw an abrupt climatic cooling, recording one of the major shifts in Earth's climate. Lamniform sharks, a clade which still occupies the highest trophic-level in extant marine ecosystems, lived through that transition, and this study tested whether Eocene-Oligocene cooling drove an increase in the body size of lamniform sharks. In total, twelve morphometric variables from 690 fossil teeth of

four genera (*Carcharodon, Isurus, Lamna* and *Odontaspis*) were studied. We found significant increases in tooth size across the Eocene/Oligocene boundary in all four genera, supporting the hypothesis that decreases in global temperature lead to increases in the size of marine organisms. Body size and tooth shape are closely linked to diet and feeding ecology. Within each genus, tooth morphospace is distinct in each time bin, and also differs from the morphospace occupied by extant representatives, suggesting significant changes in feeding ecology through time. Techniques used in this study can be applied to other climatic events, to better understand how lamniform ecology changed through time.

Walking in sthenurine kangaroos: armed or not?

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Sthenurines were the "short-faced giant kangaroos" of the Australian Pleistocene. Hindlimb anatomy evidences bipedal striding rather than hopping, and especially rather than the pentapedal (four legs plus tail) slow locomotion of extant kangaroos. What evidence could support the hypothesis that sthenurines did not use their arms like their extant relatives?
Proximal humeral morphology is indicative of forelimb weight-bearing. Terrestrial mammals have larger humeral tuberosities than arboreal ones, for the rotator cuff muscles stabilizing the body over the limb. We obtained 2-D landmark geometric morphometric data on the shape of the proximal humerus of 74 species of extant mammals classified by locomotor mode – arboreal, scansorial or terrestrial – plus 10 extant and 6 extinct species of kangaroos.
Canonical Variates Analysis of the reference group provided 82% correct classification by locomotor mode. Various permutations of entering extant and extinct kangaroos as known or unknown groupings always resulted in a non-overlapping distinction between the two groups: sthenurines tended to cluster with the arboreal reference species when entered as unknowns, and were distinct from all extant mammals when entered as a known group. The results support the hypothesis that sthenurines used their forelimbs indifferently to extant kangaroos, and that their arms were not weight-bearing.

Molecules meet fossils – an integrated approach to studying palaeodiversity in cheilostome bryozoans

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Understanding the processes that underlie diversity dynamics through time is a pivotal quest in evolutionary biology. In the past, these dynamics were commonly reconstructed using either fossil evidence or lineage-through-time plots inferred from molecular phylogenies. In our recently commenced project we integrate both types of evidence to study diversity dynamics in the Cheilostomata, the dominant order of bryozoans in modern marine assemblages which first appeared in the fossil record in the Late Jurassic. We aim to produce a time-calibrated molecular phylogeny of ~300 recent and a further ~300 fossil taxa. Speciation and extinction rates through time will be inferred from these data using the Bayesian birth-death skyline process. These rates will be tested for trait-dependent diversification associated with key innovations, and density-dependent slowdown of diversification.
Here, we present results of exploratory total-evidence and fossilized-birth-death process analyses using an existing molecular framework of 25 species and newly collated evidence from a further 25 fossil species. Furthermore, we highlight the challenges associated with constructing a morphological matrix for both fossils and recent taxa for the total-evidence dating methodology, as convergent evolution has been shown to be rife amongst cheilostomes.

Teleosaurids (Crocodylomorpha: Thalattosuchia) from the Toarcian (early Jurassic) of Luxembourg

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Thalattosuchia was a unique group of marine crocodylomorphs that flourished during the Mesozoic Era, evolving a range of wide feeding specializations and environmental adaptations. One of the two major groups within Thalattosuchia is Teleosauridae, a distinctive clade that superficially resembled modern gharials. They attained a near-global distribution that frequented shallow marine and brackish ecosystems throughout the Jurassic. Teleosaurids from the Toarcian (Early Jurassic) are commonly found in some European countries, most notably the UK, Germany, and France, and are well described in the literature. However, Toarcian teleosaurids from Luxembourg have received little research attention. We studied multiple Toarcian teleosaurids housed in the Musée national d'histoire naturelle Luxembourg (MNHNL), all collected from southern Luxembourg, and highlight their anatomy and diversity. The presence of more common species such as *Steneosaurus gracilirostris* and *S. bollensis*, in addition to the enigmatic *Platysuchus*, shows that multiple European teleosaurid taxa occupied Luxembourg at the same time during the lower Toarcian.

Forgotten phytosaurs of the Germanic Basin

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Phytosaurs are 'crocodile-like' reptiles from the Late Triassic (c. 232–201 Mya) with a near-global distribution. In Europe, the Germanic basin yields the most extensive record of phytosaurs in terms of abundance, stratigraphic range and taxonomic diversity; exceeded only by the southwestern USA. However, most historic work has focused on a subset of species from the best-sampled part of the Germanic Basin in SW Germany (Baden-Württemberg). Here we present taxonomic revisions of two neglected German phytosaur species: 'Angistorhinopsis' ruetimeyeri from Lower Saxony and Coburgosuchus goeckeli from Bavaria. These taxa were included in a comprehensive phylogenetic analysis of Phytosauria.
'Angistorhinopsis' ruetimeyeri represents the largest European phytosaur specimen, the stratigraphically youngest from Germany, and one of the youngest and most derived phytosaurs worldwide. Like specimens from the Rhaetian of North America, this taxon is robust compared to its close relatives, possibly representing an evolutionary trend in phytosaurs immediately prior to their extinction.
Coburgosuchus goeckeli is contemporaneous with four other Norian phytosaurs from Baden-Württemberg, suggesting this ecosystem could support numerous phytosaur species in a relatively restricted area. European phytosaur taxa do not form a distinct endemic clade and are interspersed with North American taxa in our phylogeny, suggesting high dispersal between these regions.

Ecological niche modelling in deep time: constraining the transitional distribution ranges of reef corals

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Ecological niche modelling (ENM) has been used to predict species distributions in a variety of modern habitats and to evaluate the impact of environmental change. The use of ENM in deep time studies is, however, in its infancy and this largely results from the rarity of global environmental datasets. However, deep time environmental data has recently become available from Earth system modelling, providing an opportunity to

incorporate ENM into palaeontology to evaluate bias and biodiversity patterns through time. Using this novel experimental approach, we compared distributional ranges of reef corals between the modern and last interglacial (LIG; 125 ka) to environmental niche distribution calculated using the machine-learning algorithm MaxEnt. Reef coral occurrence data was taken from the Ocean Biogeographic Information System and the Paleobiology Database, whilst environmental data came from the HadCM3 climate model. Our results indicate that warmer temperatures drove LIG reef corals to have a more poleward distribution than their modern day counterparts, supporting previous studies based solely on the fossil record. With validation of this approach, we look to apply this novel methodology to determine the distribution of reefs in older geological intervals, in particular, to understand the cause of the reef gap following the Triassic/Jurassic boundary.

Upware revisited – a fresh look at the 'coprolites' of the Lower Greensand (Aptian, Early Cretaceous) in Cambridgeshire

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A temporary Lower Greensand section and its unconformity with underlying Upware Limestone and Ampthill Clay members (West Walton Formation, Oxfordian, Jurassic) is discussed. For the first time since the cease of commercial 'coprolite' workings here in the late 19th century, phosphate-rich Lower Greensand is well exposed. At the base of the Lower Greensand rounded blocks of Upware Limestone are heavily bored by flask-shaped Gastrochaenolites; locally fresh-shelled brachiopods are common; higher-up, Entolium and exogyrine oysters occur; the ammonite *Ancyloceras hillsi* from earlier collections indicates a Late Aptian age for these indigenous faunas.
The lower 2 m of the Lower Greensand contain three beds rich in reworked phosphatised clasts, many with common Late Jurassic and Early Cretaceous fossil moulds. The clasts vary from fine grained mudrock to very coarse sandstone, and are heavily phosphatised, often rounded and blackened, hence their naming as 'coprolites' by early commercial exploiters. True coprolites are rare. The phosphatised faunas so far indicate: Oxfordian: *Amoeboceras*; Kimmeridgian-Volgian: perisphinctids, *Pleuromya*; Mid Volgian-Ryazanian: ?*Subcraspedites*, *Dicranodonta*, *Myophorella*, *Lyapinella*, *Rouillieria*; Early Aptian: *Deshayesites*; Mid Aptian: *Cheloniceras*.
Pleistocene reworking of the Lower Greensand gave rise to poorly bedded sands and pebble beds resulting from collapse of permafrost-bound cliff into ephemeral Fenland flood lakes.

Meiofaunal bioturbation in the late Ediacaran: occurrence and modern analogues

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The Ediacaran—Cambrian boundary is defined by the appearance of the complex trace fossils. A large diversity of ichnotaxa are now known from late Ediacaran strata globally, and typically record simple movement traces of macroscopic metazoans. Recent discoveries of coeval and older meiofaunal traces have the potential to revolutionise not only our understanding of the evolution of the earliest animals, but also of the development of the mixed layer and its influence on early animal evolution and preservation.
We here report wide stratigraphic occurrence of meiofaunal (<0.5mm wide) trace fossils from the Urusis Formation of southern Namibia. These traces are restricted to fine-grained siliciclastic horizons, and vary in length from a few millimetres to a few centimetres. They are typically undulose, recording simple horizontal movement traces, but some traces branch. Density varies from single trace occurrences on a bed to densely bioturbated horizons, occasionally co-occurring with larger traces. Experimental aquaria containing simple ecdysozoans, lophotrochozoans and agglutinating foraminifera test potential modern analogues for the meiofaunal traces,

providing critical insight into the diversity and likely behavioural complexity of microscopic trace makers in the late Ediacaran.

Diverse and dense trace fossil assemblages from the Ediacaran of Namibia

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The Ediacaran—Cambrian boundary records one of the most iconic and fundamental transitions in the history of life. It encompasses the change from the microbially-dominated world of the Proterozoic to the animal-dominated one of the Phanerozoic. Although research has traditionally focused on the Ediacaran macrofauna, it is the trace fossil record that constrains the evolution of early animal bodyplans, diversity, and behaviours.
The latest Ediacaran strata of southern Namibia host a moderate diversity of trace fossil taxa, the majority of which record simple, horizontal locomotion traces. We report here the first association of the macrofossil *Vendotaenia* in direct association with treptichnid–like traces, recording direct co-occurrence between metazoan bioturbation and a classic Ediacaran taxon. Where bioturbation has been recorded in Ediacaran beds, it is typically not intense, and of low ichnodiversity. In contrast, a thin sandstone interbed near the base of the Spitskop Member (c. 543 Ma) is densely bioturbated and hosts an assemblage of three distinct and disparate ichnogenera, including sediment bulldozing trace fossils, U-shaped burrows, and simple horizontal structures. The diversity and density of bioturbation in this bed is unprecedented for rocks of this age, and likely records colonisation in fully marine settings on the Spitskop carbonate ramp.

Does sample size affect diversity estimates for fossil microgastropods?

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Micromorphic gastropods (<2cm) are used because of their large diversity that can provide a full picture of faunas that existed in geological times, as well as more reliable data for paleoecology and biostratigraphy. Furthermore, because of their small size, they are more likely to be present in samples of smaller volume. This relation between sample size and diversity is what is being investigated presently with an aim to find which sample size is more suitable for assessing diversity and having reliable paleoenvironmental results.
Samples of three different sizes (small, medium and larger) were used, containing gastropods from the Early Pliocene of Greece (Aghia Triada, S. Peloponese). All samples are taken from the same bed. Diversity was compared to 3 levels: family, genus and species. Variation of specific diversity is plotted for the three samples, and diversity indexes are calculated with an aim of comparing the results of each size sample. The differences in diversity are more striking at the species-level, whereas they are fewer at the family-level. Generic-level seems to be more informative for all 3 samples. The largest sample is the most diverse, as expected, but the medium-sized sample is informative enough for the acquisition of reliable results.

