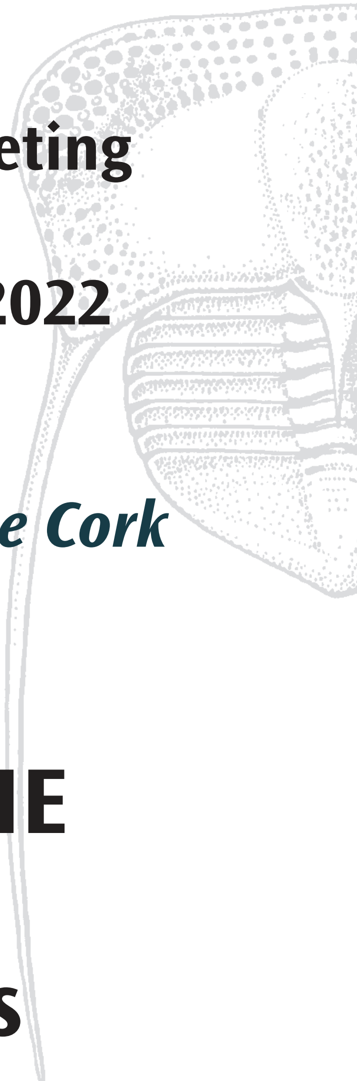
The Palaeontological Association

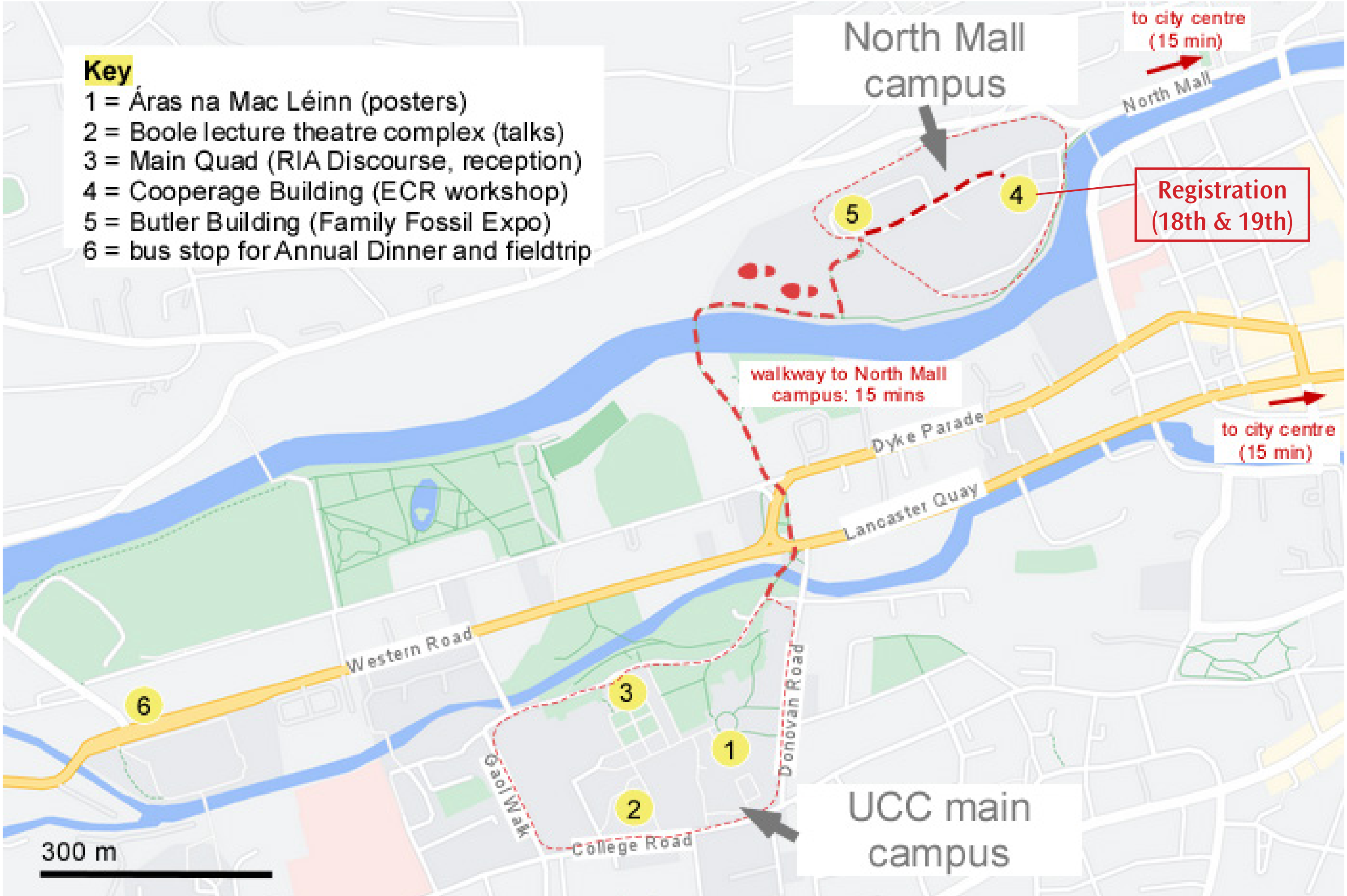
66th Annual Meeting

18th–24th July 2022

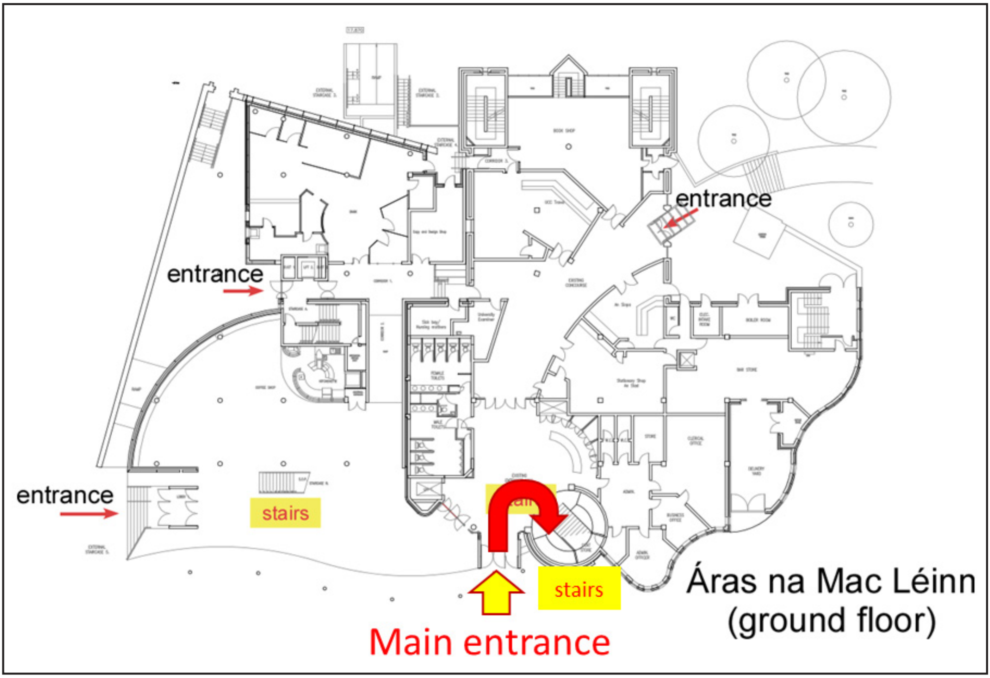
University College Cork
Ireland

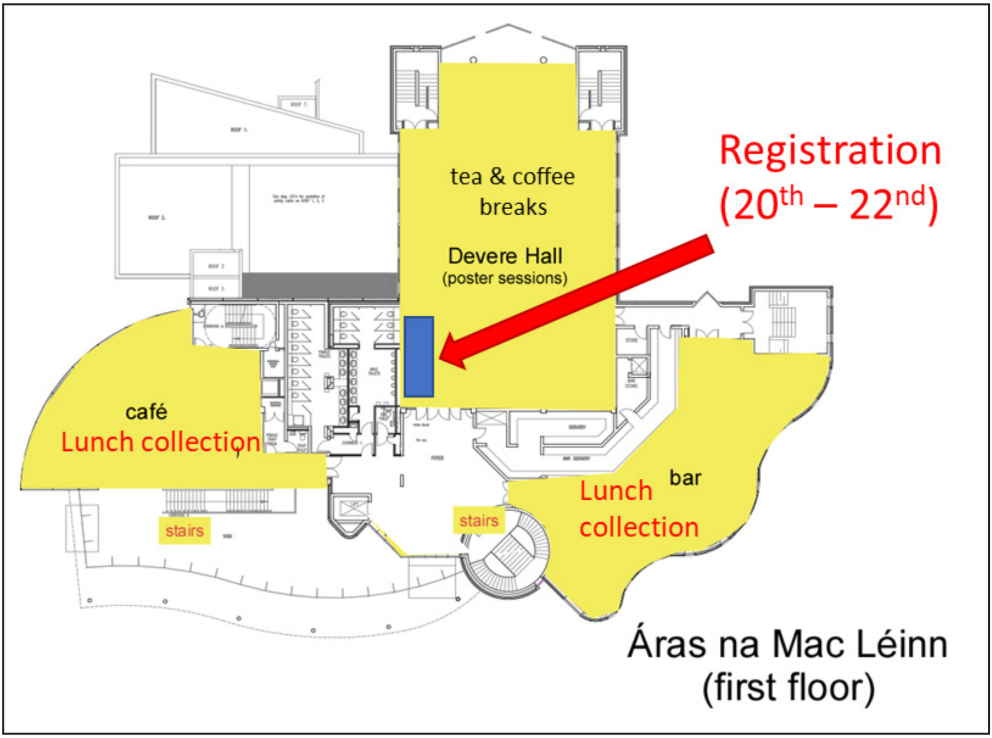


PROGRAMME
ABSTRACTS
AGM papers

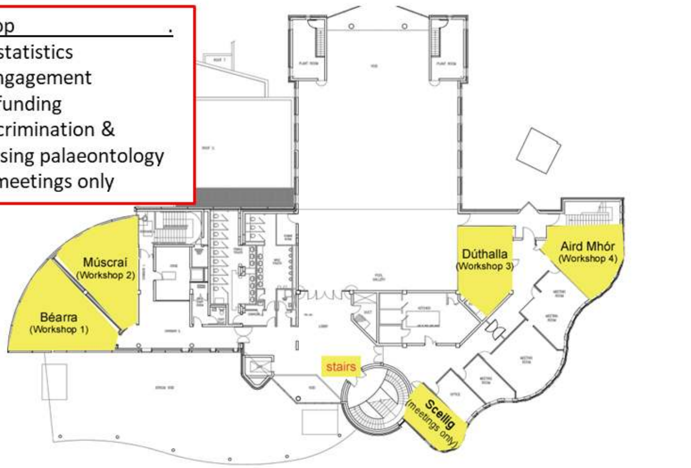

Key
1 = Áras na Mac Léinn (posters)
2 = Boole lecture theatre complex (talks)
3 = Main Quad (RIA Discourse, reception)
4 = Cooperage Building (ECR workshop)
5 = Butler Building (Family Fossil Expo)
6 = bus stop for Annual Dinner and fieldtrip
North Mall campus
UCC main campus
Registration (18th & 19th)
walkway to North Mall campus: 15 mins
to city centre (15 min)
to city centre (15 min)
North Mall
Dyke Parade
Lancaster Quay
Western Road
Donovan Road
College Road
Gaol Walk
300 m


Key
1 = Devere Hall, Áras na Mac Léinn: posters, breaks, lunch
2 = Boole complex (underground): Lecture theatres 1, 2, 4
3 = Aula Maxima, North Wing Main Quad: RIA discourse lecture & reception
= pedestrian entrances to main campus
walkway to North Mall campus: 15 mins
Western Road
Donovan Road
College Road
Gaol Walk
1
2
3
100 m

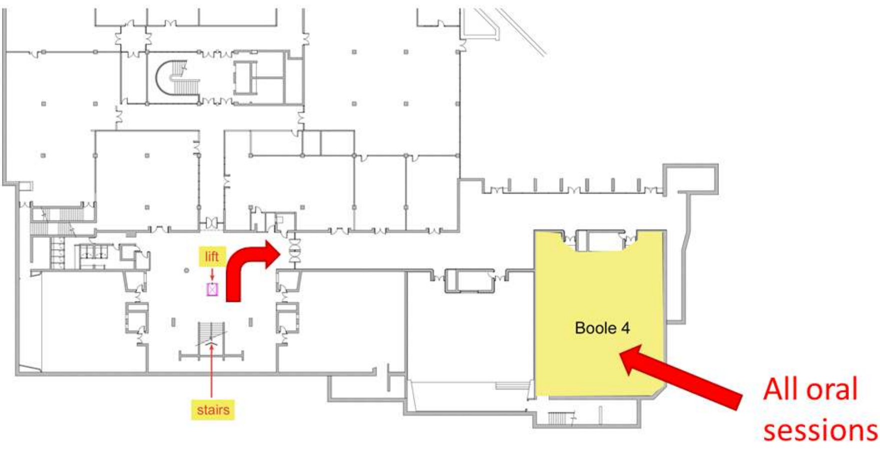

entrance
entrance
entrance
stairs
stairs
Main entrance
Áras na Mac Léinn
(ground floor)


Registration
(20th – 22nd)
tea & coffee
breaks
Devere Hall
(poster sessions)
café
Lunch collection
bar
Lunch
collection
stairs
stairs
Áras na Mac Léinn
(first floor)

Room	Workshop
Bearra	Intro to statistics
Muscrai	Public engagement
Duthalla	Getting funding
Aird Mhor	Bias, discrimination & decolonising palaeontology
Sceilig	Private meetings only



Áras na Mac Léinn (second floor)



Boole Lecture Theatre Complex

The Palaeontological Association
66th Annual Meeting
18th–24th July 2022
University College Cork

The programme and abstracts for the 66th Annual Meeting of the Palaeontological Association are provided after the following information and summary of the meeting.