Tetriary Conidae malacofauna of Crete (Greece) enriched, with the help of UV light

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Residual color patterns of shells have been used for the identification of fossil gastropod species. Many Conus species (Conidae, Neogastropoda) were identified and named using UV light in Miocene deposits of the Paratethys and Proto-Mediterranean.
Our first goal is to create to add new data on Conus species from the Tortonian (Late Miocene) of Crete (Heraklion basin, Greece). This is important for understanding migrations of Conus from the Paratethys and Proto-Mediterranean gateways. A comparison of the faunas (Karaman basin, Karpathian and Cretan areas), will yield results for species paleoenvironment and dispersal in the Late Miocene. A second goal of this work is to collect data on fossil Conidae diversity in Greece from the Miocene through the Pliocene. This will help us understand the evolution of the most diversified genus of marine invertebrates throughout time in a specific area.
Using UV light, a non-destructive method, evidence for the residual color patterns of the fossil shell, is revealed and used for taxonomy. UV light was used on Conidae from the Tortonian of Crete. Over 19 Conus species were identified, many of which are reported for the first time in the Eastern Mediterranean.

Serpukhovian-Bashkirian (Namurian) ammonoids from the Shannon Basin, western Ireland

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Ammonoid assemblages in the Carboniferous Shannon Basin, western Ireland, have not been investigated since the 1950-60s and many of the Serpukhovian-Bashkirian ammonoids occurring there are in need of revised descriptions. Recent, intensive field sampling in the outcrops of the Clare Shale Formation, a deep-water shale sequence, and the Ross Sandstone Formation, a sand-rich, deep-water fan system, has yielded many rich and previously undescribed assemblages of Serpukhovian-Bashkirian ammonoids, mostly preserved as flattened impressions within shale-dominated condensed sections. Systematic data are presented for the following taxa which occur in the basin: *Homoceras beyrichianum* de Koninck, *Homoceras smithii* Brown, *Homoceras undulatum* Brown, *Isohomoceras subglobosum* Bisat, *Homoceratoides prereticulatus* Bisat, *Homoceratoides varicatus* Schmidt, *Hodsonites magistrorum* Hodson, *Hudsonoceras proteus* Brown, *Reticuloceras pulchellum* Foord, and *Phillipsoceras paucicrenulatum* Bisat & Hudson. Since most specimens are preserved as 2D moulds, particular attention is paid to growth line ontogeny in order to aid future systematic and biostratigraphic work in the Shannon Basin and in coeval Serpukhovian-Bashkirian sections worldwide.

Postembryonic development of *Fritzolenellus* (Trilobita) from the Cambrian Series 2 strata of Newfoundland

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Trilobites of Olenellina were a major component of the Cambrian Series 2 ecosystems and are characteristic by absence of dorsal ecdysial sutures and calcified protaspid stage. Herein we describe postembryonic development of olenelline trilobite *Fritzolenellus lapworthi*.
Numerous specimens of *F. lapworthi* were collected in dark-grey shales of the Forteau Formation (Labrador Group, Newfoundland). The material is represented by isolated cephala and by articulated individuals in various stages of their development. The smallest cephala are about 0.95 mm long and 1 mm wide, the largest ones are about 25 mm long and 38 mm wide. The size of the smallest cephala of *F. lapworthi* is exceeding the size of the smallest known cephala of *Olenellus* and *Nephrolenellus*. The morphological changes during the postembryonic development of *F. lapworthi* comprises mainly the modification of the cephalic shape from sub-circular to semi-circular, expansion of the frontal glabellar lobe, gradual shortening of intergenal spines and prolongation of genal

spines. The articulated individuals have five to 15 postcephalic segments preserved and show long macropleural spines. The axial spine is not developed in specimens with less than 15 postcephalic segments.
This research is supported by the Palaeontological Association Callomon Award no. PA-CA201601.

Three dimensional soft tissue preservation of acritarch-like cysts from the Ediacaran Weng'an Biota

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While undisputed fossil evidence of animals is not known before the Cambrian, molecular clocks estimate animal evolutionary history to extend deep into the Neoproterozoic. The 609 Ma Weng'an Biota of South China provides one of the few Lagerstätten with which to test such estimates and has famously yielded microfossils that have been interpreted controversially as the embryos of animals. The biota is more diverse, however, and not all of its components have been described. Here we introduce a new class of embryo-like fossil characterized by a marginal excystment structure resembling acritarch cysts. The excystment structure varies in its extent, approaching half the circumference at its greatest extent. The majority of the internal volume is comprised of a granular matrix with a variable chemistry reflected in differences in X-ray attenuation. The matrix is permeated by micrometer scale unconnected pores. Many specimens preserve a central inner body, exhibiting a low X-ray attenuation, some with an inner core with a homogeneous high attenuation mineralogy. These central structures are reminiscent of the structures interpreted as nuclei preserved in the embryo-like *Tianzhushania* from the same samples. We consider the affinity of this new class of Weng'an fossil within protist, algal and animal milieu.

Systematic revision of the family Cothurnocystidae (Echinodermata, Stylophora)

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The family Cothurnocystidae represents a relatively well-defined group of cornute stylophorans, characterized by a delicate, boot-shaped marginal frame, posteriorly closed by two small skeletal elements (M_5-M'_5 bridge) on the lower thecal surface. Most cothurnocystids possess typical respiratory structures (cothurnopores) in the right anterior corner of their upper thecal surface. The recent description of a new cothurnocystid from the Furongian of Nevada, USA (*Cardiocystella prolixora*) and the discovery of new Ordovician cothurnocystids in the Anti-Atlas, Morocco (Fezouata Shale: late Tremadocian; Izzeguirene Formation: early Sandbian) and in Bohemia, Czech Republic (Libeň Formation: early Sandbian) prompted the systematic revision of the family Cothurnocystidae. Four distinct genera can be identified, based on their plate patterns. '*Cothurnocystis*' *fellinensis* (late Tremadocian, Montagne Noire) represents the plesiomorphic condition in cothurnocystids and should be assigned to a new genus. All three other genera are characterized by a more reduced number of skeletal elements: loss of one lateral marginal (Mc) in *Arauricystis*; loss of A_0 in *Procothurnocystis*; and loss of both A_0 and M_4 in *Cothurnocystis*. In this revised systematic scheme, *Cardiocystella* appears as a junior synonym of *Procothurnocystis*.

Palaeobiogeographic implications of new scotiaecystid cornutes (Echinodermata, Stylophora) from the Ordovician of the Anti-Atlas (Morocco) and Bohemia (Czech Republic)

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Scotiaecystid cornutes form a well-defined clade of Ordovician stylophoran echinoderms, characterized by the possession of a highly distinctive, rhomb-shaped respiratory structure (the lamellate organ), always located in the right anterior corner of the upper thecal surface. Their phylogenetic position within stylophorans is not entirely clarified yet, but they very likely derive from cornutes possessing a proto-lamellate organ (i.e. consisting of numerous, adjoining cothurnopores), as for example in *Proscotiaecystis melchiori* (Early Ordovician, Montagne Noire). The family Scotiaecystidae comprises the two genera *Thoralicystis* (Early-Middle Ordovician) and *Scotiaecystis* (Middle-Late Ordovician). New occurrences of scotiaecystids are reported here from the Anti-Atlas (Fezouata and Izzeguirene formations) and Bohemia (Letna and Vinice formations). They confirm that the palaeogeographic distribution of *Thoralicystis* is apparently restricted to high-latitude, peri-Gondwanan areas: Anti-Atlas (*T. zagoraensis*, *T.* n. sp.), Bohemia (*T. bouceki*), and Montagne Noire (*T. griffei*, *T. ubaghsi*). They also confirm that the same pattern is observed for all late Darriwilian to Sandbian occurrences of *Scotiaecystis*: Anti-Atlas and Bohemia (*S.* n. sp.), Brittany (*S. guilloui*), and Central Iberian Zone (*S. jefferiesi*). In contrast, the two youngest (late Katian) representatives of the genus *Scotiaecystis* are both known from Laurentia: northern Ireland (*S. collapsa*) and Scotland (*S. curvata*).

Evolution and extinction of the ‘Siberian unicorn’ Elasmotherium sibiricum

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The giant, one-horned rhinoceros *Elasmotherium sibiricum* was believed to have gone extinct in the Middle Pleistocene, well before the Late Quaternary megafaunal extinction event (50-4 ka). Here we show, by AMS radiocarbon dating of 21 individuals, including cross-validation and single amino-acid dating, that the species survived in Eastern Europe and Central Asia until at least 33,000 years ago, and therefore forms part of the 'late Quaternary megafaunal exticntion'. Stable isotope data indicate a dry steppe niche for *E. sibiricum* and, together with morphology, a highly specialised diet that likely contributed to its extinction under changing environmental conditions. We further demonstrate, by the first ancient DNA sequence data from the Elasmotheriinae, a very deep phylogenetic split between that subfamily and the Rhinocerotiinae that includes all the living rhinos, corroborating fossil evidence that the two lineages had diverged by the Eocene. As the last surviving elasmotheriine, the demise of the ‘Siberian unicorn’ represents an extinction not just species but at subfamily level.

Paleogene and Neogene Caribbean and South American methane seep communities

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The Caribbean and Northern South American regions have a rich fossil record of methane seep communities from the Paleogene and Neogene. The Caribbean seep communities from Cuba, the Dominican Republic, Barbados and Trinidad range in age from the Eocene to the Pliocene. The South American examples are Oligocene to Miocene in age. Although there are some faunal similarities between the fossil seeps and those from modern seeps in the Gulf of Mexico, the Caribbean and the Pacific and Atlantic sides of Central America, there are also many fossil taxa that are absent from these modern sites. These include large elongate lucinids (e.g. *Elongatolucina* and *Elliptiolucina*), large globular lucinids (e.g. *Meganodontia* and *Cubatea*), vesicomyids (Pleurophopsis), large thick-shelled bivalves superficially resembling vesicomyids, and tall abyssochrysoid gastropods (e.g. Hokkaidoconcha, Ascheria and Humptulipsia). These gastropods have origins in Mesozoic seeps and are now extinct; some bivalves, such as Meganodontia and the large elongate lucinids, are now only found only in the central Indo-Pacific Ocean; other bivalves were endemic and are now also extinct. These differences show there

was considerable biogeographic interchange between the seep faunas of the Pacific and the Caribbean region prior to the closure of the Isthmus of Panama.

The dentition of *Megacephalosaurus eulerti* (Plesiosauria, Pliosauridae) from the Turonian of Kansas and comments on the phylogenetic relationships of the last brachauchenines

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Megacephalosaurus eulerti was a large brachauchenine pliosaurid that roamed the Western Interior Seaway during the middle Turonian (Late Cretaceous). The type specimen (FHSM VP-321) consists of a nearly complete skull including the dentaries, and associated incomplete postcranial material. We assessed the dental morphology of *Megacephalosaurus* and the variability observed in its dentition. The results show that the dentition of *M. eulerti* was subisodont and subhomodont, with the most apparent differences observed in the development of the apicobasal ridges, which branch in some teeth. However, the taxonomic utility of this feature is debatable and perhaps depends on the part of the tooth crown where it develops. We further revised the cranial anatomy of the taxon, which allowed for a reassessment of some of its morphological characters used in recent phylogenetic studies. Our parsimony analyses inferred a single unambiguous synapomorphy uniting the node comprising mid- to Late Cretaceous brachauchenines (presence of conical teeth with a subcircular cross-sectional shape). The latest brachauchenines (*Brachauchenius* and *Megacephalosaurus*) can be also roughly characterized by reduction of their maxillary tooth count and, perhaps, a switch from anisodont to subisodont dentition. However, the phylogenetic relationships remain somewhat elusive and would probably improve following modifications in data sampling.

ABSTRACTS: POSTERS – GROUP B (TUESDAY)

* Candidates for the Council Poster Prize are marked with an asterisk.
Underlined author denotes the primary presenter.

A graphical method for constructing raw morphospaces

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Morphospaces allow the forms of different organisms to be quantitatively compared, and there are two well-established approaches to morphospace construction. The first involves using a generative model to produce theoretical morphologies, while the second involves representing morphology with discrete characters and using multivariate ordination to create a morphospace of reduced dimensions. However, it is also possible to formulate a morphospace in terms of observed morphological variation but prior to any multivariate ordination. This results in a raw morphospace, which captures form by the enumeration of discrete characters but can represent both theoretical and real-world morphologies. A primary obstacle to the use of raw morphospaces in studies of organic form is the visualisation of large numbers of discrete character combinations. We have taken a computer graphics approach to this problem, and have developed tools using the Python programming language that allow collections of morphologies to be visualised as images. In these imagespaces each pixel represents a unique combination of discrete characters, and we have used this approach to study the morphology of flowers from across angiosperm (flowering plant) phylogeny, and the pollen of plants growing in tropical rain forests. We also compare our imagespaces with alternative visualisations such as multipartite graphs.

Eutrophication by biogenic phosphate pollution as a triggering factor for the collapse of obolid-dominant brachiopod communities in the early Tremadocian of East Baltica

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In the early Tremadocian (Cordylodus lindstromi and Cordylodus angulatus zones) the Baltoscandian epicratonic basin was environmentally heterogeneous and comprised a black shale depocentre, rimmed in North Estonia by coastal plain and shoal complexes composed of extensive brachiopod shell accumulations. By that time, nearshore obolid-dominant brachiopod communities were extinct; while allochthonous shell beds (biogenic phosphorites) were inherited relics, eroded from Furongian shoal bioaccumulations. Unlithified quartzose sand packages, exhibiting bidirectional cross laminae and commonly punctuated by thin black shale intercalations, accumulated in tidally influenced foreshore-to-shoreface settings. Nearshore reworking and condensation of sand phosphorites is a sign of coastal eutrophication, which resulted in significant seasonal enrichment of the water column by nutrients associated with dissolved oxygen fluctuations. A possible major cause of eutrophication and water pollution, coeval with widespread deposition of kerogenous clay and extinction of shallow marine biota, not previously considered, was the increase in phosphate nutrients and increased biomass of phytoplankton. Toxicity effects would be triggered by the extensive Furongian obolid shelly substrates, flooded during the marine transgression. The presence of significant amounts of dissolved phosphate in the water at that time was marked by deposition of concretions and crusts of chemogenic phosphorites outlining the periphery of the black shale depocentre.

The oldest known cheilostome bryozoan with erect colony growth from the late Albian of southwest England

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Cheilostomata are the dominant bryozoan order in modern marine assemblages. The origin of cheilostomes dates back to the Late Jurassic but the group remained low in diversity, limited in disparity, exclusively encrusting and uncommon for over 55 million years after their first appearance. Cheilostomes commenced an explosive diversification coincident with the appearance of several key novelties during the late Albian. One of these novelties – erect colony form – is found in a hitherto undescribed species common in late Albian deposits of southwest England. The new species is a chiplonkarinid cheilostome characterised by rigidly erect colonies with cylindrical, bifurcating branches. Autozooids are dimorphic, with tubular autozooids in the axial endozone covered by multiple layers of short, stacked, box-shaped autozooids in the surrounding exozone. Porous closure plates with scars of the opercular sclerites, a primitive feature lost in later chiplonkarinids, prove the cheilostome identity of this bryozoan, which is a homeomorph of a cyclostome. The new species slightly antedates the oldest erect neocheilostome species that appeared in the earliest Cenomanian, likely representing independent origin of erect growth.

Classification and size distribution of scales suggest niche partitioning of an Early Cretaceous coelacanth of Las Hoyas (Spain)

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The coelacanth from the upper Barremian fossil site of Las Hoyas is the least common fish taxon from the locality but their remains suggest niche partitioning by size. Very few articulated specimens have been found (n = 10), most of them incomplete. Several isolated scales (n = 11) have also been recovered. Isolated coelacanth scales can be distinguished from other amioid-scales belonging to different taxa from the same locality (i.e., amiiforms) mainly by the presence of thick elongated ridges on the posterior field. Of all the articulated material and isolated scales, only four small individuals are represented. One articulated individual is 7cm TL, and the other three are even smaller. The most complete individual is considerably longer, measuring 20cm TL, and its scales are as long as 0.53cm in length. All isolated scales are longer than 0.53cm in length. This suggests that small individuals inhabited other environments and larger individuals might have been relatively rare visitors to the freshwater pool. The rule of survivorship suggests that small juveniles should be the most common sizes and small fishes of other taxa are very common at Las Hoyas. We hypothesize that another nearby stable aquatic environment could produce more smaller coelacanth individuals.

Preliminary taphonomic study of the carnivoran-dominated assemblage of Batallones-3 (late Miocene, Madrid Basin, Spain)

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Batallones-3 is one of the nine late Miocene mammalian sites found in the Batallones butte (Madrid basin, central Spain). Alongside Batallones-1, Batallones-3 contains an unusually large concentration of carnivoran remains: Batallones-1 hosting 98.39% of carnivoran remains whereas Batallones-3 99.58%. A total of 19,187 large-

mammal remains have been retrieved, belonging to at least 15 different species. The most abundant taxa are the saber-toothed cats *Machairodus aphanistus* (35.92%) and *Promegantereon ogygia* (28.81%) and the ursid *Indarctos arctoides* (19.64%). Other taxa found at Batallones-3 include the hyaenid *Protictitherium crassum*, the amphicyonids *Magericyon anceps* and *Thaumastocyon* sp., the mustelids *Eomellivora piveteaui*, aff. *Adroverictis ginsburgi* and aff. *Circamustela decheseauxi* and the mephitid *Promephitis* nov. sp.. Remains are found in marl deposited inside a domically-shaped pseudokarstic cave, with an inferred opening in the center. Two preferential orientations of the remains are observed: outwards from the center of the cave and with a northwestern trend. However, remains appear to have suffered little to no transport, since for each species the number of density clusters correlates to the MNI. Carnivore-rich fossil sites are highly uncommon in the fossil record so their taphonomic study provides valuable insights on the origin of such concentrations.

Dinner in the Iguanodon and other Participatory Palaeo Thrills - Sparking engagement with the Crystal Palace Dinosaurs, the first extinct animals brought “to life”.

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The famous Crystal Palace Dinosaurs have been thrilling visitors since their unveiling in 1854. They are the first attempts to make life-size reconstructions of the extinct animals discovered by Mary Anning, Richard Owen, William Buckland, Gideon Mantell and other pioneers of palaeontology, realised by the artist Benjamin Waterhouse Hawkins. They were the concrete manifestation of the then-new Victorian ethos that everyone can be inspired by science when it is communicated in an engaging way. As a Grade 1 Heritage Asset they still draw crowds and communicate on many levels to audiences of a wide range of sophistication, from toddlers to professional scientists. We are bringing geology, palaeontology, history and engineering to life through the interpretative lens of the CPDinosaurs. Our street theatre and education project called 'The Iguanodon Restaurant' travels to schools and festivals throughout the UK. We have produced short films in several genres: animation, humorous history, cultural documentary. We organise exciting events on site. The Friends of Crystal Palace Dinosaurs (http://cpdinosaurs.org/) are working to restore the sculptures, landscapes and build a vibrant outreach programme around these surprising heritage features. These 'stupendous monsters' retain their ability to release your imagination and evoke a sense of ancient lives and landscapes.

First record of the mosasaurine mosasaur *Carinodens* from the uppermost Maastrichtian of Stevns Klint, Denmark

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The small durophagous mosasaurine mosasaur genus (Reptilia, Mosasauridae) *Carinodens* is exceedingly rare in north European chalk deposits, with published finds limited to a small number of shed tooth crowns and two partial dentaries from the Netherlands and Belgium, all assigned to *Carinodens belgicus*. A newly discovered isolated, presumably shed, tooth crown from the UNESCO world heritage site of Stevns Klint expands the known geographical distribution of another species, *C. minalmamar*, first described from Morocco, to Denmark. The specimen was found within the uppermost metres of the Maastrichtian chalk deposits, thereby placing it within the last 50.000 years of the Cretaceous. The new tooth crown represents the northernmost occurrence of the genus *Carinodens*. Previous finds of mosasaur dental and skeletal materials from Denmark have been assigned to the

hypercarnivorous mosasaurids *Mosasaurus hoffmannii* and *Plioplatecarpus* sp. Thus, the new specimen provides important new information on ecological niche partitioning amongst large marine reptiles during the latest Maastrichtian.

Revealing rangeomorph species characters using spatial analyses

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Rangeomorphs dominate the Ediacaran Avalonian macrofossil assemblages of Charnwood Forest, UK (~565Ma). However, their unfamiliar fractal architecture makes distinguishing phylogenetically reliable characters from intraspecific features difficult. Fortunately, spatial analysis of large in-situ populations of such forms offers an independent means of assessing their taxonomy. Populations of a single biological species are likely to exhibit similar spatial distributions due to their shared responses to the biological and ecological processes acting upon them: if two named 'species' differ by a single morphological character, but exhibit the same spatial distributions, then that character is unlikely to be taxonomically significant and more likely represented an ecophenotypic response. As such, spatial analyses can be used to interrogate which are the most taxonomically deductive characters between similar species. We used Random Labelling Analyses to permutate the presence/absence of characters of *Primocandelabrum boyntoni*, *P. aethelfalaedia* and *P. aelfwynnia* from North Quarry 'B' surface. The resultant spatial distributions were compared using goodness-of-fit tests to determine which characters were associated with unique populations and which were found across multiple populations. Our results suggest that ecophenotypic characters are prevalent within the rangeomorphs, and need to be taken into consideration when defining species.

Using synchrotron tomography to elucidate the anatomy of early land plants

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The evolutionary relationships between the lineages of living bryophytes and vascular plants are still not fully understood. No consensus has yet been achieved from phylogenetic analyses alone. Living bryophytes exhibit a complex mosaic of anatomical characters that are difficult to distinguish between convergence and common descent. To determine the sequence of early land plant character evolution it is therefore essential to study early embryophyte lagerstätten, e.g. the Rhynie Chert. One of the oldest and most diverse assemblages of early embryophytes is from Lower Devonian strata at Brown Clee Hill, Shropshire, in which plant anatomy has been preserved to cellular level by charcoalification. Studies spanning the last 20 years have revealed this to be rich assemblage of early tracheophytes and a group of plants that possess both tracheophytic and bryophytic characters. While the charcoalification process has preserved these plants by converting them to chemically inert material, resistant to bacterial decay, these rare fragments are highly brittle. Traditionally they have been physically sectioned, and in many cases only fragments of the original specimens remain. Computed tomography provides a non-invasive and non-destructive alternative approach. Here we present Synchrotron Radiation X-ray tomographic microscopy of Lower Devonian charcoalified embryophytes from the Swiss Light Source, Switzerland.

Soft-tissue preservation in the upper Silurian Leintwardine Beds of Leintwardine, Herefordshire

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The upper Silurian submarine canyon deposits of Church Hill, Mocktree and Martin's Shell, Leintwardine (Herefordshire, UK), are famous for their diverse, exceptionally preserved echinoderms (mainly asterozoans) and sclerotised but non-biomineralised arthropods (eurypterids, phyllocarids and xiphosurans). These taxa, and rare palaeoscolecidan worms, are preserved with an exceptional degree of articulation, but no labile tissues have been described. Examination of material housed in Ludlow Museum (Shropshire, UK), as part of the Fossils in Shropshire (FISH) documentation project, has revealed previously unrecorded organisms from this biota, including exceptional preservation of soft tissues and soft-bodied organisms. The strata at Church Hill contain polychaete worms (with gut traces), sponges, benthic graptolites and algae. In addition, an arthropod from Mocktree is preserved with biramous limbs. This expanded Leintwardine assemblage has affinities with previously described Konservat-Lagerstätten from North America and Estonia.

A reappraisal of the Early Cretaceous margaritierid *Margaritifera* (*Pseudunio*) *valdensis* (Mantell 1844)

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Margaritifera (*Pseudunio*) *valdensis* from the Early Cretaceous Wealden Group of southern England, and contemporaneous rocks in France and Spain, was originally described as thick-shelled, oval, critically lacking a ventral sinus. In 1961 Mongin revised the taxon into the extant genus *Margaritifera*, subgenus *Pseudunio*. However, in 2015 Van Damme *et al*. confirmed the validity of the over-looked genus *Paraheudeana* Starobogatov, published in Russian in 1970, with *M. valdensis*, as the type, a revised diagnosis, based in part upon an ellipsoid-ovate outline (*Margaritifera*, is elongate-oval) and the absence of a ventral sinus.
This study re-examines the type series, recognising them as incomplete specimens lacking critical posterior portions of the shell. The lectotype, superficially oval in outline, has a shallow, but distinct ventral sinus, seemingly out-grown, the broken ventral margin not preserving actual shell shape or the commissure. Significantly, many other specimens confirm the presence of the ventral sinus and elongate-oval outline. Combined with diagnostic characters such as mantle pits, we retain the species in the genus *Margaritifera*. However, doubt surrounds *Pseudunio*, in 2016 Araujo *et al*. reviewing the phylogeny of the Margaritiferidae, concluded only the genus *Margaritifera* was valid, discounting *Pseudunio* as a valid genus or subgenus.