Venue

The Annual Meeting will take place at various locations at University College Cork. All scientific sessions, workshops, the Symposium and Royal Irish Academy Discourse Lecture will take place on the University's main campus. Of these events, the Royal Irish Academy Discourse Lecture will take place in the Aula Maxima in the Main Quad; all other talks will take place in Boole Lecture Theatre 4, part of the underground Boole theatre complex beneath the Boole Library. The early-career researcher event and Family Fossil Expo will take place on the University's Distillery Fields campus, which is a 15 minute walk along the River Lee walkway from main campus. The early-career researcher event will take place in laboratories G12 and G13 in the Cooperage Building and the Family Fossil Expo will take place in Butler Building room BB1. There are bus stops on Western Road beside main campus that connect with the bus station in the city centre in less than ten minutes. Alternatively, main campus is a 25 minute walk from the bus station and a 35 minute walk from Cork Kent train station. The Distillery Fields campus is a five minute walk from the city centre.

Registration

Registration will be possible on Monday 18th July (14.00 – 19.00) and Tuesday 19th July (08.00 – 17.00) in the 4th year Hub in the Cooperage Building on the Distillery Fields campus. On Wednesday 20th, Thursday 21st, and Friday 22nd July there will be a registration desk in Devere Hall in Áras na Mac Léinn on main campus from 08.00 – 18.00.

Oral presentations

The Symposium speakers have each been allocated 40 minutes (30 minutes plus 10 minutes questions). All other speakers have been allocated either a regular talk slot or a lightning talk slot. The regular talk slots are 15 minutes. It is therefore expected that you prepare to speak for no more than 12 minutes to allow time for questions and switching between presenters. The lightning talk slots are five minutes; you should prepare to speak for no more than four minutes to allow time for a question and switching between presenters. The Meeting does not feature parallel sessions. The Boole 4 lecture theatre has an AV projector linked to a large screen. All presentations should be in PowerPoint or PDF format.

Presentations may be submitted in advance of the meeting to Maria McNamara (e-mail <**annualmeeting2022@palass.org**>). Any presentations not submitted prior to the Meeting must be uploaded to the local system and checked. You can do this at the dedicated presenter station outside the Boole 4 theatre from 08.00 – 18.00 on Wednesday 20th and Thursday 21st July and from

08.00 – 14.00 on Friday 22nd July. This should be done as early as possible, ideally the day before the allotted presentation slot. The Meeting organizers cannot guarantee an opportunity to check the presentation file if uploaded on the same day as the scheduled talk slot.

Poster presentations

Posters will be displayed in Devere Hall on the first floor of Áras na Mac Léinn. Poster boards will accommodate an A0-sized poster presented in portrait format only. Materials to affix your poster to the boards (e.g. pins, Velcro) will be available in the Hall. Posters should be mounted between 08.00 and 18.00 on Wednesday 20th July or first thing on the morning of Thursday 21st July (between 08.00 and 08.45).

Travel grants to student members

Students who have been awarded a PalAss travel grant should see the Executive Officer, Dr Jo Hellawell, at the Association's stand to receive their reimbursement.

Childcare

There are baby changing facilities on campus, and a nursing room can be made available as required.

Accessibility

All buildings in the University are accessible via ramps and/or lifts. For assistance during the meeting please speak to volunteers on the registration desk.

Meals

Delegates who have pre-booked lunch on the 20th, 21st and/or 22nd may collect it from the College Bar on the first floor of Áras na Mac Léinn. For delegates who have not pre-booked lunch, options on main campus will be limited as the Meeting will take place outside term time. Options on main campus include the café in the Glucksman Gallery and Starbucks on the ground floor of Áras na Mac Léinn. Options located outside the University include the Natural Foods Bakery in Fitzgerald's Park (a five minute walk), the Green Frog café opposite the eastern gates to main campus, and various options along Western Road and Washington Street (a five to ten minute walk).

Cork

Cork is Ireland's second city and is situated on Ireland's south coast, on the shores of the Atlantic Ocean. The city has been rated as one of the top three "Friendliest Cities in the World" (*Conde Nast Traveller*). The city centre is located on an island in the River Lee, with extensive quays and docks that lead towards Cork Harbour, one of the largest natural harbours in the world. The city was originally a monastic settlement and was expanded by the Vikings from *c.* 915 AD. The city is known as the "Rebel city" (and County Cork as the "Rebel County") because it supported the Yorkist cause in the English Wars of the Roses. Cork is traditionally strongly nationalist, which led to the burning of the city during the War of Independence by the British forces. According to *Lonely Planet*, "everything good about Ireland can be found in Cork": over 1,200 km of coastline, a rich culinary tradition, and a hub for live music, cultural events, history and outdoor activities. We hope that you enjoy your stay.

The Palaeontological Association thanks the Organizing Committee:

Chair:

- Professor Maria E. McNamara

Administrative support lead:

- Naomi O'Reilly

Committee:

- Hannah Binner
- Daniel Falk
- Beatriz Carazo del Hoyo
- Dan Cirtina
- Dr Chris Mays
- Aaron Quigley
- Dr Chris Rogers,
- Dr Valentina Rossi
- Anna Schoneberger
- Tiffany Slater
- Dr Zixiao Yang

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

College of Science, Engineering and Food Science, UCC

Cork Convention Bureau

Environmental Research Institute, UCC

Failte Ireland

Geological Society of London

Geological Survey of Ireland

Geological Survey of Northern Ireland

Irish Centre for Research in Applied Geosciences

Irish Geological Association

Institute of Geologists of Ireland

Ireland's Fossil Heritage

JEOL

Lampert

Mason Technology

Niton UK

National Museum of Ireland

Perkin Elmer

Renishaw

Royal Irish Academy

School of Biological, Earth and Environmental Sciences, UCC

The Paleontological Institute

The Royal Society

Wiley

College of Science, Engineering & Food Science
UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

CORK CONVENTION BUREAU

Fáilte Ireland

Environmental Research Institute

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh
School of Biological, Earth and Environmental Sciences

The Geological Society
serving science, profession & society

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

IRELAND'S FOSSIL HERITAGE

IRISH GEOLOGICAL ASSOCIATION

INSTITUTE of GEOLOGISTS of IRELAND

Acadamh Ríoga na hÉireann
Royal Irish Academy

LAMPERT.
PRECISION WELDING

museum
National Museum of Ireland
Ard-Mhúsaem na hÉireann

iCRAG
SFI RESEARCH CENTRE IN APPLIED GEOSCIENCES

MASON TECHNOLOGY

JEOL

NitonUK

PerkinElmer

RENISHAW
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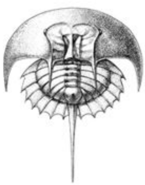

THE ROYAL SOCIETY

WILEY

Department for the Economy
www.economy-ni.gov.uk

GSNI
Geological Survey of Northern Ireland
www.bgs.ac.uk/gsni

BGS
British Geological Survey

Summary of Schedule

Monday 18th July:
Family Fossil Expo and Royal Irish Academy Discourse Lecture

Registration will be available from 14.00 – 19.00 in the 4th year Hub in the Cooperage building on Distillery Fields campus.

The Meeting will begin with an interactive public fossil exhibition at the School of Biological, Earth and Environmental Sciences, UCC from 16.00 – 19.00 on 18th July. The exhibition will feature fossil-themed activities and games delivered by staff and students of the School of Biological, Earth and Environmental Sciences at UCC, with contributions from other delegates of the Annual Meeting and representatives of the Palaeontological Association and the Irish Centre for Research in Applied Geosciences.

The exhibition will be followed at 20.00 by a public lecture delivered by Prof. Larisa deSantis of Vanderbilt University, entitled “Decoding the past to conserve our future”. This lecture forms part of the Royal Irish Academy Discourse Lecture series (<**https://www.ria.ie/public-engagement/royal-irish-academy-discourse-series**>) and represents the first time that the Discourses are associated with a major scientific meeting.

The Discourses are the oldest and most renowned series of talks in Ireland, with the first Discourse presented in 1786. The RIA Discourses were traditionally the occasions reserved for the most distinguished academics to first present and discuss new work in public, and today aim to bring thought leaders to the Academy to discuss important contemporary issues. Historical Discourses of note include those by Robert Mallet on his pioneering work on earthquakes, and by Sir William Rowan Hamilton on quaternion algebra. Recent speakers include various Nobel Laureates, former president of Ireland Mary McAleese and former Secretary General of the European Commission Catherine Day.

Tuesday 19th July:
Early-career researcher event

Registration will be available from 08.00 – 17.00 in the 4th year Hub in the Cooperage Building on Distillery Fields campus.

The “Career Links workshop” is a dedicated early-career researcher (ECR) event that will run from 09.00 – 17.00 and will focus on networking. The event will provide an opportunity for ECR participants to get to know their peers and senior researchers in their field, and to learn more about career progression options and strategies. The event will also allow senior researchers to make connections with up-and-coming researchers in their field who may become future collaborators and/or members of their research group.

Wednesday 20th July:
Workshops, Lab tours, Symposium and Reception

Registration will be available in Devere Hall in Áras na Mac Léinn on main campus from 08.00 – 18.00.

The morning of 20th July features several concurrent workshops on topics that include statistics, public engagement and finding funding. The workshops are led by specialists from different groups, including Transmitting Science, the Irish Centre for Research into Applied Geosciences, Irish Fossil Heritage and the Environmental Research Institute. See below for more details.

Concurrent with the workshops, there will be tours of the palaeobiology/taphonomy and microbeam laboratory facilities at the School of Biological, Earth and Environmental Sciences.

Delegates who have pre-booked lunch may collect it from the College Bar from 12.00 – 13.00, where there is ample seating. You will need to show your lunch ticket.

The scientific part of the Annual Meeting will begin with the Annual Symposium, which will run from 13.00 – 17.45 with the theme “Chemical fossils”. Please see below for details of the full schedule, with the list of speakers and talk titles.

Following the Symposium there will be an icebreaker reception from 17.45 to 20.00 in the Aula Maxima, Main Quad on UCC’s main campus. You will need to show your reception ticket for entry.

Thursday 21st July:
Scientific sessions, Annual Address and Annual Dinner

Registration will be available in Devere Hall in Áras na Mac Léinn on main campus from 08.00 – 18.00.

The scientific sessions will start at 08.45 in Boole Lecture Theatre 4 in the underground Boole lecture theatre complex. Posters will be set up in Devere Hall in Áras na Mac Léinn where lunch and coffee breaks will also be held.

Delegates who have pre-booked lunch may collect it from the College Bar from 13.00 – 14.00, where there is ample seating. You will need to show your lunch ticket.

There will be an extended coffee break in the morning (10.45 – 11.30) and another in the afternoon (15.45 – 16.30); these double up as poster sessions.

The Annual Address will be delivered by Prof. Dani Schmidt from the University of Bristol. The Address will start at 16.30 in Boole Theatre 4 and is titled “What – if anything – can palaeontology contribute to understanding our climate crisis?”.

The Annual Dinner will be held at Páirc Uí Chaoimh, Cork’s premier stadium for the Irish national sports Gaelic football and hurling. Buses to the venue will leave Western Road beside main campus at 18.30. You will need to show your dinner ticket for entry. The dinner will be preceded by a reception beginning at 19.00 accompanied by live instrumental traditional Irish music and with a live hurling match on the pitch, visible from the venue. The dinner begins at 20.00 and will feature a four-course meal accompanied by drinks (delegates can opt to receive two free alcoholic drinks or up to four non-alcoholic drinks); there will be two open cash bars. The dinner will be followed by a céilí (an energetic dance party with traditional group dances and live band). Buses will bring delegates back to the city centre and Western Road, leaving Páirc Uí Chaoimh at *c*. 23.00, 24.00 and 01.30.

Friday 22nd July:
Scientific sessions and prizes

Registration will be available in Devere Hall in Áras na Mac Léinn on main campus from 08.00 – 18.00.

The scientific sessions will start at 09.00 in Boole Lecture Theatre 4 in the underground Boole lecture theatre complex. Posters will be set up in Devere Hall in Áras na Mac Léinn where lunch and coffee breaks will also be held.

Delegates who have pre-booked lunch may collect it from the College Bar from 13.00 – 14.00, where there is ample seating. You will need to show your lunch ticket.

There will be an extended coffee break in the morning (10.45 – 11.30) and another in the afternoon (15.15 – 16.00), which double up as poster sessions.

Talks will end at 17.45, after which time the conference will close with presentations by the organizing committees of upcoming meetings, the award of the President's Prize and the Council Poster Prize, and concluding remarks.

Saturday 23rd July – Sunday 24th July:
Conference field-trip

A two-day post-conference field-trip will visit the Carboniferous rocks of North Clare on Ireland's Atlantic seaboard. Delegates will visit several Lower Carboniferous (Viséan) sites in the remarkable Burren region and Upper Carboniferous (Namurian) sites along the coast, including the Cliffs of Moher. The Burren is the largest glaciokarst in Europe and is celebrated for its spectacular scenery but also its unique flora and archaeological heritage. The visually stunning Cliffs of Moher, which rise to over 200 m above sea level, are the longest sea cliffs in Europe and host internationally important seabird colonies. The field-trip will visit various sites of palaeontological and geomorphological interest and will include hikes of up to several hours on uneven terrain.

The trip will depart from Cork at 08.00 on the 23rd, returning *c.* 19.00 on the 24th. The pickup and collection points are the same, on Western Road.

Field-trip leaders: Maria McNamara and Chris Mays.

The Palaeontological Association

Registered Charity Number: 1168330

Code of Conduct for Palaeontological Association meetings

The Palaeontological Association was founded in 1957 and has become one of the world's leading learned societies in this field. The Association is a registered charity that promotes the study of palaeontology and its allied sciences through publication of original research and field guides, sponsorship of meetings and field excursions, provision of web resources and information, and a programme of annual awards.

The Palaeontological Association holds regular meetings and events throughout the year. The two flagship meetings are the Annual Meeting, held at a different location, normally each December, and the annual Progressive Palaeontology (ProgPal) meeting, run by students for students with the support of the Palaeontological Association. The Association Code of Conduct relates to the behaviour of all participants and attendees at annual events.

Behavioural expectations: It is the expectation of the Palaeontological Association that meeting attendees behave in a courteous, collegial and respectful fashion to each other, volunteers, exhibitors and meeting facility staff. Attendees should respect commonsense rules for professional and personal interactions, public behaviour (including behaviour in public electronic communications), common courtesy, respect for private property, and respect for intellectual property of presenters. Demeaning, abusive, discriminatory, harassing or threatening behaviour towards other attendees or towards meeting volunteers, exhibitors or facilities staff and security will not be tolerated, in either personal or electronic interactions.

Digital images and social media: Do not photograph a poster or record a talk without the author's express permission. While the default assumption is to allow open discussion of presentations on social media, attendees are expected to respect any request by an author to not disseminate the contents of their talk or poster.

Reporting unacceptable behaviour: If you are the subject of unacceptable behaviour or have witnessed any such behaviour, you can report it to us (anonymously if you choose to) via our online reporting form at <**https://www.palass.org/meetings-events/report-meeting-code-conduct-violation**>.

Anyone experiencing or witnessing behaviour that constitutes an immediate or serious threat to public safety, or a criminal act, is expected to contact the appropriate law enforcement agency. Those witnessing a potential criminal act should also take actions necessary to maintain their own personal safety.

Schedule of events and timetable of presentations

Monday 18th July

Registration for the conference available in the 4th year Hub, Cooperage Building, North Mall campus.

Public engagement day

16.00 – 19.00 **Family Fossil Expo** hosted by the Cork palaeobiology group, the Palaeontological Association, iCRAG and others. Delegates are free to visit the expo; pre-registration not necessary.
Room BB1, Butler Building, Distillery Fields campus

20.00 – 21.30 **Royal Irish Academy Discourse Lecture**
Decoding the past to conserve our future
Prof. Larisa DeSantis
Aula Maxima, Main Quad, UCC main campus
Delegates must pre-register as spaces are limited.

Tuesday 19th July

Registration for the conference available in the 4th year Hub, Cooperage Building, North Mall campus.

Early-career researcher (ECR) event: Career Links Workshop

Rooms G12 and G13, Cooperage building, Distillery Fields campus

Delegates must pre-register for the ECR workshop as spaces are limited.

09.00 – 09.30 Registration (participants may register for the full meeting)

09.30 – 10.00 Tea/coffee, scones

10.00 – 10.15 Welcome

10.15 – 10.45 Introductions

10.45 – 12.00 Peer meetup in research zones

12.00 – 12.45 Lunch

12.45 – 13.30 5-min lightning talks by senior researchers on their labs and research

13.30 – 14.30 Meetup with senior researchers in research zones

14.30 – 15.00 Tea/coffee break

15.00 – 16.15 10 min talks on career paths (2 x tenured academics and 2 x PhD graduates now working in non-academic careers)

16.15 – 17.30 Panel discussion on career pathways with all senior researchers present

18.00 – 20.00 Dinner at the nearby Fran Well microbrewery

Wednesday 20th July

Workshops, lab tours, Symposium and Reception

Registration will be available in Devere Hall on the first floor of Áras na Mac Léinn on main campus from 08.00 – 18.00 each day from Wednesday 20th to Friday 22nd July. On Wednesday 20th July, poster setup will be available from 08.00 – 18.00.

Pre-meeting workshops

The workshops will take place in the meeting rooms on the second floor of Áras na Mac Léinn on main campus. Participants must be pre-registered as spaces are limited.

09.00 – 12.00 **Introduction to Statistical Analysis**
Instructor: Soledad De Esteban-Trivigno (Transmitting Science)
Béarra Meeting Room

09.00 – 12.00 **Getting Funded**
Instructor: Sonia Monteiro (Environmental Research Institute, UCC)
Dúthalla Meeting Room

09.00 – 12.00 **Public engagement**
Instructors: Dr Jess Franklin (Ireland's Fossil Heritage, UCC) and
Elspeth Sinclair (iCRAG)
Muscraí Meeting Room

09.00 – 12.00 **Bias, discrimination and decolonising palaeontology**
Instructor: Cassius Morrison (UCL & NHM)
Airdmore Meeting Room

Tours of the Cork Palaeobiology laboratories

The laboratory tours each last approximately 1 hr 10 min and will begin at 09.00, 09.25, 09.50, 10.15 and 10.40. Participants must be pre-registered as spaces are limited; participants have been pre-assigned to a specific tour. The meeting point for each tour is underneath the walkway between the Butler Building and Enterprise Centre, Distillery Fields campus.

12.00 – 13.00 Lunch. Pre-booked lunches may be collected from the College Bar on the first floor of Áras na Mac Léinn.

Symposium: *"Chemical fossils"*

Boole Lecture Theatre 4, Boole Theatre Complex, main campus.

12.50 – 13.00 Welcome address

13.00 – 13.40 **Ocean deoxygenation and acidification at the end-Triassic extinction the one-two punch of elevated CO_2**
Jessica H. Whiteside

13.40 – 14.20 **Braving the elements: taphonomic and diagenetic pathways to protein preservation**
Paul V. Ullmann

14.20 – 15.00 **Illuminating the 3D ultrastructure and chemical composition of the earliest plants and fungi**
Christine Strullu-Derrien

15.00 – 15.45 Tea/coffee break (Devere Hall, Áras na Mac Léinn)

15.45 – 16.25 **Biomolecular and structural analyses of fossil plants – tools for tracing survival strategies during mass extinctions**
Vivi Vajda

16.25– 17.05 **Authenticating ancient proteins: exploring the phylogenetic potential of proteins and measures of their endogeneity**
Michael Buckley

17.05 – 17.45 **Chemical investigations resolve enigmatic features within Burgess Shale-type fossils**
Farid Saleh

Reception

17.45 – 20.00 Aula Maxima, Main Quad

Thursday 21st July

Scientific sessions, Annual Address and Annual Dinner

Underlined author denotes designated speaker.
* Candidates for the President's Prize are marked with an asterisk.
† Lightning talks are marked with a dagger.

08.00 – 08.45 Poster set-up in Devere Hall on the first floor of Áras na Mac Léinn

All talks will take place in Boole Lecture Theatre 4, Boole Theatre Complex, main campus.

Session 1
Chair: Orla Bath-Enright

09.00 – 09.15 **Pterosaur take-off: estimating launch capabilities in one of the largest flying animals**
*Benjamin Griffin, Elizabeth G. Martin-Silverstone, Rodrigo V. Pêgas, Oliver E. Demuth, Erik Meilak, Colin Palmer and Emily J. Rayfield

09.15 – 09.30 **How to become a crab: phenotypic constraints on a recurring body plan**
Joanna M. Wolfe, Joy C. Julius, Lauren Ballou, Javier Luque, Victoria M. Watson-Zink, Jonas Keiler *et al.*

09.30 – 09.35 **The oldest hurdiid radiodont in China known from complete specimens †**
Dongjing Fu, Allison C. Daley, Melanie J. Hopkins, Xiaoya Ma, Orla G. Bath Enright, Harriet B. Drage *et al.*

09.35 – 09.40 **A novel interpretation of the Ediacaran rangeomorph *Culmofrons plumosa* as a reclining organism †**
*Giovanni Pasinetti and Duncan McIlroy

09.40 – 09.45 **Why the eyes of phacopid trilobites look the way they do †**
Brigitte Schoenemann and Euan N. K. Clarkson

09.45 – 10.00 **Convergent evolution of raptorality in Telluraves**
*Brigit Tronrud

10.00 – 10.15 **Multiple increases in atmospheric oxygen and marine productivity through the Neoproterozoic and Palaeozoic**
*Richard G. Stockey, Devon B. Cole, Una C. Farrell, SGP Trace Metal Working Group, Noah J. Planavsky and Erik A. Sperling

10.15 – 10.30 **The origin of panarthropod legs**
*Alavya Dhungana and Martin R. Smith

10.30 – 10.35 **A brief history of the "Age of Barnacles" †**
Andy S. Gale

10.35 – 10.40 **Stratigraphic completeness in phyletic evolution: insights from astronomically paced carbonate platform successions †**
Emilia Jarochowska, Niklas Hohmann, David De Vleeschouwer, Rachel C. M. Warnock, Joël Koelewijn and Peter Burgess

10.40 – 10.45 **Current issues with conodont tissues: using multi-analytical methods to unravel the conodont conundrum †**
*Bryan Shirley and Emilia Jarochowska

10.45 – 11.30 **Tea/coffee break and posters**
Devere Hall, Áras na Mac Léinn

Session 2
Chair: Pierre Gueriau

11.30 – 11.45 **Climatic drivers of pterosaur origins**
Emma M. Dunne, Alexander Farnsworth, Richard J. Butler, Sterling Nesbitt, Nicholas C. Fraser, Stephen L. Brusatte *et al.*