Taphonomic controls on melanin-bearing tissues from river lamprey (Lampetra fluviatilis).

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Melanin is a ubiquitous pigment that is found in numerous tissues across a wide range of taxa. Melanin plays a pivotal role in a variety of biological and ecological functions, such as protection from ultraviolet radiation and camouflage patterning. Recently, palaeontological studies have used evidence of fossilised melanin and the organelles that produce it - melanosomes - to infer ecological adaptations of extinct taxa and to help resolve the phylogenetic placement of several enigmatic species. However, the in vivo characteristics of melanin-bearing tissues and their melanosomes in extant taxa are not fully resolved. Moreover, little is known about how the pigment within these tissues is affected by decay, crucial to understanding the preservation potential of such tissues. Here we present preliminary data showing the distribution and characteristic morphology of melanin and

melanosomes throughout tissues in river lamprey (Lampetra fluviatilis) during several stages of decay. Initial results suggest that different tissues contain characteristic melanosome morphologies and distribution of melanin, and that the distribution of pigment within L. fluviatilis is affected by decay. Understanding these effects is critical to successfully interpreting pigmentation patterns in comparable fossil taxa, and the ecological or phylogenetic implications that can be drawn from them.

First evidence of tetrapod burrowing from the Lower Triassic of Sardinia: implications for understanding survival in Permo-Triassic equatorial extreme conditions

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A new burrow cast is described from the Early Triassic of the Cala Viola Formation, North-West Sardinia, and is tentatively associated with a terrestrial tetrapod, possibly cynodont or procolophonid excavator. Comparisons of architectural morphology between Permo-Triassic and extant burrows, finds that several similarities occur between the structure of subterranean excavations created by non-mammalian therapsids. The three-dimensional cast is cautiously identified as a complex burrow system, indicating gregarious behaviour of its inhabitants and a subterranean mode of life. The burrows likely represent distal terminal chambers of a burrowing system, due to their elliptical domed shape and lack of bilobate ventral surface. A paucity in tetrapod burrows from this period means that the new Sardinian specimen provides significant insight to our understanding of adaptations by early Mesozoic vertebrates to challenging palaeo-environmental conditions. We integrate our ichnological and palaeoecological observations with lithostratigraphy, thanks to a new highly detailed revised stratigraphic section of the locality, postulating that the occurrence of a burrow within such close proximity of the Permo-Triassic boundary, indicates a close relationship between the evolution of burrowing and the onset of harsh climatic conditions.

Taphonomic controls of ubiquitous phosphatisation of soft tissues in Sirius Passet, North Greenland

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Sirius Passet is an early Cambrian Konservat Lagerstätte situated in North Greenland. It is one of the least studied of the 'great three' Cambrian localities with exceptional preservation that includes the Burgess Shale and Chengjiang. However, Sirius Passet is unique for its density of exceptional fossils as well as its preservation. Muscle tissue and intestinal tracts are commonly preserved in three dimensions in black mineral, which is surmised to be derived from calcium phosphate. The high amount of phosphatisation is unique for Sirius Passet, but the depositional context for its preservation is poorly understood. Here we present a taphonomic model for the ubiquitous preservation through phosphate. Microbial mats are ubiquitous in Sirius Passet and form coherent and patchy sheets on most bedding plane surfaces. Microbial mats are commonly seen in other localities with exceptional preservation, such as the Solnhofen Plattenkalk, and may have acted as sealing barriers limiting diffusion and as a source of phosphate from decaying organic material. Other factors that most likely played a role is evidence for high primary productivity in the water column. Modern zones of upwelling are responsible for current phosphate deposits. We also highlight an apparent taxonomic bias in phosphatisation and discuss its correlation.

New occurrence of the blastozoan echinoderm *Felbabkacystis* in the mid-Cambrian of the Skryje–Týřovice Basin (Czech Republic)

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The primitive blastozoan echinoderm *Felbabkacystis* was recently described from the Drumian Jince Formation (Příbram-Jince Basin, Barrandian area, Czech Republic). This unique echinoderm is important for studying the relationships and evolutionary history within the early blastozoans. *Felbabkacystis* shows a specific morphology of its body plan. This genus is considered as a transitional form between calyx-bearing and theca-bearing blastozoans. The aim of this contribution is to report a new occurrence of this blastozoan echinoderm from the lower to middle levels of the Drumian Buchava Formation (Skryje–Týřovice Basin, Barrandian area, Czech Republic). Finds of blastozoans are generally rare in the Buchava Formation. Only two genera have been known from this unit: *Lichenoides* and *Luhocrinus*. *Felbabkacystis* specimens are preserved as internal and external moulds in sandy greywackes. The type of preservation is not as good as in the Jince Formation. All studied material is deposited in the collections of the Czech Geological Survey, Prague.

MicroCT and 3D modelling of *Ophiderpeton brownriggi* and *Dolichosoma emersoni*: implications for aïstopod evolution and ecology

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The Pennsylvanian (Langsettian) Jarrow assemblage in Ireland is home to two species of aïstopod, *Ophiderpeton brownriggi* and *Dolichosoma emersoni*. First described in 1866, little work has been done on them despite major revisions of the order Aïstopoda at the start of the century. This is due to the poor appearance of the specimens and the pyrite decay of the holotype of *D. emersoni*. Four specimens, two *O. brownriggi* and two *D. emersoni*, were scanned using microCT. Three of the resulting datasets where then rendered in Spiers. The presence of tightly packed gastralia and dorsal ovoid osteoderms in *D. emersoni* indicate that it is an immature *Ophiderpeton* rendering the former species invalid. Thus, the first occurrence of two separate aïstopod species co-inhabiting an ecosystem is pushed up to the Linton Assemblage (Asturian).
Growth series of *O. brownriggi* indicates that near complete ossification of both the cranium and the post cranium occurs at an early stage, a common characteristic among the "Lepospondyli". Several bones ossify at a later stage, including the ribs on vertebrae C1-C3 which maybe a result of the need to accommodate a relatively large skull growth. 3D models provide a more accurate description of *Ophiderpeton brownriggi*.

Digital technology restores stolen fossils at Joint Mitnor Cave, Devon

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Joint Mintor Cave is a SSSI and the type site for the Joint Mitnor Cave Mammal Assemblage Zone. Excavations of the 120,000 year old site revealed an exceptionally rich interglacial fauna, including an unusual mix of African game and temperate woodland animals. An unexcavated section of these deposits, including the remains of straight-tusked elephant, brown bear and spotted hyaena, has been maintained since 1962 by the William Pengelly Cave Studies Trust as an educational resource. Vandalism of the site in 2015 resulted in the theft of surface specimens and damage to the section. This sparked a collaborative effort to restore the site.

Specimens, similar to those stolen, were identified from the Natural History Museum (London) collections using photographs of the site before vandalism. The specimens were CT scanned to produce high resolution digital replicas, and used subsequently to develop detailed 3D prints to replace the stolen specimens. These objects were also integrated into Virtual Reality Cave database.
This highly successful collaborative project, using expertise from different specialists and institutions, opens up new avenues for using 3D data from museums' collections. It also highlights some of the current issues with security and conservation of heritage sites such as Joint Mitnor Cave.

What is your Rate? EarthRates—a new research coordination network for linking scales across the sedimentary crust

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A Research Coordination Network "EarthRates: Linking Scales Across the Sedimentary Crust" has recently been funded by the US NSF to provide the framework and opportunity to engage critical communities and forge new collaborations in order to foster transdisciplinary research in Earth's sedimentary crust. We will bring together community-driven entities such as the Paleobiology Database, Neotoma, Macrostrat, EarthTime, EarthChem, Earth-Life Transitions, the Continental Scientific Drilling Coordination Office, and Flyover Country, to strategize, leverage and build partnerships and collaborative efforts to enable the geoscientific community to address major grand challenges in Earth system science. These include how have the oceans, the Earth's sedimentary crust, carbon sinks and soils, and life itself evolved together, and what does this tell us about the future trajectory of the integrated Earth-life system? And what are the ranges of ecosystem response, modes of vulnerability, and resilience to change in different Earth-system states? By bringing these groups together and building stronger partnerships and alliances, we will move towards the goal of developing a fully integrated four-dimensional digital Earth to fully understand dynamic Earth system evolution. We are looking for international partners and collaborators in this effort.

Quantifying the hydrodynamic performance of the Cambrian arthropod *Isoxys* using computational fluid dynamics

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Isoxys, a Cambrian nektonic bivalved arthropod, is known from over 15 species with diverse forms, from the relatively symmetrical and short-spined type species *Isoxys chilhoweanus*, to the more asymmetrical long-spined *Isoxys longissimus*. The shape of the bivalved carapace must have influenced the drag and lift forces experienced by *Isoxys* as it travelled through the oceans, impacting on the energy requirements of the animal to move through and up and down in the water column.
Two-dimensional models of *Isoxys chilhoweanus* and *Isoxys longissimus* were created and computer simulations of fluid flow carried out in ANSYS Fluent, using angles of attack ranging from 0° to 25°. The results show that *Isoxys chilhoweanus* generated higher drag than *Isoxys longissimus*. The lift generated by *Isoxys longissimus* increased with the angle of attack, but the opposite pattern was seen for *Isoxys chilhoweanus*, with lift decreasing as the angle of attack increased. This suggests that *Isoxys* species with longer spines and more asymmetrical carapaces were better able to move horizontally and vertically within the water column than forms with shorter spines.

Ecology of brachiopod and mollusc assemblages across the Early Toarcian (Early Jurassic) extinction event in the Lusitanian Basin, Portugal

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The ecological changes across the Early Toarcian warming/extinction event were assessed through a detailed bed-by-bed study of brachiopods and bivalves assemblages from the marlstones and micritic carbonates of the ca. 28 m thick Fonte Coberta/Rabaçal section in the Lusitanian Basin, Portugal. Comparison of the taxonomic composition of pre- and post-extinction assemblages reveals an almost complete faunal turnover in brachiopods and a less severe one in bivalves. The pre-extinction assemblages are dominated by brachiopods whereas in the post-extinction assemblages bivalves are more abundant, yet small-sized. The diversity, highest in the pre-extinction interval, reaches the lowest values in the ca. 1.3 meters below the extinction level. The post-extinction diversity is otherwise comparable to the average diversity values observed in the pre-extinction. The ecological structures before and after the extinction are unrelated unlike the crisis interval assemblages, which are still related to the pre-extinction phase.

Wolff's law and terrestrialization: structure / function adaptation

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The lifestyle of extinct tetrapods is often difficult to assess without clear adaptations such as swimming paddles. For example, the external anatomy of salamanders gives no data about their lifestyle. According to the Wolff's law, the trabecular bone architecture follows the principal stress trajectories generated from external loads. Theoretically, a terrestrial tetrapod will show a marked main trabecular orientation, while an aquatic tetrapod will show a trabecular orientation more isotropic. The Wolff's law has been extensively studied in mammals and birds, but rarely in reptiles and amphibians. These animals with transverse posture like that of first tetrapods have various lifestyles (aquatic, amphibious and terrestrial). We will scan their humeri and analyze many trabecular parameters: spacing, thickness, anisotropy and connectivity. Finite element analysis (FEA) reconstructs stress, strain and deformation in a digitalized structure. A new concept, the 'inverse Wolff law's', consists in inferring from the trabecular bone architecture the magnitude, direction and distribution of contact forces at the articular surface. From the 3D reconstruction of a bone microarchitecture, we will solve an optimization problem yielding the articular forces satisfying a target value of homeostasis. This concept tested on living species could allow inferring lifestyles of extinct species.

Revisiting the affinities of Chancelloriids: are they sponges after all?