11.45 – 12.00 **Cambrian bivalved arthropods revisited: evolution and ecology of a disparate group**
*Alejandro Izquierdo Lopez and Jean-Bernard Caron

12.00 – 12.05 **Documenting diagenetic alteration of an aragonitic Miocene giant clam (*Tridacna* sp.) with implications for strontium isotope stratigraphy (SIS) †**
*Max Fursman, Viola Warter, Linda Marko, David Evans, Willem Renema, Dominik C. Hezel and Wolfgang Müller

12.05 – 12.10 **How to build a Lagerstätte: new taphonomic and sedimentological insights into the preservation of exceptional Ediacaran fossils at Spaniard's Bay, Newfoundland †**
*Christopher McKean, Rod S. Taylor and Duncan McIlroy

12.10 – 12.15 **Uncovering the true diversity of the Wealden iguanodontians †**
*Joseph A. Bonsor, Susannah C. R. Maidment and Paul M. Barrett

12.15 – 12.30 **Examining the morphological response of marine calcifying taxa to extreme environmental change during the Cretaceous-Paleogene mass extinction in Southern Ocean shelf, open-ocean, and deep-sea ecosystems**
James D. Witts, Heather Birch, Amy Flower, Calum MacFie and Daniela N. Schmidt

12.30 – 12.45 **Were there multiple bursts in the early evolution of Ichthyosauromorpha?**
Benjamin C. Moon

12.45 – 12.50 **Anatomy and phylogeny of the first macraucheniid (Mammalia: Litopterna) from the Neogene Bahía Inglesa Formation (late Miocene), Atacama Region, Northern Chile †**
*Hans P. Püschel, Jhonatan Alarcón-Muñoz, Sergio Soto-Acuña, Raúl Ugalde, Sarah L. Shelley and Stephen L. Brusatte

12.50 – 12.55 **Cabinet of curiosity: a fungal community in Late Devonian *Callixylon newberryi* wood from the University College Dublin historical slide collection †**
Carla Harper, Anne-Laure Decombeix, Thibault Durieux and Michael Krings

12.55 – 13.00 **Description of *Helmetia expansa* and phylogenetic analyses of concilitergans †**
*Sarah R. Losso, Jean-Bernard Caron and Javier Ortega-Hernández

13.00 – 14.00 **Lunch**
Devere Hall, Áras na Mac Léinn

Session 3
Chair: Ross Anderson

14.00 – 14.15 **DeepDive: deep learning estimation of palaeodiversity from fossil data**
*Rebecca Cooper and Daniele Silvestro

14.15 – 14.30 **Reviving vetulicolians: a "lost chapter" in chordate history?**
*Giovanni Mussini, Frances S. Dunn and M. Paul Smith

14.30 – 14.35 **The Las Hoyas (Serrania de Cuenca, Spain) fossil biases reveal a constantly changing ecosystem during the Barremian †**
Hugo Martin-Abad, Candela Blanco-Moreno, Paloma Alcorlo, Zain Belaústegui, Miguel Ángel Rodríguez-Pascua, José Francisco Mediato Arribas and Ángela D. Buscalioni

14.35 – 14.40 **A 300 million year record of ecosystem change – what conodonts can tell us †**
*Christopher Stockey, Philip C. J. Donoghue, Duncan J. E. Murdock and Mark A. Purnell

14.40 – 14.45 **Terrestrial vertebrates from Triassic caves of south-west Britain: older than we thought †**
Michael J. Simms and Kerstin Drost

14.45 – 15.00 **Palaeontological heritage as a powerful resource to promote the understanding of ecology and evolution concepts at schools in a project based learning initiative**
Lara de la Cita García and Ángela D. Buscalioni

15.00 – 15.15 **Increasing the equitability of data citation in palaeontology: a view to the future**
Jansen Smith, Nussaïbah B. Raja, Danijela Dimitrijević, Emma M. Dunne, Laura P. A. Mulvey, Paulina Nätscher *et al.*

15.15 – 15.30 **Disentangling phylogenetic and ecomorphological signal in 2D skull shape in the radiation of archosaurs**
Roland Sookias, Nicole Grunstra, Anne Le Maître and Christian Foth

15.30 – 15.35 **Insect decline in the last 100 million years investigated with quantitative morphology: the example of lacewing larvae †**
Carolin Haug and Joachim T. Haug

15.35 – 15.40 **Gondwanan araucariaceous genus related to *Wollemia* was restricted to the southern high latitudes †**
*Miriam A. Slodownik and Robert S. Hill

15.40 – 16.30 **Tea/coffee break and posters**
Devere Hall, Áras na Mac Léinn

Annual Address

Boole Lecture Theatre 4

16.30 – 17.30 **What – if anything – can palaeontology contribute to understanding our climate crisis?**
Daniela N. Schmidt

Reception & Annual Dinner

Páirc Uí Chaoimh stadium

18.30 Transport from Western Road, beside UCC main campus

19.00 – 20.00 **Reception**

20.00 – 01.30 **Annual Dinner followed by céilí**

Friday 22nd July

Scientific sessions

All talks will take place in Boole Lecture Theatre 4, Boole Theatre Complex, main campus.

Session 4
Chair: Emily Mitchell

09.00 – 09.15 **Fossilized soft tissues from the Colli Albani: a new mode of preservation for feathers**
Valentina Rossi, Dawid Iurino, Edoardo Terranova and Raffaele Sardella

09.15 – 09.30 **A Cambrian tommotiid preserving soft tissues reveals the metameric ancestry of lophophorates**
Jin Guo, Luke A. Parry, Jakob Vinther, Gregory D. Edgecombe, Fan Wei, Jun Zhao *et al.*

09.30 – 09.45 **Revising taxonomy using a collaborative tool (Xper3) with an example from Early Triassic conodonts**
Lilian Lacome, Samuel Ginot and Pauline Guenser

09.45 – 10.00 **A biogeographic theory of thermal habitat loss during global temperature change**
Adam Tibor Kocsis, Erin E. Saupe and Carl J. Reddin

10.00 – 10.15 **Estimating bite force in extinct dinosaurs using phylogenetically predicted physiological cross-sectional areas**
Manabu Sakamoto

10.15 – 10.30 **Rangeomorph orientations with independent current indicators demonstrate the reclining rheotropic mode of life of the Ediacaran rangeomorph taxa *Fractofusus misrai*, *Bradgatia* sp. and *Pectinifrons abyssalis***
*Daniel Pérez Pinedo, Jenna M. Neville, Giovanni Pasinetti, Christopher McKean, Rod S. Taylor and Duncan McIlroy

10.30 – 10.35 **Floral diversity, disparity and turnover at the Siluro–Devonian boundary: palynological evidence from the Anglo-Welsh Basin, UK †**
Alexander C. Ball, Charles H. Wellman, John B. Richardson, Stephen Stukins and Paul Kenrick

10.35 – 10.40 **Variscan deformation: the driving force in bone alteration of the Jarrow tetrapods †**
Aodhán Ó Gogáin, Gary O'Sullivan, Thomas Clements, Brendan Hoare, John Murray and Patrick N. Wyse Jackson

10.40 – 10.45 **An exceptional Jurassic fern with biotic interactions from southern Sweden †**
Stephen McLoughlin

10.45 – 11.30 **Tea/coffee break and posters**
Devere Hall, Áras na Mac Léinn

Session 5
Chair: Thomas Harvey

11.30 – 11.45 **Assessing skull function in tyrannosauroids using 3D finite element analysis**
*Andre Rowe, Emily J. Rayfield, Michael J. Benton and Thomas E. Williamson

11.45 – 12.00 **Evolutionary innovation and competitive replacement drove the rise of modern coral reefs**
*Joseph Flannery Sutherland, Alexander Farnsworth and Michael J. Benton

12.00 – 12.05 **Study of decay in the branchiopod crustacean *Triops* in sediment using micro computed tomography †**
*Madeleine Waskom, Sarah R. Losso and Javier Ortega-Hernández

12.05 – 12.10 **Palaeobiology's next top model: combining evidence from morphology and stratigraphy †**
*Laura Mulvey, Imran A. Rahman and Rachel C.M. Warnock

12.10 – 12.15 **Untangling the web of arachnid systematics: using confocal microscopy to image Devonian trigonotarbids †**
*Emma Jayne Long, Gregory D. Edgecombe, Xiaoya Ma and Brett Clark

12.15 – 12.30 **True colours: a new model for the taphonomy of melanin chemistry and the identification of phaeomelanin in Miocene and Cretaceous fossils**
*****Tiffany Slater**,** Shosuke Ito, Kazumasa Wakamatsu, Fucheng Zhang, Peter Sjövall, Martin Jarenmark, Johan Lindgren and Maria E. McNamara

12.30 – 12.45 **Biogeographic observer bias: Devonian Gondwana**
Elizabeth Dowding

12.45 – 12.50 **Comparative taphonomy of anurans from lacustrine-hosted Cenozoic Lagerstätten †**
*Daniel Falk, Oliver Wings and Maria E. McNamara

12.50 – 12.55 **Anatomy and phylogeny of a close relative of the chondrichthyan *Cladoselache* from the Devonian of Morocco †**
Christian Klug, Linda Frey, Michael Coates, Merle Greif, Melina Jobbins, Alexander Pohle, Abdelouahed Lagnaoui, Wahiba Bel Haouz and Michal Ginter

12.55 – 13.00 **Frontal appendages from the Fezouata Biota (Morocco) reveal high diversity and ecological adaptations in radiodonts during the Early Ordovician †**
*Gaëtan Potin, Pénélope Claisse, Pierre Gueriau and Allison C. Daley

13.00 – 14.00 **Lunch**
Devere Hall, Áras na Mac Léinn

Session 6
Chair: Frances Dunn

14.00 – 14.15 **The continental end-Permian extinction event of eastern Gondwana – a song of slime and fire**
Chris Mays, Vivi Vajda, Tracy D. Frank, Christopher R. Fielding, Sam M. Slater and Stephen McLoughlin

14.15 – 14.30 **Taxonomic variation in teleostean fishes from Las Hoyas (Lower Cretaceous) using shape analysis**
Carla San Roman, Hugo Martín-Abad and Jesús Marugán Lobón

14.30 – 14.45 **Does your data collection method matter? Investigating the differences in palaeoecological reconstructions from published and citizen science data**
*Rebecca Walley, Richard J. Twitchett, Jessica H. Whiteside and Stephen Stukins

14.45 – 15.00 **Dental form and function in the early feeding diversification of dinosaurs †**
*Antonio Ballell Mayoral, Michael J. Benton and Emily J. Rayfield

15.00 – 15.05 **Diversity of shield morphologies in crabs of the group Carcinidae – a quantitative approach †**
Florian Braig and Joachim T. Haug

15.05 – 15.10 **Appendicular and axial modular change reveals different routes taken by secondarily aquatic mammals and reptiles †**
*Kiersten Formoso, Graeme T. Lloyd and David J. Bottjer

15.10 – 15.15 **Bryophytes in the fossil record: two examples from non-amber preservational contexts †**
Candela Blanco Moreno, David Horcajada, Hugo Martín-Abad, Ruth A. Stockey, Gar W. Rothwell, Ángela D. Buscalioni and Alexandru M.F. Tomescu

15.15 – 16.00 **Tea/coffee break**
Devere Hall, Áras na Mac Léinn

Session 7

Chair: John Cunningham

16.00 – 16.15 **The role of fossil tips in inferring the tree of life**
Nicolas Mongiardino Koch, Luke A. Parry and <u>Russell J. Garwood</u>

16.15 – 16.30 **Putting your best foot forward: the ecology of early theropod flyers refined by their feet**
<u>Michael Pittman</u>, Phil R. Bell, Case Vincent Miller, Nathan J. Enriquez, Xiaoli Wang, Xiaoting Zheng, Leah R. Tsang, Yuen Ting Tse, Michael Landes and Thomas G. Kaye

16.30 – 16.45 **Thermal structure of Late Pliensbachian assemblages determines their response to Early Toarcian warming pulses**
<u>Carl J. Reddin</u>, Jan Landwehrs, Georg Feulner, Erin E. Saupe, Clemens Ullmann and Martin Aberhan

16.45 – 17.00 **The first Cambrian tunicate from Laurentia reveals the origins of the ascidian body plan**
<u>Karma Nanglu</u>, Rudy Lerosey-Aubril and Javier Ortega-Hernández

17.00 – 17.15 **Associations between trilobite moulting variability and morphometry**
<u>Harriet B. Drage</u>, James D. Holmes, Diego C. García-Bellido and John R. Paterson

17.15 – 17.30 **The Las Hoyas (Serranía de Cuenca, Spain) fossil biases reveal a constantly changing ecosystem during the Barremian**
<u>Carlos Martinez Perez</u>, Gisella Della Costa, Humberto Ferrón, Duncan J. E. Murdock, M. Paul Smith, Guillermo Albanesi and Philip C. J. Donoghue

17.30 – 17.45 **Post-extinction recovery of the Phanerozoic oceans and the rise of biodiversity hotspots**
<u>Michael J. Benton</u>, Pedro Cermeño, Carmen García-Comas, Alexandre Pohl, Simon Williams, Chhaya Chaudhary *et al.*

Closing business

Boole Lecture Theatre 4

17.45 – 18.00 Presentation from the organizing committee of PalAss 2023 (Cambridge).

18.00 Presentation of the President's Prize and the Council Poster Prize followed by closing remarks.

Saturday 23rd July

Post-conference field-trip

Departure time is 08.00 from the bus stop on Western Road, beside UCC's main campus. We expect to arrive back in Cork *ca.* 19.00 on Sunday 24th July.

Field-trip leaders: Maria McNamara and Chris Mays

Royal Irish Academy Discourse Lecture

The RIA Discourse Lecture will be given on Monday 18th July at 20.00.

Decoding the past to conserve our future

Larisa R. G. DeSantis
Vanderbilt University, USA

Mammalian communities have undergone dramatic ecological and evolutionary changes throughout time. While it can be difficult for us to recognize and perceive the magnitude of these changes in a human lifetime, conservation palaeobiology leverages the fossil record to provide critical insights into mammalian responses to climate change across the globe. From the study of ancient animals like sabretooth cats and marsupial lions, ancient life serves as ‘canaries in the coal mine’ – alerting global citizens to the consequences of climate change for life on Earth. This talk will explore how dietary information locked in fossilized teeth is decoded, and how the ancient past can reveal cautionary conservation lessons and even warn us about our potential future.

Abstracts: Symposium Talks

Underlined author denotes designated speaker.

Authenticating ancient proteins; exploring the phylogenetic potential of proteins and measures of their endogeneity

Michael Buckley
The University of Manchester, UK

The sequencing of ancient proteins grabbed attention worldwide with reports of sequences retrieved from dinosaur remains 15 years ago, initially from *Tyrannosaurus rex*, and subsequently for *Brachylophosaurus canadiensis*. Although the authenticity of the sequences from both of these specimens was critiqued on several grounds, and no other lab has reported similar success despite many attempts, exceptional preservation is difficult to rule out. However, the authenticity of ancient sequences, whether DNA or protein, can be evaluated via both the sequences themselves, or through decay signatures therein. In this presentation I will discuss the great insights that proteomic techniques can give us for improving our understanding of phylogeny and palaeobiodiversity, as well as its limitations, largely focusing on type 1 collagen, the dominant protein in bone and skin and one of the most abundant proteins in the animal kingdom. I will introduce some of the newer mass spectrometric techniques that will undoubtedly shape our understanding of ancient biomolecule preservation as a whole.

Chemical investigations resolve enigmatic features within Burgess Shale-type fossils

Farid Saleh
Yunnan University, China

Palaeontologists can often become perplexed by certain fossilization patterns in the rock record. Fossils can unexpectedly preserve minute details of labile anatomies, that decay very quickly under natural conditions. And, on numerous occasions, fossils show unrecognizable anatomical remains shadowed by processes such as decay and modern weathering. With the development of new analytical tools and technologies, palaeontologists have new means to investigate enigmatic patterns from the fossil record, by focusing on their chemistry. Here two examples from the Cambrian Chengjiang biota (China) and the Ordovician Fezouata Shale (Morocco) will be presented. It will then be shown how chemical investigations can resolve enigmatic patterns of both exquisite and obscured preservation in the rock record, thus contributing to our understanding of Earth's early diversification events such as the Cambrian Explosion and the Ordovician Radiation.

Illuminating the 3D ultrastructure and chemical composition of the earliest plants and fungi

Christine Strullu-Derrien[1,2], **Alan R. T. Spencer**[1] **and Paul Kenrick**[1,3]

[1]*Natural History Museum, London, UK*

[2]*Muséum national d'Histoire naturelle, Paris, France*

[3]*Imperial College London, UK*

Fossil plants and fungi are key to our understanding of early life on land. Recent advances in technology allow us to document these in unprecedent detail at sites of exceptional preservation like the Rhynie chert (Scotland, UK) dating to 407 Ma and the Esnost chert (Massif Central, France) dating to *c.* 330 Ma, and more generally where permineralization of tissue systems occurs (*e.g.*, Châteaupanne quarry, Armorican Massif, France: 407 Ma). Techniques include confocal laser scanning microscopy (CLSM) to document microorganisms. CLSM outperforms standard brightfield illumination, with the resultant high-quality 3D models created close to the diffraction limit of light. Fluorescence lifetime imaging (FLIM) is a technique producing colour imagery from the time flurosphores remain in an excited state before emitting photons. In addition to mapping cells and tissues, the method delivers information on their molecular environment. Lastly, a combination of propagation phase-contrast synchrotron radiation X-ray microcomputed tomography (PPC-SRμCT), synchrotron-based scanning transmission X-ray microscopy (STXM) and X-ray absorption near edge structure (XANES) spectroscopy allows the investigation of cell structure and residual chemistry of the most ancient woody plant *Armoricaphyton chateaupannense*, enabling digital visualization of the cell walls in unprecedented detail and characterization of their chemical composition.

Braving the elements: taphonomic and diagenetic pathways to protein preservation

Paul V. Ullmann

Rowan University, USA

Traditional views on the preservation of soft tissues in the fossil record long held that their component biomolecules, such as proteins, either decay beyond recognition or are replaced by mineral during fossilization, but many recent studies have shown that this is often not the case. However, the taphonomic and diagenetic circumstances which facilitate biomolecular stability over such vast timescales remain unclear. In this contribution, I review what we have learned and outstanding questions about protein preservation pathways, and share insights garnered from three recent studies by myself and my colleagues which capitalized on the utility of trace elements to clarify spatiotemporal attributes of hydrodynamic and geochemical regimes throughout diagenesis. Taphonomic and trace element analyses of three Cretaceous nonavian dinosaurs previously shown to retain endogenous collagen reveal compelling similarities (and contrasts) which elucidate factors influencing the postmortem decay of proteins. Based on these three studies, brief interaction with diagenetic pore fluids and rapid fossilization (*i.e.* equilibration in early diagenesis) followed by geochemical constancy promote long-term biomolecular stability. While these insights illuminate critical aspects of protein taphonomy, molecular preservation mechanisms will remain enigmatic until similar studies are conducted on fossils preserved under diverse other palaeoenvironmental and diagenetic contexts.

talks

Biomolecular and structural analyses of fossil plants – tools for tracing survival strategies during mass extinctions

Vivi Vajda
Swedish Museum of Natural History, Stockholm, Sweden

Exceptional preservation of macrofossils in general, and fossilized cellular organelles in particular, is extremely rare but highly significant, as these structures provide details of the evolution of life and the functioning of ancient cells. Geochemical 'fingerprinting' of fossil plants is a relatively new research field complementing morphological analyses and providing information for palaeoenvironmental interpretations and diagenetic histories. A range of techniques exist to derive chemical information from fossilized material, including Raman spectroscopy, IR-spectroscopy and X-ray fluorescence microscopy (XFM). This review specifically focuses on experimental methods, geochemical changes within sediments or within organic compounds of exceptionally-preserved fossil plants across major extinction events. While the end-Permian and end-Triassic events are considered to result from intense volcanic activity, the end-Cretaceous extinction was caused by an asteroid impact. A question arises whether the different killing-mechanisms can be traced in the micro-molecular adaptations of plant leaves. The chemical fingerprints of fossil plants, together with the microstructural morphologies, may answer questions concerning survival traits during the end-Triassic and end-Cretaceous extinction events. These cutting-edge techniques combined with exceptionally-preserved fossils offer opportunities for advancing our understanding of plant evolution and survival during times of catastrophic environmental change.

talks

Ocean deoxygenation and acidification at the end-Triassic extinction: the one-two punch of elevated CO_2

Jessica H. Whiteside[1], Calum P. Fox[2,3], Paul E. Olsen[4], Xingqian Cui[5,6], Roger E. Summons[6], Erdem Idiz[7] and Kliti Grice[2]
[1]*University of Southampton, UK*
[2]*Curtin University, Australia*
[3]*Khalifa University of Science and Technology, UAE*
[4]*Lamont-Doherty Earth Observatory of Columbia University, USA*
[5]*Shanghai Jiao Tong University, China*
[6]*Massachusetts Institute of Technology, USA*
[7]*University of Oxford, UK*

Fossils and high-resolution biomarker and compound-specific isotopes demonstrate euxinia and acidification were the double-edged marine kill mechanisms driven by Central Atlantic magmatic province (CAMP) CO_2 degassing at the end-Triassic mass extinction (ETE, 201 Ma). For the recently suggested extinction interval of the basal Blue Lias Formation (Bristol Channel Basin, southern UK), biomarker distributions reveal an interval of persistent photic zone euxinia (PZE) that extended upward into surface waters. Shelly taxa are almost completely absent from this interval. The basal paper shales of the Blue Lias Formation yield a Lilliput assemblage of bivalves, rare calcitic oysters (*Liostrea*) and ghost fossils of decalcified aragonitic bivalves, and lack well-preserved vertebrate fossils. After intense PZE, bivalve and foraminiferal species richness increases, along with the appearance of *Psiloceras planorbis*. Polycyclic aromatic hydrocarbons and compound-specific isotopes of regular isoprenoids and plant-derived *n*-alkanes from the same strata reveal an episode

of soil erosion plausibly linked to CAMP-driven acid rain. Distal sources of smoke suggest fire elsewhere in the UK/European basins, in contrast with the depiction of intensive wildfire activity from European, Chinese and Greenland extinction sections. Notably, disruptions to continental and oceanic ecosystems were synchronous, indicating ecosystem perturbations across multiple habitats during the Rhaetian.

Abstract of Annual Address

The Annual Address will be given on Thursday 21st July at 16.30.

What – if anything – can palaeontology contribute to understanding our climate crisis

Daniela N. Schmidt
University of Bristol, UK

The Intergovernmental Panel for Climate Change in the 6th Assessment stated that historical and palaeontological records show that climatic variability has high potential to affect biodiversity and human society and that "… global biodiversity crises [are] often triggered by rapid warming". Often these records of change occur over millennia and are only studied regionally or at limited taxonomic levels in incomplete records. This is raising the question what the contribution of the geological record can be to answering questions on impacts and risks of climate change on natural systems. We draw on the fantastic records in our archives and museums around the world, but these have gaps that are both geographic and temporal. Most recently, the climate crisis is not seen in isolation any more but strongly coupled to the biodiversity crisis. In this presentation I will draw on examples of links between environmental change and biotic response in the fossil record, and highlight the power of our methodologies working with challenging records and our experience in combining climate and biological records. I will argue that, while we cannot say much about the risks of climate change in the coming decades, the fossil record has fundamental contributions to make via the analysis of ecosystem resilience and responses.