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Chancelloriids are one of the most mysterious groups of Cambrian problematica. Their body fossils are remarkably similar to cactuses, having a club-shaped morphology dotted with rosettes of hollow sclerites. They were originally described as primitive sponges in the early twentieth century but later studies showed notable similarities in the fine structure of their sclerites and those of some stem group molluscs, casting doubt on the original interpretation. Depending on whether the sclerite structure is reconstructed as a synapormophy or as a plesiomorphy, chancelloriids are interpreted as aberrant stem molluscs, the coeloscleritophora hypothesis, or as early diverging eumetazoans. Despite the loss of popularity of the sponge affinity hypothesis, recent reinterpretations of the anatomy of a group of Cambrian sponges might be able to rekindle it by providing a

potential link between chancelloriids and protomonaxonids. Here we review the arguments proposed for and against the sponge interpretation and assess them in the context of poriferan evolutionary morphology.

The Sedimentology and paleontology of the Lower Cambrian Withycombe Farm Borehole, Oxfordshire, England

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The pre-trilobitic lower Cambrian of the Withycombe Formation is a 194 m thick siliciclastic succession dominated by interbedded offshore red-purple and green pyritic mudstones with minor sandstones. The mudstones contain a hyolith-dominated small shelly fauna including: orthothecid hyoliths, hyolithid hyoliths, the rostroconch *Watsonella crosbyi*, early brachiopods, the foraminiferan *Platysolenites antiquissimus*, the coiled gastropod-like *Aldanella attleborensis*, halkieriids, gastropods and a low diversity ichnofauna including evidence of predation by a vagile infaunal predator. The assemblage contains a number of important index fossils (*Watsonella, Platysolenites*, *Aldanella* and the trace fossil *Teichichnus*) that enable correlation of strata around the base of Cambrian Stage 2 from Avalonia to Baltica. The pyritized nature of the assemblage has enabled the study of some of the biota using micro-CT, augmented with petrographic studies, revealing pyritized microbial filaments of probable giant sulfur bacteria. We aim to produce the first complete description of the core and the abundant small pyritized fossils preserved in it and develop a taphonomic model for the pyritization of the "small" shelly fossils.

Macroevolutionary trends and palaeoenvironmental changes during the early Toarcian mass extinction in Bulgaria

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The early Toarcian mass extinction was one of the most important biotic crises of the Mesozoic era, with severe disruptions in the marine realm resulting in the loss of 15-20% of marine families and genera. This event is closely linked to the Karoo-Ferrar Large Igneous Province, the postulated driving mechanism for severe contemporary geochemical perturbations leading to anoxia and extinction. Despite the global nature of the extinction event, the majority of existing records come from North-Western European epicontinental sedimentary sections. We will present new quantitative palaeoecological and facies data, alongside geochemical records (Sr, C and O, carbonate and organic), from more easterly Tethyan Lower Jurassic sections in North-West Bulgaria. These data document major palaeoenvironmental changes and track macroevolutionary trends of marine shelf ecosystems from an area closer to the open Tethys Ocean. A lack of black shales in Bulgarian sections, which are well recognised during the Toarcian time interval in the North-West European Boreal Realm, suggests there was a much weaker manifestation of anoxia in the region.

Textures of exceptional preservation – quantitative analysis based on 3D characterization of surfaces

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In many Lagerstätte, exceptional preservation of non-biomineralised tissues is linked to particular modes of mineralization – early authigenic phosphatization, for example. But in some cases, exceptionally preserved fossils do not exhibit detectable compositional differences from the matrix; the boundaries of the organism and thus the

shape of the body are unclear. Similarly, in specimens that exhibit changes in colour relative to matrix, external haloes linked to chemical changes around a decaying carcass can cause problems in anatomical interpretation. Here we test the hypothesis that exceptionally preserved fossils exhibit surface textures that are quantitatively distinct from those of the surrounding matrix. Our tests are based on statistical analysis of parameters derived from ISO 25178 Characterisation of Areal Surface Texture. The results reveal that in a number of Lagerstätte there are clear and significant differences between matrix and fossils, providing additional evidence where anatomical boundaries are uncertain, and a new source of taphonomic data. Furthermore, variation in texture between different body parts within fossils provides a guide to differences between the original tissues from which anatomical characters were constructed.

Aragonite and pyrite preservation in ammonites from Jurassic mudrocks

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Aragonite and pyrite both contribute to ammonite preservation in the Jurassic mudrocks of Dorset (Charmouth Mudstone Formation). Nacreous aragonite is scarce but recorded from three genera and four species of Lower Liassic ammonites. Preservation of original bio-mineralic aragonite consistently occurs in the posterior of the body chamber of ammonite fossils confirming a palaeobiological influence in its survival through the Taphonomically Active Zone. Nacreous aragonite preservation outlines the soft tissue attachment areas. Their consistent position and extent suggest that locally increased shell thickness promoted survival of an otherwise vulnerable component in the depositional environment.
Pyrite preservation is more abundant, found as the internal moulds of ammonite fossils. Petrographically diverse pyrite replacement textures show predictability through position in the body chamber and phragmocone. Density increases adapically and an evolution from equant to aggregated pyrite suggests more complete pyritisation. Internal sedimentation and inclusion of exotic fauna within body chambers indicate bottom water currents. Amorphous external pyritisation and obscured surface detail result from syn-replacement fracturing of fragile components and subsequently, a more readily available sulphate supply. Complementary sedimentological data suggest pyrite formation persisted in reducing microenvironments in variable sea bottom oxygenation.

New look at London Clay sponge crabs: original material reconsidered

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The Dromiidae, also known as sponge crabs, are one of the earliest families of Brachyura. Since their presumed apparition in the Jurassic their significant occurrence during the Eocene epoch triggered the descriptions of well-known fossil species yielded from the London Clay deposits (England) within the two last centuries. The here proposed study is based on a simple observation: the original material which allowed the description of the Eocene crab species Dromilites bucklandii (H. Milne Edwards, 1837) from the Isle of Sheppey differs from all the material subsequently described as such. It actually corresponds to a less common species, with a rather flat carapace, which has been described much later as a new species: D. simplex. Here, we demonstrate that this latter species has actually to be considered as D. bucklandii and we create a new Dromilites n. sp. This new taxa includes all the fossil crabs, displaying a more ornamented carapace, that have been mistakenly identified as D. bucklandii for 180 years. We show, by providing good imaging (e.g. photogrammetry) of ancient non-figured and new well-preserved material, that these two species differ genuinely one from another, regardless of the growth stage of the carapaces.

Structure and growth of Heterostracan bodywall extensions and the evolution of vertebrate paired fins

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Paired appendages, alongside jaws, are a key component of the gnathostome bodyplan, yet their evolutionary origin has long courted controversy. Palaeozoic jawless vertebrates show an array of fin-like structures, however, this debate has often neglected the significance of the ability to extend the bodywall laterally. This is a key innovation which must, paradigmatically, underpin the origin of paired fins. We investigate the nature of the earliest lateral bodywall outgrowths, found in heterostracans, and find their structure and perceived development shares fundamental similarities to the dorsal spine in the same taxa. We propose spine growth begins with a rounded tubercle which splits medially, allowing apposition of successive generations of tubercles. This process is facilitated by resorption, which also allows thickening of a compact vascular layer, possibly strengthening the spine. This implies that heterostracan skeletogenesis is more dynamic than previously suggested. We also reconstruct the distribution of paired bodywall outgrowths and find that lateral bodywall extensions appear to have arisen independently at least twice in early vertebrate history. This leads us to suggest that a fin competency region may have been duplicated as early as 542 million years ago.

Life inside a dinosaur bone: a thriving microbiome

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Dinosaur bone has been hypothesized to contain endogenous organics such as collagen, osteocytes, and blood vessels. However, proteins and labile lipids are unstable through diagenesis and deep time; bone is also an open system, allowing organic and microbial influx. Organics within fossil bone of appreciable age/thermal maturity producing ‘vessel’- and ‘cell’-shaped molds have alternatively been identified as biofilm. Here, chemical and biological analyses of freshly-excavated, aseptically-acquired, Late Cretaceous dinosaur bones and sediment controls show a thriving microbiome. Pyrolysis GC-MS pyrograms of the fossil bone do not match modern, collagen-containing bone. Amino acid composition of the fossils does not match collagen and is L-amino-acid-dominated, suggesting recent amino acid input. Interestingly, amino acid, DNA, and organic carbon concentrations are higher in the fossil than the surrounding mudstone matrix, suggesting the presence of a microbiome. Further microbial community characterization by 16S rRNA amplicon sequencing reveals the predominance of Actinobacteria and Proteobacteria in the bone. Sequences affiliated with the classes Nitriliruptoria and Deltaproteobacteria were more abundant relative to the adjacent mudstone. Fossil bone likely provides an ideal, nutrient-rich (e.g., phosphate, iron) microbial habitat inside vascular canals capable of moisture retention, suggesting caution regarding claims of dinosaur bone soft tissue.

Selective taphonomic processes in the Fezouata Konservat-Lagerstätte (Lower Ordovician, Morocco): storm influence on the brachiopod record

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Taphonomic processes are responsible for the transition of an organism from the biosphere to the lithosphere. In marine settings, these processes involve both pre-mortem and post-mortem biological, chemical and physical parameters in the water column and in the sediments. Previous detailed studies focused on the influence of these parameters on the fossil record (Lilliput effect, fossil sorting, presence of mineralized organisms). The pre-mortem physical conditions of the water column, however, have not been considered important. The brachiopod record in the Fezouata Shale suggests that these physical processes should be taken into consideration to explain the size composition of the brachiopod assemblages. In this Formation, epibenthic brachiopods show an abnormal distribution (small-sized individuals only) in proximal sites and a normal demography in distal localities, while the distribution of endobenthic brachiopods was standard in both proximal and distal sites. This discrepancy can be related to storm intensities influencing the Fezouata palaeoenvironments. In shallow settings, living epibenthic brachiopods were more influenced by weak storms than deeply-burrowing endobenthic taxa, which were only affected by stronger events. This indirect ecological defense strategy provided more time for endobenthic individuals to grow, therefore displaying a wider range of sizes in proximal settings than epibenthic communities.

The effect of acidification on *D. majorinum* (Mollusca: Scaphopoda) in the Southern Ocean

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Polar oceans are projected to be highly affected by warming and ocean acidification making the Antarctic continent an ideal test laboratory. Regional differences in temperature and carbonate chemistry due to the different oceanography make Weddell and Amundsen Sea ideal test setting in which to assess biotic response to different environmental conditions. Here we focus on an understudied group the Scaphopoda specifically *Dentalium majorinum*. We found differences in morphometric parameters such as ventral and dorsal diameters, length and rib number, volume and densities. On average, the Amundsen Sea specimens are smaller in length and volume than the Weddell Sea specimens. Length, ventral and dorsal diameter are higher at depth below 1600m depth in the Weddell Sea. Internal difference in shell morphology are been analysed by microtomography (microCT) and synchrotron based x-ray tomographic microscopy (SXRTM). No distinct growth rings, indicating difference with growth rates between winter and summer, are visible in the specimen.

A Trilobite from the Lower Cambrian reveals structure and function of an ancient compound eye

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Fascinating relicts of highly differentiated compound eyes have been described from the Lower Cambrian. They show dense lattices of hexagonal arrangements, reminiscent of compound eyes of modern bees, dragonflies or certain crustaceans. No convincing evidence, however, has been given so far about the internal structures, different possibilities for simple arrangements of sensory equipment may be envisaged. Alternatively an ommatidium may have lain below each lens, as in modern crustaceans, insects and xiphosurans. Here the light is concentrated by a dioptric apparatus (lens or lens cylinder and a crystalline cone) onto a light-guiding rhabdom. The latter is part of the sensory cell system by which it is surrounded. The sensory units are isolated against each other by a pigment screen, so each ommatidium provides one 'pixel' collectively producing a mosaic-like image.
In the holotype of the phosphatised trilobite *Schmidtiellus reetae* Bergström, 1973, the right eye is slightly abraded and shows the internal structures of the visual units. It shows the typical ommatidial principle, however, there is no lens, and each unit lies in a separate kind of 'cellular basket'. It is shown that this system worked without a lens properly as a compound eye, more than half a billion years ago.