Abstracts: Talks

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

Dental form and function in the early feeding diversification of dinosaurs

***Antonio Ballell Mayoral, Michael J. Benton and Emily J. Rayfield**
University of Bristol, UK

Dinosaurs were remarkably successful, dominating Mesozoic ecosystems with a diversity of diets. Most dietary adaptations were clade-specific, but the origins of these diverse diets are uncertain. The craniodental disparity of Late Triassic and Early Jurassic forms suggests early dinosaurs explored different feeding habits. However, these are still contentious, as dietary inferences have mostly relied on qualitative comparisons of dental morphology with extant analogues. Here we use biomechanical and geometric morphometric methods to investigate the dental morphofunctional diversity of early dinosaurs in comparison with extant squamates and crocodylians, and predict their diets using machine learning classification models. We find evidence for diversification in tooth shape and mechanical behaviour among early dinosaurs, showing variation in dental traits that span those of extant sauropsids with different diets. Early saurischians/theropods are consistently classified as carnivores. Sauropodomorphs underwent a dietary shift from faunivory to herbivory, experimenting with diverse diets during the Triassic and Early Jurassic, and early ornithischians were likely omnivores. Obligate herbivory was a late evolutionary innovation in both clades. Carnivory is the most plausible ancestral diet of dinosaurs, but omnivory is equally likely under certain phylogenetic scenarios. This early dietary diversity was fundamental in the rise of dinosaurs to ecological dominance.

Post-extinction recovery of the Phanerozoic oceans and the rise of biodiversity hotspots

Michael J. Benton[1], Pedro Cermeño[2], Carmen García-Comas[2], Alexandre Pohl[3,4], Simon Williams[5], Chhaya Chaudhary[6], Guillaume Le Gland[2], R. Dietmar Müller[7], Andy Ridgwell[3] and Sergio M. Vallina[8]
[1]*University of Bristol, UK*
[2]*Institut de Ciències del Mar, Spain*
[3]*University of California, Riverside, USA*
[4]*Université Bourgogne Franche-Comté, France*
[5]*Northwest University, China*
[6]*Helmholtz Centre for Polar and Marine Research, Germany*
[7]*University of Sydney, Australia*
[8]*Instituto Español de Oceanografía, Spain*

A long-running debate in palaeontology is the diversity-through-time graph. As David Raup said in 1972, there is tension between empirical fossil record data and bias, so it is unclear whether life in the sea increased continuously (expansion), in steps (multiple equilibria) or reached carrying capacity in the Ordovician (saturated logistic). Fossil-based

talks

studies are compromised by the impossibility of sampling correction and geographic heterogeneity of habitats and of sampling. In a new analysis, we couple a palaeogeographic model in 82 steps through the Phanerozoic with the cGenie Earth System model to explore how the oceans filled with life. The model uses extent and ages of continental shelves, climate, and predictions of temperature and food supply as determinants of generic richness. Mass extinctions are imposed according to three sources. It predicts modern oceanic biodiversity well, and so provides a plausible model of actual biodiversity in the oceans through the Phanerozoic. Life in the oceans has been undersaturated throughout, but hot spots since the Triassic have been stable and so diversity has built up. The various runs of the model fit the exponential best, then the calibrated logistic, and the saturated logistic (carrying capacity reached in the Ordovician) least well.

DeepDive: deep learning estimation of palaeodiversity from fossil data

***Rebecca Brown Cooper[1,2] and Daniele Silvestro[1,2,3]**
[1]*University of Fribourg, Switzerland*
[2]*Swiss Institute of Bioinformatics, Switzerland*
[3]*University of Gothenburg, Sweden*

Palaeodiversity estimates remain hampered by the incomplete and biased nature of the fossil record, with recent studies demonstrating that spatial and temporal heterogeneities in preservation and sampling probabilities still challenge estimates made using state of the art methods. Here we develop a new approach based on biodiversity simulations and a deep learning model to infer species richness through time while incorporating age uncertainties, spatial, temporal and taxonomic sampling biases. We assess model performance using simulated datasets and compare it with that of other available methods. Our preliminary results show that the new software, named DeepDive, consistently outperforms alternative methods when used to re-estimate simulated biodiversity trajectories from degraded datasets. We further explore the ability of our method to infer robust confidence intervals around predicted diversity and re-estimate the diversity dynamics of empirical clades with different levels of preservation in the fossil record. The deep learning models developed in DeepDive offer a robust approach to integrate diverse sampling biases to infer the evolution of biodiversity through time.

The origin of panarthropod legs

***Alavya Dhungana and Martin R. Smith**
Durham University, UK

Panarthropoda is a clade of three segmented, appendage-bearing animal phyla: Euarthropoda, Tardigrada and Onychophora. The earliest panarthropods – lobopodians – are characterized by their stubby legs, which often bear cone-in-cone claws. Precisely how these features evolved along the panarthropod stem, from a legless worm to a lobopodian, remains obscure. With new fossil data, we identify paired, stub-like appendages crowned with cone-in-cone elements on a Cambrian palaeoscolecid worm, *Cricocosmia jinningensis*. Our phylogenetic analyses confirm that cricocosmiid appendages and conical elements are homologous with lobopodian legs and claws, with cricocosmiids resolving on the panarthropod stem-group – supporting a longstanding but speculative hypothesis that panarthropods evolved from palaeoscolecid-like worms.

talks

Biogeographic observer bias: Devonian Gondwana

Elizabeth Dowding

University of Oslo, Norway

Biogeographic relationships are built from overlaps, associations, and absences. Necessary efforts to identify the impact of colonialism are gaining traction within palaeosciences, providing insight on and evidence for distorted estimates on biodiversity. Global correlations are influenced by the legacy issues in palaeosciences in general. Using Devonian faunal distributions, the influence of observer bias on biogeographic inter-relationships are studied at three scales: cumulative faunal data from the Palaeobiology database, Devonian trilobites, and the inter-relationships of the Devonian Homalonotidae. Using these data, it is possible to highlight patterns that, rather than being indicative of a true biogeographic process, are representative of observer bias and legacy issues in palaeoscience. This approach is applied to the current understanding of the biogeography and bioregionalization of Gondwana during the Devonian. This study acts as a template for the consideration of biogeographic correlations and area histories within the Devonian and Palaeozoic given the connection between diversifying and decolonising palaeontological knowledge.

talks

Associations between trilobite moulting variability and morphometry

Harriet B. Drage[1], James D. Holmes[2], Diego C. García-Bellido[3,4] and John R. Paterson[5]

[1]*University of Lausanne, Switzerland*

[2]*Uppsala University, Sweden*

[3]*University of Adelaide, Australia*

[4]*South Australian Museum, Australia*

[5]*University of New England, Australia*

Trilobite moult assemblages are preserved in great number in the global fossil record, showing extreme variability in their exoskeleton disarticulations, perceived movements and resulting configurations. The biological associations of this variability, causal or consequential, are virtually unknown for this evolutionary long-lived, diverse, and ubiquitous euarthropod group. We use a large dataset of trilobite moults to test for significant associations between moulting behaviour and morphometry to inform on whether this impacted their morphology. Few associations are found to be significant, only thorax length, segment count and pygidium width, and in particular for individuals with inverted librigenae. Little difference in occupation of morphospace is observed, though specimens showing Salter's moulting mode may be more morphometrically constrained. A case study using ~500 specimens of *Estaingia bilobata* from the Cambrian Series 2 Emu Bay Shale found similar results. Both studies indicate moulting mode had little to do with creating an appropriately-sized exuvial gape, and may be a function of movements and articulation strengths. The *E. bilobata* dataset also highlighted the importance of randomised field sampling of moults to offset collection biases. Questions of why trilobites were flexible in moulting behaviour, and what impact this had on their evolutionary history, remain open.

Climatic drivers of pterosaur origins

Emma M. Dunne[1], Alexander Farnsworth[2,3], Richard J. Butler[1], Sterling Nesbitt[4], Nicholas C. Fraser[5,6], Stephen L. Brusatte[5,6], Daniel Lunt[2], Paul Valdes[2], Stig Walsh[5,6], Paul M. Barrett[7] and Davide Foffa[1,4,5]
[1]*University of Birmingham, UK*
[2]*University of Bristol, UK*
[3]*Institute of Tibetan Plateau Research, Chinese Academy of Sciences, China*
[4]*Virginia Tech, Blacksburg, Virginia, USA*
[5]*National Museums Scotland, Edinburgh, UK*
[6]*University of Edinburgh, UK*
[7]*Natural History Museum, London, UK*

Pterosaurs were the first vertebrates to evolve powered flight; however, their origin and early evolution are still poorly understood. The global distribution of pterosauromorphs (the group composed of pterosaurs and their closest relatives, lagerpetids) during the Triassic indicates that climate may have shaped their early evolution; pterosaurs were restricted to low latitude coastal habitats of the Northern Tethyan region, whereas lagerpetids had a much wider latitudinal spread. We examined climate niche evolution of Triassic pterosauromorphs within a spatially explicit framework, using a general circulation palaeoclimate model combined with palaeobiogeographic data. We found minimal overlap in geographic range and climate niches; lagerpetids typically occurred in drier environments within a wider range of temperatures, and in contrast pterosaurs primarily occupied humid, lower-latitude regions that were subject to less extreme temperature fluctuations. The sudden and relatively localized radiation of the first pterosaurs in the Norian, and the synchronous arrival of lagerpetids in the tropical belt, indicates that the biogeographical expansions of these groups may have been enabled by the removal of low-latitude climatic barriers. The first vertebrates to evolve flight appeared after these expansions, suggesting that climate played a key role in one of the biggest transitions in vertebrate evolution.

Evolutionary innovation and competitive replacement drove the rise of modern coral reefs

Joseph Flannery Sutherland, Alexander Farnsworth and Michael J. Benton
University of Bristol, UK

After a cryptic Ordovician origin, modern corals (Scleractinia) appeared in the fossil record in the Triassic during a remarkable period of reef recovery following the end-Permian mass extinction. Microbially-bound biostromes proliferated in the aftermath of the catastrophe before the rise of sponge-dominated Wetterstein reefs in the Middle Triassic. These were then supplanted by coral-dominated Dachstein reefs in the Late Triassic, yet the tempo and drivers of this succession remain unexplored using deep-time climate reconstructions or modern macroevolutionary methods for inferring diversification processes. We infer sampling-corrected scleractinian and sponge diversification dynamics in a Bayesian framework (PyRate, mcmcDivE). We then use ecological niche modelling to link the biogeographic radiation of scleractinians to macroscale changes in palaeogeography and climate. We show that sponges were competitively replaced by scleractinians as dominant reef builders with the advantages provided by evolutionary innovations of coloniality and photosymbiosis offset by broader environmental controls, including a potentially undocumented middle Norian mass extinction event, to produce an episodic pattern of

expansion through the Late Triassic. This origin is antithetical to the current crisis facing corals, with widespread coral bleaching from photosymbiote loss under ecologically stressful conditions precipitating their mass replacement by sponges and algae in reef ecosystems.

Pterosaur take-off: estimating launch capabilities in one of the largest flying animals

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Launch is a vital part of powered flight which constrains the size of modern birds. Pterosaurs are known to have reached sizes far larger than modern birds without any indicators of loss of flight. Three different hypothesized launch motions have been proposed as explanations for how pterosaurs circumvented this modern limit: bipedal burst launching, bipedal countermotion launching, and quadrupedal launching. Using range of motion constraints and inverse kinematics we generated complete launch motions for each hypothesis using a 5 m wingspan ornithocheiraean as our model. The moment arms for 37 key muscles utilized during these motions were determined using a musculoskeletal model. To determine which launch motion had the greatest moment generating capacity we calculated the maximum isometric force for each muscle within the simulation using muscle architecture data from living animals and applied these values to the moment arm sequences of each launch. While different modelling assumptions have a substantial effect on the magnitude of the available leverage, in all our models we found the quadrupedal launch to have the largest moment generating capacity at launch and is therefore the motion most capable of circumventing the size limit seen in modern flying animals.

A Cambrian tommotiid preserving soft tissues reveals the metameric ancestry of lophophorates

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Among animals, Lophotrochozoa accounts for the majority of phyla. Lophotrochozoans radiated rapidly during the Cambrian explosion, obfuscating their inter-relationships and

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many aspects of their early evolution. Many of the earliest lophotrochozoans are known only from isolated skeletal microfossils that are derived from animals with complex multi-element skeletons. Tommotiids are a key group of phosphatic early skeletal fossils that first appear in the early Cambrian. Although their affinities were previously obscure, growth, microstructure and partial scleritomes have provided links between some tommotiids and Brachiopoda and Phoronida, two of the lophophorate phyla. In contrast, camenellan tommotiids remain a palaeontological mystery, with hypothetical reconstructions representing motile, benthic, dorsally-armoured worms. Here we describe an articulated camenellan from the Chengjiang biota, China, revealing the morphology of the scleritome and the first soft tissues from an adult tommotiid. The new taxon carries two dorsal rows of sclerites in a highly asymmetric arrangement, flanked by smaller, cap-shaped sclerites. The scleritome was fringed by iterated fascicles of chaetae and two layers of flattened lobes. This discovery confirms that camenellans occupy a deep branch in lophophorate phylogeny, prior to the acquisition of a sessile lifestyle, revealing a metameric body plan reminiscent of annelids early in lophophorate evolutionary history.

Cambrian bivalved arthropods revisited: evolution and ecology of a disparate group

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Characterized by their cephalothoracic carapace, bivalved arthropods are relatively common in many Cambrian Burgess Shale-type deposits. Despite this, their taxonomy and exact position in early arthropod evolution remain largely unresolved. Two main groups of bivalved arthropods have been recognized: the stem-group euarthropod isoxyids and the hymenocarines. Previously considered early euarthropods, several historically significant hymenocarine species like *Branchiocaris* are now regarded as early mandibulates, but many previously published species have yet to be restudied in detail. Here we provide a new overview on the taxonomy and evolution of bivalved arthropods based on recent discoveries from the Burgess Shale, Canada. We report the presence of mandibles in *Odaraia*, further supporting a mandibulate affinity. Second, we discuss a new reconstruction of *Tuzoia*, one of the most common bivalved arthropods of the Cambrian, previously known almost entirely from carapaces based on new specimens preserving soft tissues. Finally, we highlight the morphological disparity of hymenocarines, exemplified by a wide array of carapace shapes, different cephalic conformations and post-cephalic tagmae, which similarly hint to a wide ecological diversity. Overall, we highlight the importance of bivalved arthropods in the context of early mandibulate evolution and discuss future lines of work for this group.

A biogeographic theory of thermal habitat loss during global temperature change

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Global warming has been implicated as a trigger of mass extinctions in the past. Although species track their thermal niches as isotherms move poleward, systematic changes in the area of habitable space (*i.e.* their thermal habitat) are expected to influence their extinction risk. However, quantifying thermal habitat changes is difficult in the geological past, where information about geography and the distributions of species is highly incomplete. We therefore present a formalized model of thermal habitat change, resulting from the interaction of spherical geometry, thermal niche preference, latitudinal temperature profile and warming. Our results suggest an overall decrease in available thermal habitat when global temperature increases. Thermal habitat is lost primarily from lower latitude and polar areas, whereas temperate areas are less affected. Although patterns of extinction are ultimately dependent on the geography of available habitat space, the extent to which species occupy their thermal niches, and biotic interactions, our simple theoretical model provides the basic expectation for spatial patterns of habitat loss, and therefore potentially species loss during global warming.

The evolution of morphological and functional complexity in the earliest conodonts

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Conodonts are the first vertebrates to develop a mineralized skeleton, manifest as a complex array of tooth-like elements, the function and ecological significance of which has long been the subject of debate. Most functional analyses have focused on derived euconodonts (prioniodontids) with blade and platform element morphologies that are difficult to interpret functionally. Paraconodonts and 'primitive' (non-prionidontid) euconodonts commonly exhibit simple coniform elements, where subtle morphological changes in their cross-section can be easily interpreted in terms of mechanical advantage. Furthermore, they exhibit overlapping morphologies with different degrees of tissue differentiation. Here using elliptic Fourier analysis and beam theory, we analyse the early morphological diversification and biomechanical performance of these coniform conodonts in an ecological and evolutionary context. Our analyses show that compared to paraconodonts that lack crown tissue, early euconodonts exhibit greater morphological disparity and functional diversity in terms of resistance to bending and torsion. This corroborates existing hypotheses on the key role of the origin of the euconodont crown which facilitated morphological differentiation, repair and renewal throughout the lives of conodonts. This capacity for more disparate element morphologies underpins the significant ecological roles that euconodonts adopted during the Palaeozoic and early Mesozoic.

The continental end-Permian extinction event of eastern Gondwana — a song of slime and fire

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The threat of wildfires and harmful microbial blooms to land and freshwater ecosystems is increasing today, exacerbated by CO_2-driven warming. Similarly, the end-Permian event (EPE; ~252.2 Ma), the most severe of all mass extinctions, has been consistently linked to a rapid increase in CO_2, an attendant temperature spike and, as our recent findings show, a peak in wildfire activity and freshwater microbial blooms. Our recent study of the charcoal records from Permian–Triassic strata of eastern Australia and the Lambert Graben, East Antarctica, reveal increasing fire activity during the late Permian (Lopingian), reaching a maximum at the onset of the EPE. This end-Permian 'burn-out' was followed by a depressed fire regime for >3 million years. In contrast, fossil freshwater algae and bacterial remains have their greatest abundances immediately above the fossil-poor 'dead zone' following the EPE horizon. These reached concentrations typical of modern toxic microbial blooms, remaining intermittently high for >3 million years. These data indicate that the EPE collapses in land and freshwater ecosystems were heralded, and likely driven in part, by these ecological stressors. Drawing on recent climate projections and ecological impact assessments, we propose a revised model of continental extinction drivers during this end-member of hyperthermal mass extinction events.

The role of fossils tips in inferring the tree of life

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Fossils provide direct evidence of evolution in deep time, and including them in phylogenetic analyses adds the dimension of time to macroevolutionary studies. However, how to best incorporate fossil character and stratigraphic ages into phylogenetic analyses is controversial due to myriad competing methods, fossil incompleteness and a lack of clarity on how they modify tree topologies. We have developed a simulation framework to investigate how fossils behave during morphological phylogenetic analyses. Combining fossils with extant terminals improves the accuracy of phylogenies and increases the number of resolved nodes. They also induce the collapse of ancient and highly uncertain relationships that tend to be incorrectly resolved when sampling only extant taxa. Furthermore, the fossilized birth–death process outperforms undated methods of inference: the stratigraphic ages of fossils contain vital information. We further demonstrate that inaccurate fossil placement does not compromise tip-dated divergence times, thus fossils with uncertain position and large amounts of missing data can be incorporated without detriment to the analysis. However, we find that timescales inferred from morphological data alone show low accuracy of node ages for both deep and shallow portions of the tree. For both divergence times and topology estimation, including additional fossil data is always beneficial.

Were there multiple bursts in the early evolution of Ichthyosauromorpha?

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Ichthyosauromorpha were among the first Mesozoic reptile clades to invade the oceans after the end-Permian mass extinction (EPME). Their rapid transition has been identified as an 'early burst' in recent studies of cladistic disparity and body size, with taxa over 10 m occurring within 7 Ma of the EPME and 3 Ma of the first ichthyosauromorph fossils. Here I use a newly-curated database of Ichthyosauromorpha occurrences – supplementing the Paleobiology Database – to explore their diversification. Occurrence ranges were restricted, where possible, to substage or biozone, standardized to Geologic Time Scale 2020 ages. Two peaks of diversity in the Olenekian and Anisian are preceded by high rates of cladogenesis in time-calibrated phylogenies, and separated by a distinct drop in diversity. Estimates of diversification from PyRate show multiple early bursts in speciation timing; however, they suggest initial high diversification rates increase to a single peak in the latest Olenekian with a decrease through the Middle Triassic. Effects of these differences on rates of trait evolution will be explored. Focus on temporally and spatially restricted Lagerstätten leads to a bonanza effect and multiple diversity peaks, while much interim ichthyosauromorph diversity was likely present in non-preserved or under-sampled deep water environments.

Reviving vetulicolians: a "lost chapter" in chordate history?

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Over the past few decades, former 'weird wonders' of the Cambrian Explosion have been reinterpreted as stem-group relatives of extant phyla and classes, illuminating the patterns and polarity of character acquisition in early animal evolution. However, vetulicolians have proven less tractable than most. Due to their perplexing character combination, these bilaterians have been variously interpreted as ecdysozoans, chordates, basal deuterostomes, or stem-group tunicates. Moreover, their monophyly remains contested. Following the description of new exceptionally preserved specimens from the Sirius Passet Lägerstatte, North Greenland, we reconstruct vetulicolian affinities under alternative phylogenetic frameworks. Using ancestral states reconstructions, we explore the implications of vetulicolians for the patterns and polarity of character evolution among bilaterians. We complement our cladistic results with a comprehensive analysis of vetulicolian morphospace occupancy, and test the applicability of computational fluid dynamics (CFD) to actively swimming problematica using vetulicolians as a case study. Finally, we describe vermiform fossils associated with Sirius Passet vetulicolians, some of which show key similarities to vetulicolian "symbionts" from Chinese Lagerstätten. Taken together, our results suggest that vetulicolians may best be interpreted as a morphologically distinct and ecologically diverse grade of stem-group chordates, hinting at a 'lost chapter' in the early history of our phylum.

The first Cambrian tunicate from Laurentia reveals the origins of the ascidian body plan

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Tunicates are an ecologically and evolutionarily significant group of animals. They are a major filter-feeding contributor to the vertical transfer of nutrients in marine systems. Further, as a sister-group to Vertebrata, understanding the early evolution of the tunicates is essential to understanding our own deep-time origins. Principal among questions concerning tunicate origins is whether the last common ancestor was free living like the appendicularians, or an animal attached to the benthos like the ascidians. Efforts to answer such questions are hamstrung by the exceptionally poor fossil record of tunicates, making it difficult to understand the acquisition of key biological characters. We describe a new 500-million-year-old tunicate from the Marjum Formation of Utah, USA, which features a barrel-shaped body with gill bar-like structures, and two long siphons with well-developed longitudinal muscles. Reminiscent of modern ascidiaceans, this new species suggests a bi-phasic lifestyle where a planktonic larva metamorphosed into a sessile epibenthic adult may be ancestral to all tunicates. Alternatively, the divergence point between appendicularians and asicidiaceans (including thaliaceans) may be 50 million years older than currently estimated using molecular clocks. In either scenario, the fundamental components of the modern ascidian body plan were already established shortly after the Cambrian Explosion.

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Putting your best foot forward: the ecology of early theropod flyers refined by their feet

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The feet of living birds are tightly correlated to their ecology. The cursoriality and feeding mode of living birds and their grasping ability are reflected in the toe pads, foot scales, joints and claws. To uncover these ecological aspects from the feet of early theropod flyers, we present the equivalent fossil evidence preserved as soft tissues surrounding the bones. The anatomy, diet and locomotion capabilities of the earliest theropod flyers and the environments and climates they lived in have been used to study their ecology. We interpret our results in the context of these existing lines of evidence. The feet of the earliest theropod flyers like *Anchiornis* and *Archaeopteryx* from the Middle-Late Jurassic indicate a more ground-dwelling lifestyle. Aerial lifestyles diversified in the Early Cretaceous, including generalists like *Confuciusornis* and specialists like the climbing *Fortunguavis*.

Some early birds had complex ecologies that appear to be unique among sampled modern birds, such as the Berlin *Archaeopteryx* and the Early Cretaceous *Sapeornis*. The non-bird flyer *Microraptor* was unexpectedly recovered with a more specialized raptorial lifestyle. Its hawk-like characteristics were rare among known contemporaneous theropod flyers. This suggests that non-bird flyers like *Microraptor* were specialists, similar to some birds in modern ecosystems.

Rangeomorph orientations with independent current indicators demonstrate the reclining rheotropic mode of life of the Ediacaran rangeomorph taxa *Fractofusus misrai*, *Bradgatia* sp. and *Pectinifrons abyssalis*

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Deep-sea Ediacaran fossil biotas of Newfoundland are some of the oldest architecturally complex soft-bodied macro-organisms. Most organisms in the Mistaken Point-type biotas of Avalonia have been traditionally interpreted as living erect within the water column. However, due to the scarcity of documented physical sedimentological proxies, in many instances, Ediacaran palaeocurrents have been inferred from fronds preferential orientation. This bears a risk of introducing circular reasoning between frond orientation and palaeocurrents. In this study we present an integral approach from a newly described fossiliferous surface, the 'Cambridge Surface', in the Fermeuse Formation at Melrose, on the southern portion of the Catalina Dome, in the Discovery UNESCO Global Geopark, Canada, combining unequivocal physical sedimentological evidence for palaeocurrent direction in the form of climbing ripple cross lamination, and a series of statistical analyses based on clustering techniques reflecting the circular nature of recorded orientation. This study demonstrates the reclining rheotropic mode of life of the rangeomorph taxa *Fractofusus misrai*, *Bradgatia* sp. and *Pectinifrons abyssalis*, suggesting that the null hypothesis for the position of life of Ediacaran organisms should be amended so that these organisms are interpreted as reclining on the seafloor, as they are preserved in the fossil record.