Preliminary study of bioclaustration cases from Devonian of Asturias

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This is a study of some bioclaustration cases from the Early Devonian of North Spain. The Aguión Formation (Emsian) in Asturias displays an exquisite preservation, although recrystallized, for a variety of embedment structures resulted from overgrowth of different symbionts by bryozoans (mostly fistuliporids and trepostomes). Sectioned specimens allow for observation of growth of bryozoan zooecia adapted to the morphology of the embedded organisms. These bioclaustration structures are described and included in preliminary groups according to the taxa represented in the associations and the morphology of the embedment structure. The identified bioclaustration cases were caused by growth of bryozoans associated with both skeletonised and soft-bodied symbionts, skeletonised biota being represented by rugose corals and soft-bodied taxa by unidentified vermiform animals.
We suggest that the rugose corals grew in symbiosis with the fistuliporid bryozoans. The association is apparent when observing that the inner surface of the calices are not encrusted by the fistuliporid bryozoans. The tubes of unidentified soft-bodied organisms secreted by their host bryozoans seem to indicate that a few trepostome species sheltered vermiform symbionts that lived and grew in association with their host.

The 'Great Ordovician Biodiversification Event': a rapid, spectacular explosion of diversity or an extended mosaic of ecological and taxonomic expansion?

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Some authors have considered the 'Great Ordovician Biodiversification Event' (GOBE) as a spectacular, short-lived 'event' representing a massive increase in the diversity of marine organisms during the Middle Ordovician. This concept is based on a restricted view by authors focusing on a single fossil group, possibly on a single palaeocontinent. John (Jack) Sepkoski established, in the 1970s and 1980s, the statistical reality of the Ordovician radiation, a term promoted by Droser et al. (1996) in their seminal paper 'The Ordovician Radiation'. The 'GOBE' was defined by Webby (2004), based on Sepkoski's concept, as the sum of many individual events. The GOBE includes several Biotic Immigration Events (BIMEs), such as the 'Richmondian Invasion' and the 'Boda Event,' but also successive biodiversity pulses including a succession of diversifications in the planktonic (late Cambrian - Early Ordovician), level-bottom benthic (Early-Middle Ordovician) and reef communities (Middle-Late Ordovician), although the boundaries of these 'events' are diachronous (as for the entire GOBE). The GOBE is thus an aggregate of the diversity trends of all individual fossil groups displaying rapid increases, diachronously, during different intervals and across different regions.

Ichnotaxonomy of a sporadically-exhumed dinosaur tracksite: the Cretaceous Lee Ness Sandstone, East Sussex

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New dinosaur footprint finds have been reported from the Wealden exposed in the cliffs near Hastings on 37 occasions dating back to 1846, when a single imprint was first presented to the Geological Society of London. These finds all occurred along a stretch of coastline approximately 18 km long, between Cooden to the west and Fairlight to the east. Typically the footprints are observed in collapsed blocks of cliff material sourced from several key horizons, the most lucrative of which is the Lee Ness Sandstone of the Ashdown Beds Formation.

We present an ichnotaxonomic list of the vertebrate and invertebrate ichnofauna of the Ashdown Beds Formation. The sporadic and periodic exhumation of the tracks by cliff retreat attests to the tracks occurring in patches on the base of the Lee Ness Sandstone, despite them being found singularly. Estimates of the rate of cliff retreat are used to interpret the spacing between trackways. Due to occurring at the same stratigraphic level, the ichnofauna provides a key snapshot of the dinosaur and invertebrate fauna living on the floodplain of a Cretaceous meandering river.

Mandibular eco-morphology reveals how dietary specialisation shaped synapsid macroevolution following the Permo-Triassic mass extinction event

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Synapsids experienced great taxonomic and ecological success through the Permian, and dominated terrestrial ecosystems, but were severely impacted by the Permo-Triassic mass extinction. Diversity of surviving clades (Anomodontia and Eutheriodontia) recovered quickly, but ultimately fell through the later Triassic, with archosaurs taking over as the most diverse and abundant clade. The macroevolutionary drivers of the transition have been debated, whether it resulted from intrinsic archosaur "competitive superiority" or the extrinsic impact of the extinction. Here we provide an eco-morphological perspective, assessing synapsid macroevolution from the Late Permian to the Early Jurassic. We use geometric morphometric methods to plot mandibular disparity and morphospace through time, using mandibular feeding functionality to infer patterns of trophic ecology and evolution. Our results reveal a novel pattern of eco-morphological decline across the Permo-Triassic that suggests dietary specialisation did not necessarily reduce survivability through the extinction event. Furthermore, we find contrasting patterns of trophic evolution within surviving synapsids that sheds further light on the recovery of terrestrial ecosystems following the extinction. Our study favours an extrinsic driver of synapsid macroevolution through the early Mesozoic, and illustrates how investigations of macroevolution benefit from consideration of morphological, as well as traditional taxonomic approaches.

Comparative synarcual morphology in extant and extinct batoids (skates and rays; Chondrichthyes)

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Batoidea (skates, rays; Chondrichthyes) comprise approximately half of all Elasmobranchii and are the most morphologically diverse members of this group, inhabiting most marine ecological niches. Characteristic featurees include dorsoventrally depressed body and the synarcual, a tessellated cartilaginous tubular structure comprising fused anterior vertebrae. A comparative study of synarcual morphology among extant (computed tomography) and extinct batoids (macrophotography) examines how structural variation reflects function, including locomotion and feeding. Batoids with pectoral fin-based locomotion (e.g., Raja clavata) have stronger, shorter synarcuals, and a reinforced neural tube inside the synarcual supporting the large pectoral girdle, dorsally attached via the pectoral arch. Axial-based batoids (Rhinobatos formosensis, Rhina ancyclostoma) have an anterior-posteriorly longer synarcual, reinforcing rigidity along the axial skeleton, but with a less robust pectoral arch and less expansive fin span. Some batoids (Narcine tasmaniensis) show a combination of features, using pectoral and axial locomotion. Extinct batoids have shorter synarcuals and robust pectoral arches, indicating pectoral-based locomotion; which appears to be the plesiomorphic condition in early batoids. Feeding involves cyclic dorsoventral cranial movement in N. tasmaniensis, with the synarcual providing rigidity and support; R. formosensis uses the anterior body to trap prey against the substrate.

Traquair's lungfish from Loanhead: dipnoan diversity and tooth plate growth in the late Mississippian

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R. H. Traquair, the eminent palaeichthyologist and museum curator, procured an extensive collection of Palaeozoic fishes from across Scotland with the help of local miners and quarrymen. One productive locality near Edinburgh was Loanhead. He described numerous fossil fish from this Serpukhovian site, including four lungfish taxa: *Ctenodus interruptus*; *Sagenodus quinquecostatus*; *Uronemus splendens*; and *Ctenodus angustulus*. The first three are quite well known but the fourth was only briefly described and never figured. A fifth taxon, *Conchopoma* sp., has recently been identified. This is the earliest known occurrence of the genus, extending its range into the Mississippian. The presence of five lungfish at a single locality is unprecedented in the Carboniferous and indicates that the high level of lungfish diversity encountered in the Tournaisian of the Scottish Borders continued throughout the Mississippian. This may have been due to changes in tooth plate growth enabling greater variation in dentition and diet. Tooth plate growth in most Devonian taxa can be explained by comparison with that in extant forms, but analysis of Carboniferous tooth plates suggest growth was different in many taxa, allowing for novel patterns of tooth ridges and different types of teeth to develop on the same plate.

Intraspecific variation and evolutionary trends in conodonts

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How shape changes through time? The set of theoretically possible forms is bounded by the way they can be generated during ontogeny, possibly driving evolution into preferential directions.
Patterns of shape variation in conodont elements have been documented mostly qualitatively and at the species level, no generalized pattern of variation has been described. Because conodont elements are used for feeding, their complex morphology may reflect functional adaptations to specific diets. Yet, they must also reflect developmental constraints. It is thus mandatory to understand if and which traits might be adaptive or not. Conodont elements are likely highly integrated, that is their morphological characters are not independent but covary with each other. In this study, we investigate patterns of intraspecific variation in two very distinct and distant assemblages, one from the Late Devonian, and one from the Late Triassic. In both cases, empirical observations have led some authors to hypothesize evolutionary trends in conodonts morphology. Here we are assessing those 'trends' in a quantitative way. For this purpose, we have 3d scanned hundreds of elements from both assemblages and investigated quantitatively patterns of variation and covariation with geometric morphometric analysis.

The energetics of marine calcification under ocean acidification

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The marine fossil record is dominated by the calcium carbonate skeletons of past organisms. Ocean acidification events in the geological record have impacted the diversity of marine calcifiers, and anthropogenic ocean acidification threatens numerous ecologically important modern taxa. However, the metabolic demand of skeletal manufacture is poorly understood hampering accurate forecasts of extinction risk. In this work, we develop a generalized mathematical framework to delineate the fundamental costs faced by organisms in precipitating shells out of seawater. We show that the energetic demand of inorganic, calcium carbonate is typically less than the organic matrix used as a template in skeletons, limiting whole-shell cost sensitivity to values less than roughly 10-20%. Instead, we highlight the importance of rate, as opposed to cost, in determining the extinction risks of marine organisms. We discuss the central importance of larval mortality and discuss key future experiments that may help inform the differential extinction risks.

Atmospheric pCO2 decreased prior to the sudden O-isotope change at the Eocene-Oligocene boundary

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A unique collection of fossil leaves belonging to species Eotrigonobalanus furcinervis (extinct trees of the beech family, Fagaceae) from a stratigraphic sequence in central Germany was utilised to derive an atmospheric pCO2 record with the stomatal proxy method. The record comprises multiple data points spanning the late middle to latest Eocene, two sampling levels which may be earliest Oligocene, and two samples from later in the Oligocene. The new record indicates that pCO2 decreased continuously by ca. 40% in the late middle to late Eocene, from ca. 630 ppm to ca. 410 ppm at the Eocene-Oligocene boundary. Based on the subsequent records, pCO2 in later parts of the Oligocene was similar to latest Eocene values. A significant drop in pCO2 at the Eocene-Oligogene boundary is not observed, in contrast to marine oxygen isotope records. These results may suggest that: 1) decrease in pCO2 preceded the large shift in temperatures and/or ice sheet expansion that characterizes the Eocene-Oliogocene boundary, probably when a certain threshold of pCO2 was crossed; and 2) that pCO2 levels – and thus this climate change threshhold – were lower than previously assumed, suggesting important implications for estimations of climate sensitivity

Trilobite! Japan?

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Trilobites are widely represented in the Silurian and Devonian strata of Japan, with taxa described from the South Kitakami, Hida Gaien and Kurosegawa Palaeozoic terranes. Here present a review of five of the trilobite groups represented in the Japanese Siluro-Devonian sequences: Illaenida, Scutelluidae, Phacopidae, Proetida and Encrinuridae that have received recent taxonomic revision. The proetids suggest an endemic signal at species-level, not just between Japan and other East Asian terranes, but also at the level of the individual Japanese terranes; Silurian illaenids and scutelluids show multiple genus and species-level links with the Australian segment of the Gondwana palaeocontinent, but not between the Japanese terranes; encrinurids also suggest possible species-level links with Australia, and also between the Japanese terranes; and Devonian phacopids suggest links with the North China palaeocontinent. These markedly different patterns may in part reflect the fragmentary biostratigraphical record of the Japanese trilobites, but also appear to be explicable in terms of the facies ranges and ecology of the different groups. This cautions against the use of the Japanese trilobite assemblages for biogeographical assessment without reference to their autecology and facies distribution, an assessment of which should give a clearer understanding of their true palaeogeographical significance.

Endocranial morphology of Powichthys thorsteinssoni Jessen and the phylogeny of early Stem-group Dipnoi (Osteichthyes, Sarcopterygii)

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Resolving phylogenetic uncertainties within the lungfish stem is crucial to understanding early sarcopterygians and osteichthyan evolution. *Powichthys thorsteinssoni* is one of the earliest known sarcopterygian taxa, from the Early Devonian Drake Bay locality, Prince of Wales Island, in Arctic Canada. *Powichthys* possesses a fused dermal cranial joint, which has been suggested as an incipient stage in lungfish cranial fusion. However, competing hypotheses place *P.thorsteinssoni* as either a porolepiform, the sister group of all other total-group dipnoans, or as a more proximate relative of the crown than porolepiforms. Here we add phylogenetically useful data on the endocranial morphology of *P. thorsteinssoni* using x-ray computed microtomography. We observe an elbow-like hypophysial chamber is present as in *P.spitsbergensis*. Similarly to *P.spitsbergensis* and *Youngolepis*, the pituitary vein foramen is more anterior than in porolepiforms. Nasal capsule morphology resembles that of *Porolepis*.
The interpretation of pores on Jessen's 'mushroom structure' as lacunae suggests *P.thorsteinssoni* possession of ventral processes, a proposed *Powichthys* autapomorphy. Phylogenetic analyses suggest that *P.thorsteinssoni* is more closely related to *Youngolepis* and *Diabolepis* than Porolepiformes.

How well do environmental parameters preserved in the geologic record describe benthic ecological niches?

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Ecological niche modelling (ENM) is an emerging technique in modern macroecology for the quantitative prediction of species distributions based on abiotic environmental parameters. The PaleoENM framework has laid the groundwork for the application of ecological niche modelling to the fossil record, opening an exciting research frontier for understanding interactions between biodiversity and environmental changes in deep time. The palaeontological record, unfortunately, does not directly record many of the abiotic environmental variables utilized by benthic marine ecology models in the modern ocean. In this study, we address the potential of indirect environmental signals available in the geologic record to parametrize the ecological niche space of modern benthic macroinvertebrates by applying machine learning methods to large oceanographic and biodiversity datasets from the benthic ecosystems of Southern California. Random forest algorithms are employed to evaluate the potential of the geologic record to predict modern ecological distributions in the absence of direct oceanographic variables, focusing on bathymetry, sedimentology and geochemistry. Through this approach, we hope to advance understanding of how geologically available parameters relate to modern ecological processes and assess the proportion of ecologically relevant environmental information preserved in the geologic record.

Global paleobiogeographical patterns and correlations in the palm macrofossil record

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Palms (Aracaceae/Palmae) are an important component of some modern and ancient forested terrestrial ecosystems. Dominantly tropical in distribution today, their macrofossil record extends back to Cretaceous time and, during some periods, into polar paleolatitudes. While there has been much recent work on the evolution, systematics, historical ecology, and biogeography of modern palms, what deserves more study is the global macrofossil occurrence of this group from leaf, fruit, axis, and inflorescence remains.
More than 300 palm macrofossil occurrences from over 220 localities reported in the published literature were collected in a database of taxonomic (genus, species, and/or form) and locality (formation, literature age, age constraint, preservation lithology, modern geographic coordinates, paleogeographic coordinates) data.
These data show the greatest paleolatitudinal extent of the palm macrofossil record to be during Early Paleogene time (spanning >100 latitudinal degrees). The data also show a bimodal paleolatitudinal concentration in the northern and southern subtropics when totaled across Cretaceous to Recent occurrences, in line with marine carbonate and evaporite lithofacies distributions.

Understanding the paleobiogeographical record of these iconically tropical plants (in the modern world) can help elucidate Earth's paleoclimate, paleoecological, and paleoenvironmental history in ancient worlds and provide context for modern and future climate change.

Fossil micrometeorites hidden within acid-digestion residues

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Disrupted asteroids and sublimating short-period comets produce a continuous flux of submillimetre extraterrestrial dust. This material, termed micrometeorites, spirals into the inner solar system and is either captured by terrestrial planets or consumed by the Sun. On Earth, infalling micrometeorites become incorporated into actively forming marine sediments and are ultimately preserved in the geological record. Thus, palaeontologists searching for microfossils, have unknowingly collected, extracted and curated an abundance of micrometeorites, which today remain hidden within acid digestion residues. In this study we explore several conodont residues for cosmic dust. Although the yield of micrometeorites recovered is relatively small, the initial rock samples analysed were also modest. By contrast, several systematic large-scale micropalaeontology projects have previously dissolved significantly larger samples, even exceeding 100kg. From such projects, an interdisciplinary collaboration re-examining the detrital remains would generate vast numbers of cosmic spherules, thereby providing a significant contribution to our collective understanding of the extraterrestrial flux over geological time and the formation of asteroid families. The aim of this presentation is to highlight the potential for further research into micropalaeontology residues as collection sites for micrometeorites.

Petrosal bone Upper Miocene Odontoceti from Northern Ciscaucasia (Krasnodar region and Adygea)

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Three petrosal bone from the late Miocene of Northern Ciscaucasia (locality near Gladkovskaya and a number of locality in Adygea) are close in morphology to samples from the lower Serravalia Visiano (Clayey quarry, Northern Apennines, Parma, Italy), described as Acrodelphidae or Delphinidae (see Gigala-Fulgosi, Pilleri, 1985, Table 6, Figures 1-6). However, the Caucasian samples, in comparison with the Visiano samples, have a more robust and shortened anterior process, and also a relatively smaller opening of aqueductus cochleae. We scanned and investigated petrosal bone from smaller toothed whales in the Paleontological Institute of Russian Academy of Sciences, on the X-ray micro-CT Skyscan 1172. Microtomography parameters: I=100 mA, U=103-104 kV, a filter – Al (1 mm), a pixel size was from 25 to 34.1 μm, a rotation - 180º, steps of rotation were 0.7º, random movement – 10, frame averaging – 8. TView, NRecon, CTAn programs are used. As a result of the work, it was possible to describe in detail the morphology of the reconstructed virtual sections and construct a 3D model of the labyrinth of the petrosal bone. This work was supported by the FRP RAS Biodiversity of Natural Systems. Biological resources of Russia: assessment of state and fundamental principles monitoring.

New data about inner morphology of petrosum of Miocene baleen whale *Vampalus sayasanicus* from Chechnya

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Vampalus sayasanicus is very interesting Miocene baleen whale from Chechnya and very differs from other typical Cetotheriidae (i.e. typical cetotheriinae and herpetocetinae). We scanned the right cochlea of *V.*

sayasanicus. The specimens were scanned in NRC "Kurchatov Institute" by using "Kurchatov synchrotron radiation source" and "Research reactor IR-8". A spatial resolution was 130 μm for synchrotron tomography and 160 μm for neutron tomography. Recovered virtual sections have been morphological described by neutron data because a strong contrast on the rock that filled some cavities (or small crystals grown in these cavities) was observed on synchrotron data. The 3D model was obtained by synchrotron data ready. The result found that the cochlea has approximately 3.25 turnover, which differs from herpetocetinae - 2.5-2.75 turns (Park et al., 2017), Cetotheriinae – about 2.7 turns (Tarasenko et al., 2017). Earlier *V. sayasanicus* was considered to herpetocetinae (Tarasenko et Lopatin, 2012), but the new data of the morphology of the petrosum, some morphological features of the external morphology of this bone, make it necessary to revise the taxonomic position of this whale.This work was supported by the FRP RAS Biodiversity of Natural Systems. Biological resources of Russia: assessment of state and fundamental principles monitoring ".

The strange case of a Silurian fish fossil from the Kalana lagerstätte, Estonia

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The Kalana Lagerstätte of the Silurian age (Aeronian, Llandovery) in Estonia has revealed rich exceptionally preserved non-calcified algal flora. The faunal fossils in Kalana display a rich biota, within which benthic, nektic and planktic faunas are all well represented. However, the preservation of different groups, depending upon their lifestyle and skeletal mineralogy, is rather variable. The excellent preservation of some fossils, e.g. crinoids suggests that they were buried in situ. Yet a considerable proportion of shelly fossils, including brachiopods and gastropods, are common in storm accumulated coquina lenses. Gastropods, as a rule, are preserved as internal moulds only.
A recent discovery of an agnathan head shield is a remarkable addition to the species list. This specimen belongs to Osteostraci, and as the earliest member of the group, pushes back the timing of the assumed origin of the clade by about 10 million years. The elemental analysis performed with EDS in order to determine the chemical composition of the dorsal head shield, revealed that instead of the supposed major constituent of the dermal skeleton - calcium phosphate – the fossil consists of carbonaceous matter only. The missing of phosphate in the fossil is extraordinary, especially taking into consideration that the locality yields also conodonts, which show normal preservation.

Foraminiferal reaction to changes in Pliocene climate

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Anthropogenic atmospheric carbon dioxide (pCO_2) is rapidly rising. This increase is impacting on the ocean, affecting the biological pump, ocean chemistry and marine organisms. Marine calcifiers are affected by increased CO_2, but future consequences are still unknown. We quantify the relationship between changing environmental conditions and calcification in foraminifera, a group essential to the biogeochemical and carbon cycle during the Pliocene. The Pliocene was the last time interval when atmospheric CO_2 concentrations were comparable to today. We measured the test size of planktic foraminifera and the weight of the dominant species *Globigerinoides ruber* through the Pliocene at Ocean Drilling Program Site 999 in the Caribbean. Test size shows high-frequency variability not related to carbonate chemistry or to temperature, as these are generally stable at Site 999 during this interval. During marine isotope stage M2, foraminiferal test size increases and may have been linked to changes in stratification in response to the closure of the Panama Isthmus. From ongoing observations, foraminiferal weight is larger at higher temperatures and thereby for inference higher CO_2. CT scans will be used to distinguish the driver of the observed changes such as wall thickness changes or increased number of chambers on the weight of foraminifera.

A new marine snake (Palaeophiidae) from the early Paleogene of Morocco, a signal of early Cenozoic diversification

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The early Cenozoic phosphates of Morocco have yielded a diverse marine vertebrate fauna. Among these are the Palaeophiidae, a group of large to giant marine snakes. Previously, all *Palaeophis* specimen from Morocco have been identified as *P. maghrebianus*. We describe a new palaeophiid from the Palaeocene/Eocene boundary of the Oulad Abdoun basin. The fossil consists of disarticulated vertebrae and ribs, and is referred to the family Palaeophiidae based on the horizontal axis of the cotyle-condyle, the low position of the synapophyses, the long and slightly curved ribs, and lateral compression of the vertebrae. It differs from primitive palaeophiid snakes and resembles *Pterosphenus* in exhibiting a hypertrophied neural spine, which extends to twice the length of the centrum on trunk vertebrae, and in the pterapophysis protruding slightly over the dorsal height of the zygosphene at a low angle. Parsimony analyses based on 29 characters and 24 fossil snake taxa suggests a relatively derived form with affinities to the *Pterosphenus* clade. The specimen illustrates the extreme aquatic adaptations of this clade, and suggests that Palaeophiidae underwent a major diversification in the Paleocene and early Eocene in response to the extinction of Cretaceous marine reptiles and concurrent global warming.

Cosmine means cosmine: morphology and phylogeny of sarcopterygian dermal tissue

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Cosmine has traditionally been described as a sarcopterygian synapomorphy consisting of a single enamel layer overlaying a series of pore cavities connected by underlying canals in dentine. The discovery of such pore canals in several actinopterygian taxa have caused confusion about the definitive structure and phylogenetic signature of cosmine. We used synchrotron tomography to generate the first three dimensional model of cosmine in *Megalichthys hibberti*, the taxon cosmine was originally defined in. Accompanied by studies on the cosmine of the dipnomorph Porolepis, we propose that cosmine is indeed an informative rhipidistian synapomorphy. Ancestral state reconstruction further suggests that cosmine is a specific elaboration of an older osteichthyan pore canal system important for vascular supply through the dermis. This study provides a new framework for studying sarcopterygian relationships using specific structural differences in the pore canal systems, while also helping further clarify the positions of enigmatic basal osteichthyan taxa.

Mica-agglutinating worm tubes from the Upper Ordovician of Tafilalt, southeastern Morocco

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A small number of organisms create exoskeletons not through biomineralisation, but rather through agglutination: binding sedimentary particles from their environment in a cement or organic matrix. Most agglutinating organisms use any and all materials available, but a small proportion show greater selectivity, for particle size or particle kind.
Here, we describe fossils from Ordovician strata of the Tafilalt region in southeastern Morocco which appear to be agglutinated tubes composed wholly of muscovite mica. Mica-agglutinating fossils have previously been described from the Cambrian of Estonia and the southwestern United States of America under the generic name Onuphionella, and interpreted as polychaete worm tubes.

We investigated the Moroccan fossils through microscopy and SEM analysis. These are similar to Onuphionella in their tubular form and micaceous mineralogy, but differ in a number of important respects. Most particularly, the mica flakes in the Moroccan material are arranged parallel to the tube length, rather than perpendicular as in Onuphionella; the Moroccan specimens also differ in width (smaller), length (longer), and flexibility (evidently much higher, with some specimens folded back on themselves). The specimens all appear to be lying flat on bedding plane surfaces, but are not current aligned, making palaeoecological and taphonomic interpretation puzzling.

A new species of *Parotodus* (Lamniformes: Otodontidae) from the Oligocene of Japan

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The genus *Parotodus* Cappetta 1980 is a lamniform shark ranging from the Eocene to the Pliocene. Its teeth are rare and are usually found in mid to outer shelf deposits. In Japan it occurs in rocks of early Oligocene to late Pliocene age.
Three fossil shark teeth were collected from the Yukiaino Sandstone Member, Karatsu Formation in Saga Prefecture, south-western Japan. They were referred to the genus *Parotodus* because they could be distinguished from other lamniform sharks by the following combination of characters: absence of serrated cutting edges; presence of broad neck; U-shaped basal edge of the root and development of the lingual protuberance of the root. These teeth were originally identified as *Parotodus benedenii* (Le Hon 1881), a Neogene species, based on their size and lack of lateral cusplets. However, two specimens possess a small pair of lateral cusplets similar to the middle Eocene species *P. mangyshlakensis* Kozlov 1999. Given that an increase in size and the progressive loss of lateral cusplets are a trend in *Parotodus*, we hypothesize that our specimens and some early Oligocene specimens described from Belgium by Leriche (1910) are a new species intermediate in morphology between *P. mangyshlakensis* and *P. benedenii*.

A new site with *Pleuromeia* remains from the late Buntsandstein of the Holy Cross Mts, Poland

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Pałęgi claypit are already known from numerous arthropods remains: conchostracans, cycloid crustacean and insects. Exposed siltstones, mudstones and sandstones of the Late Buntsandstein age (latest Olenkian-early Anisian) represents fluvial deposits and have yielded also bivalves, invertebrate ichnofossils as well as vertebrate bones and foot tracks. Until now plant fossils were mentioned only within stratigraphic context. Palynological expertise showed that deposits from Pałęgi claypit can be correlate with latest Olenkian-early Anisian units of the German Basin. Macrofloral remains are preserved as compressions and casts. Present are vegetative plant organs (leaves, stems and roots) along with reproductive structures: seeds, sporangia, cones. Our recent study reviled the presence of the floral assemblage consisting of lycophytes, horsetails, ferns and conifers. The most abundant are remains resembling Triassic plant from the genus *Pleuromeia*. Characteristic features of the fossils are suggesting the similarity of Polish specimens to *Pleuromeia* sternbergi from Bundtsandstein of Germany. *Pleuromeia* is the most important and typical plant from the Buntsandstein of the Germanic or Central European Basin. That would be the first complete description of that taxa from Triassic of Poland.

A first insight into macroflora from the Early Devonian (Emsian) of the Holy Cross Mountains, Poland

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New macroflora data has been obtained from Bukowa Góra Quarry, western part of the Łysogóry Region of the Holy Cross Mountains. The formation consists of several dozen meters of sandy facies interbedded with thin mudstones and siltstones interpreted as a near shore (lagoon to shelf) paleoenvironment. The macroflora remains were found in mudstones intercalations. The fossil material includes impressions of plant stems, roots, charcoalified vascular strands, but also cuticles, as well as abundant spores. Preliminary study reviled presence of fragmented stems resembling *Taeniocrada* sp. with characteristic central xylem strand and branching *Hostinella*-like remains. Samples processed for palynology unveiled a great diversity of plant cuticles with stomata preserved, isolated tracheids of different types and fungal hyphae. Palynological examination allowed to assigned samples with macroflora to the *douglastownense-eurypterota* Zone (Emsian/Eifelian). Important miospore taxa found include *Emphanisporites* spp., *Hystricosporites corystus*, *Grandispora douglastownense*, *Ancyrospora* spp., *Dibolisporites* spp. and *Retusotriltes* spp. The lack of *Ancyrospora eurypterota* indicates that the age is not older than Emsian. Plant fossils are accompanied by numerous and diverse arthropods remains.

Persistence of shallow dwelling Cenozoic isocrinid crinoids in the Southern Hemisphere: implications for the Marine Mesozoic Revolution

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Increased predation pressure as a result of the Marine Mesozoic Revolution (MMR, starting ~200 million years ago) shaped the ecological structure of benthic sea floor communities from the Mesozoic to the Recent. It has been argued that less mobile groups such as stalked isocrinids moved out of shallow water environments by the Late Cretaceous (100–66 million years ago) to evade increased predation pressure. Newly collected and described taxa from Antarctica and Australia, supplemented by data gathered from the literature, demonstrate a substantial Southern Hemisphere fossil record of stalked isocrinid crinoids (Order Isocrinida), which inhabited shallow water until the Eocene/Oligocene boundary (~34 million years ago). These occurrences, from often overlooked isolated crinoid columnals, as well as newly discovered articulated crinoid fossils, challenges the perceived notion that the majority of stalked crinoids became restricted to deep water in the mid-late Mesozoic. The delayed migration of the Southern Hemisphere isocrinids to deeper waters after the Eocene/Oligocene boundary may have been due to intraorder competition from the more motile comatulids, which became dominant in the Southern Hemisphere following major ocean circulation changes including the onset of the Antarctic Circumpolar Current.

A new basal actinopterygian from Nova Scotia: stem group survivorship in the early Carboniferous

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The vertebrate fossil record of the earliest Carboniferous is notoriously poorly-sampled, obscuring a critical interval in the evolution of modern vertebrate diversity. Recent studies of diversity across the Devonian-Carboniferous boundary propose a vertebrate mass-extinction at the end-Devonian, and recent phylogenetic and molecular work suggests that the origin of the actinopterygian crown may have occurred in the earliest Carboniferous, as part of a broader recovery fauna. However, the data necessary to test this are limited. Here, we describe a partial actinopterygian skull, including diagnostic elements of the posterior braincase, from the Tournaisian Horton Bluff Formation of Blue Beach, Nova Scotia. The braincase surprisingly shows characters typical of Devonian taxa but absent in Mississippian forms, such as an open spiracular groove, open ventral cranial fissure, anteriorly-restricted parasphenoid, and lateral dorsal aortae that pass through open groves in the ventral

otoccipital region. Phylogenetic analysis places it deep within the actinopterygian stem, among Devonian moythomasiids and mimiids, suggesting broader survivorship of plesiomorphic actinopterygians across the end-Devonian mass extinction. With high lineage survivorship in tetrapods and lungfish across the Devonian-Carboniferous boundary and high vertebrate diversity at other Tournaisian localities, this hints at a more gradual turnover between Devonian and Carboniferous vertebrate faunas.

Palaentology and stratigraphy of an exceptionally fossiliferous spherule-rich bed at the Cretaceous–Paleogene (K–Pg) boundary in Mississippi, USA: implications for events before, during, and after the K–Pg mass extinction

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We describe an outcrop of the Cretaceous–Paleogene (K–Pg) boundary in Union County, Mississippi, USA, consisting of the Owl Creek and overlying Clayton formations. The Owl Creek Formation is rich in the ammonites *Discoscaphites iris* and *Eubaculites carinatus*. These indicate the *D. iris* Assemblage Zone and deposition in the final 300 kyr of the Cretaceous, confirmed by microfossil analysis. The base of the Clayton Formation marks the K–Pg boundary, and consists of a 15-30 cm thick muddy, poorly sorted quartz sand that contains abundant and well-preserved 0.5 mm to 1 mm-sized impact spherules, derived from the Chicxulub crater 1500 km to the south. The spherule bed contains a rich macrofossil fauna of 35 species of molluscs, echinoid fragments, and crab and shark remains. The infill of mollusc shells is identical to the surrounding matrix (including spherules) and differs from the underlying Owl Creek. This suggests the animals were either alive or loosely scattered on the sea floor at the time of deposition. A combination of geochemical and sedimentological analyses suggests multiple environmental and depositional changes during the K–Pg interval in the Gulf Coast. These can be related to both the Chicxulub impact and longer term environmental variability.

Reconstructing trophic networks across the early Toarcian Ocean Anoxic Event (Lower Jurassic)

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Trophic guild diversity, connectivity, and robustness of trophic networks decreases across the Early Toarcian Ocean Anoxic Event. We focus on the reconstruction of trophic network dynamics across the early Toarcian extinction event; which is thought to have been driven by an Ocean Anoxic Event. The analysis is based on a field database collected from the Pliensbachian-Toarcian of the Yorkshire Coast, with 162 macrofossil species assigned to trophic guilds using the Bambach ecospace model. Although there is limited evidence for the decoupling of pelagic and benthic ecosystems, there is a major loss of motile, metabolically demanding benthic fauna. Network connectivity is greater in the late post-extinction recovery than in pre-extinction, although the number of guilds remain equal. This is likely due to the appearance of new predatory guilds that display a high degree of centrality, i.e. well connected to other nodes, in the networks. The results suggest that the early Toarcian extinction event was likely a top-down extinction with metabolically demanding benthic guilds, such as motile predators, disappearing during the Ocean Anoxic Event, as they were more sensitive to dysoxic and anoxic conditions than stationary benthic faunas with lower metabolic demands.

The early Cambrian origin of Pancrustacea revealed by micro-computed tomography

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The early evolution of Pancrustacea is mainly informed by exceptional Cambrian microfossils preserved as three-dimensional phosphatic replicates in Orsten-type assemblages, or as flattened 'small carbonaceous fossils' (SCFs) from organic-rich shales. Although these taphonomic windows capture minute anatomical details, their preservation potential is strictly limited to larval stages (Orsten) or recalcitrant fragmentary remains (SCFs), precluding direct comparisons with macroscopic taxa from Burgess Shale-type deposits. We employ X-ray computed tomography to reveal the exceptionally preserved three-dimensional appendicular anatomy of the bivalved euarthropod *Ercaicunia multinodosa* from the Cambrian (Stage 3) Chengjiang Lagerstätte in China. The head comprises four differentiated appendage pairs, including well-developed antennules with sensorial setae, hook-shaped antennae composed of three robust podomeres, subquadrate serrated mandibles, and subtriangular maxillules with a multiarticulated distal palp. The gnathal limbs surround an oval-shaped hypostome. The trunk bears 16 pairs of biramous appendages. Each trunk limb consists of an endopod with five to nine podomeres with rounded endites, a three-segmented exopod with posterior-facing setae, and a proximal leaf-shaped epipodite attached to the basipod. The appendicular organization of *E. multinodosa* indicates affinities with stem-group Pancrustacea, with comparable implications for morphologically similar bivalved euarthropods from early and middle Cambrian Burgess Shale-type biotas such as clypecaridids, waptiids and hymenocarines.

A review of *Loxodonta atlantica* (Pomel, 1979) based on newly identified materials from the Muséum national d'Histoire naturelle (Paris, France)

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Among the two surviving genera of extant proboscideans, the African elephant *Loxodonta* has been long-held as the more evolutionarily conservative taxon. However, discussions over the deep-time evolution of this lineage remained unsatisfactory due to the presence of few identifiably diagnostic fossil materials. We hereby report previously unpublished craniomandibular elements of *Loxodonta atlantica* from the Pleistocene of Algeria, the most morphologically derived species from the genus, and one of the very largest. The specimens were collected during expeditions led by Camille Arambourg and now housed in the collections of the Muséum national d'Histoire naturelle, Paris, France. The rediscovered Algerian materials allow a thoroughly emended diagnosis for the poorly discussed species. The craniomandibular morphology of *L. atlantica* supports its attribution to the genus *Loxodonta*, but a few noticeable autapomorphies preclude it from the ancestral lineage leading to the extant Loxodonta species: *L. africana* and *L. cyclotis*. These systematic inferences are supported by a preliminary cladistic analysis.