Thermal structure of Late Pliensbachian assemblages determines their response to Early Toarcian warming pulses

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Marine assemblages are expected to undergo substantial reorganization under anthropogenic climate change. Assemblage vulnerability to reorganization can be indicated by the thermal niches of its component species but the link between thermal adaptations within an assemblage and the risk of local or global extinction is unclear. To address this gap, we infer species' thermal niches based on observed distributions of Jurassic invertebrate fossils on palaeoclimate maps over the hyperthermal pulses at the

Pliensbachian–Toarcian boundary and the Toarcian Oceanic Anoxic Event. We evaluate evidence that emigrants from a fossil assemblage after warming, alongside those species that went extinct, were most likely from the pool of species that were already close to their upper thermal limits before warming. Conversely, assemblage immigrants had warmer thermal niches than the assemblage pre-warming average. Pliensbachian and early Toarcian species distributions were likely squeezed between the poleward push of marine isotherms and the spread of anoxic bottom waters.

Fossilized soft tissues from the Colli Albani: a new mode of preservation for feathers

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The Pleistocene griffon vulture (*Gyps fulvus*) discovered within the pyroclastic succession of the Peperino Albano ignimbrite (Colli Albani, Rome, Italy) is renowned for the preservation of several soft tissues as external moulds (*e.g.* nictitating membrane and tongue) and for the evidence of partially preserved plumage. This specimen offers a unique opportunity to investigate the mode of preservation and the taphonomic controls that allowed the preservation of the soft tissues in volcanoclastic settings. Here we used scanning electron microscopy (SEM) coupled with energy dispersive X-Ray spectroscopy (EDS) to study the physical and chemical preservation of the feathers of *G. fulvus*. Our results reveal that the rachises are always preserved as moulds whereas the barbs and barbules are preserved three-dimensionally. SEM-EDS analysis of samples of soft tissues shows high concentration of Al and Si, whereas C is absent. These findings suggest that the feathers of *G. fulvus* are preserved via aluminosilification, a process known to occur in shallow, water-rich sediments in the presence of abundant of Al-Si ions in acidic conditions. According to our results, we propose that the vulture carcass was buried by a low temperature, water-rich non-turbulent mud flow associated with the last eruptive phase of the Colli Albani volcanic complex.

Assessing skull function in tyrannosauroids using 3D finite element analysis

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Tyrannosauroids are a well-studied clade of fossil taxa, which varied greatly in their body size distribution. Derived tyrannosaurid genera such as *Daspletosaurus* and *T. rex* are noted for their broadly set jaws and robust skulls. While the impact of size on locomotory ability has been studied in theropods, the impact of large body size on feeding performance is largely unknown. Here we used 3D finite element analysis (FEA) to test whether skull shape becomes more or less resistant to feeding induced forces as taxa body size increases. It was found that large-bodied tyrannosaurids with broader skulls and more deeply set jaws experienced higher absolute stresses compared to their smaller-bodied relatives, as they were able to accommodate high stresses because their skulls were so much larger. When surface area values were scaled, smaller individuals experience greater stresses than larger relatives due to the more robust cranial osteology of large tyrannosauroids. These results may indicate that the wide crania of large tyrannosaurids convey a functional advantage

that smaller taxa lacked. This advantage may have enabled large tyrannosauroids to prey on large herbivorous dinosaurs common in Late Cretaceous North America, while slenderer tyrannosauroids like *Alioramus* pursued smaller prey, including mammals and juvenile dinosaurs.

Estimating bite force in extinct dinosaurs using phylogenetically predicted physiological cross-sectional areas

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Reconstructing muscles is a crucial step in biomechanical modelling in extinct animals, such as biting mechanics in non-avian dinosaurs. However, muscle architecture is difficult to reconstruct accurately, and often only able to do so in a relatively small taxonomic sample. Sample size is a limiting factor in comparative studies of evolutionary biomechanics. A simple but accurate approach to estimate muscle parameters is needed to enable wide taxonomic sampling. Here I present a Bayesian phylogenetic predictive modelling approach to predict the physiological cross-sectional areas of jaw adductor muscles in extinct dinosaurs from a simple morphological predictor variable, the skull width. Initial prediction accuracy in dinosaurs is low using models based solely on extant data but improves (up to 90 %) in models that include cross-sectional areas measured from reconstructed muscles in extinct archosaurs. I then used the predicted cross-sectional areas to calculate bite force in extinct theropod dinosaurs. Bite forces based on model-predicted muscle parameters are congruent with those based on reconstructed muscle parameters. Phylogenetic predictive modelling on an easily measurable skull metric is a powerful tool for predicting muscle parameters in extinct taxa, to a reasonable level of accuracy, that enables a wider comparative framework for evolutionary biomechanical studies.

Taxonomic variation in teleostean fishes from Las Hoyas (Lower Cretaceous) using shape analysis

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Teleostean fish represent the most abundant vertebrate group of Las Hoyas (Barremian, Cuenca, Spain), and today encompass a collection that exceeds 5,000 specimens. However, diagnostic limitations have historically hampered their taxonomic assessment and only traditional morphometric proxies have illuminated nuances of their life history such as sexual dimorphism, yet only when species were distinguishable (*Rubiesichthys*). To overcome such limitation, we have devised a shape analytical protocol based on geometric morphometric techniques; the aim was to decode aspects of the taxonomy and to separate them from traits related to their life history, such as allometry and phenotypic plasticity. To test the reliability of the approach, we studied two well-known species of Gonorynchiform fossil fish (N = 400 specimens) from the site, *Gordichthys conquensis* and *Rubiesichthys gregalis*. The first challenge was to mathematically remove opisthotonic curvature, a biostratinomic artefact, that strongly biases the analyses. After successfully unbending the specimens, the analyses easily separated *Gordichthys* and *Rubiesichthys*, even detecting the sexual dimorphism previously described in the latter species. Furthermore, the analyses captured the allometric trends of each species, which were unknown. These results confirm the solvency of the methods, which can be extended to unravel latent information from the most cryptic teleosts of Las Hoyas.

True colours: a new model for the taphonomy of melanin chemistry and the identification of phaeomelanin in Miocene and Cretaceous fossils

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Melanin pigments play a critical role in physiological processes. Fossil melanin is thus a unique resource for understanding the functional evolution of melanin. Accurate evolutionary models require robust fossil evidence, but the impact of fossilization on molecular signatures for eumelanin and, especially, phaeomelanin is not fully understood. Here we use alkaline hydrogen peroxide oxidation-high performance liquid chromatography (AHPO-HPLC) to explore changes in melanin chemistry during taphonomic experiments simulating burial. We thermally matured black and orange feathers from the domestic chicken, *Gallus gallus*, and white feathers from the little egret, *Egretta garzetta*, at temperatures up to 250°C. Our results reveal which molecular signatures are authentic signals for thermally matured eumelanin and phaeomelanin, which signatures are artefacts derived from the maturation of non-melanin proteins, and how these chemical data are impacted when samples receive HCl treatment. Based on these data, we present a new model for the chemical taphonomy of fossil eumelanin and phaeomelanin. This model predicts the melanin chemistry in several Miocene and Cretaceous vertebrates and, moreover, supports the identification of phaeomelanin in these fossils. This taphonomic framework is an essential addition to the geochemical toolbox that underpins reconstructions of melanin evolution and of melanin-based colouration in fossil vertebrates.

Increasing the equitability of data citation in palaeontology: A view to the future

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Large compilations of palaeontological data unlock new scientific questions and insights about the history of life. Even so, the use of compiled data in palaeontology has moved at a faster pace than the development of best practices for citing data sources. It is commonplace for large-scale analyses to draw data from many smaller-scale publications

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but to omit formal citation of the data sources. By focusing professional rewards toward data users and away from data creators, this disconnect may threaten the sustainability of big science in palaeontology. To better understand the extent of this issue, we examined approximately 400 publications to quantify the number of citations data-creating studies would have accrued if subsequent publications drawing data from the Paleobiology Database would have cited them. The number of omitted citations varies by publication; however, it is clear there is a large disparity in the use and citation of data in palaeontology. Our findings highlight the need for sustainable, systemic change in how data-creating studies are recognized. We argue for, and provide examples of, new, professionally meaningful approaches to data citation to improve research practices across our discipline and beyond.

Disentangling phylogenetic and ecomorphological signal in 2D skull shape in the radiation of archosaurs

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Numerous factors underlie morphological form, with selection, phylogeny and functional constraints all strong influences. Disentangling these signals has been subject to extensive work, with isolating phylogenetic signal especially attempted to better reconstruct the relationships between fossil taxa, but separating the different signals remains extremely challenging. A recently developed method applied to 2D geometric morphometrics to separate outline or 'global' shape from 'local' or constructional details (*i.e.* residual shape) has demonstrated some success in separating ecomorphological signal, *i.e.* phylogenetic signal. We apply this method to an expanded dataset of 2D cranial reconstructions of fossil archosaurs, bracketing the rise of dinosaurs and pterosaurs and the diverse radiation of Triassic pseudosuchians, alongside an ecomorphological proxy dataset based on dental/jaw characters. We find that – based on existing discrete character phylogenies – outline shape shows more ecomorphological and less phylogenetic signal than residual. Phylogenies reconstructed from total, outline and residual shape using phylogenetic morphometrics do not closely approach existing phylogenies, but monophyly of key groups is supported, and constraints based on postcranial information yield more similar topologies. Work using extant, and possibly postcranial, data would fully test the method's utility in archosaurs.

Multiple increases in atmospheric oxygen and marine productivity through the Neoproterozoic and Palaeozoic

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It is widely believed that Earth's oxygenation proceeded in two steps, with the second broadly correlated with the appearance of macroscopic animal fossils in the late Neoproterozoic. Records of redox-sensitive trace metals in anoxic shales are one of the strongest lines of evidence for a Neoproterozoic oxygenation event. We present statistical learning analyses of a large dataset of Tonian–Carboniferous geochemical data and associated geological context assembled by the Sedimentary Geochemistry and Paleoenvironments Project. Contrary to previous analyses of raw data, we show that there was no major stepwise increase in marine Mo or U concentrations until the Devonian. Our analyses do, however, indicate a stepwise increase in shale total organic carbon (TOC) around the Ediacaran–Cambrian boundary, followed by further increases through the Palaeozoic. We apply a combined biogeochemical modelling approach using cGENIE, CANOPS and a three-sink metal mass balance to investigate the range of atmospheric oxygen and marine productivity scenarios consistent with the deconvolved trends we observe in Mo, U and TOC. We reconstruct three broad phases of atmospheric pO_2, marine primary production, global marine anoxia and shallow marine dissolved $[O_2]$ for the Neoproterozoic and Palaeozoic, with implications for hypotheses linking environmental changes to the evolution of early animal ecosystems.

Convergent evolution of raptoriality in Telluraves

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Accipitriformes, Strigiformes, and Falconiformes are the three extant raptorial avian clades, most members of which use their feet to kill and carry prey. The disparate grouping of these clades with similar foot use has been hypothesized to result from retention of raptoriality from a telluravian ancestor, which has not been tested using ecomorphological methods. I evaluated the hypothesis by testing the anatomical correlates of raptoriality in extant birds using geometric morphometrics and phylogenetic comparative shape analysis on the tarsometatarsus bone, and then mapped the ancestral states of raptoriality across the phylogeny, including fossil taxa. Hypotarsus shape is a statistically significant indicator of raptoriality in birds: raptorial birds tend to possess a deep and wide monosulcate hypotarsus (one sulcus on the proximal end of the tarsometatarsus bone through which flexor tendons run). This relationship can be used to infer raptorial foot use in stem taxa throughout Telluraves known only from fossils. Using these inferred states in ancestral character estimation demonstrates that all extant raptorial groups have convergently evolved raptoriality, contradicting existing hypotheses of a raptorial ancestry of Telluraves as a whole. However, this does not rule out the occurrence of carnivory in the ancestor of Telluraves.

talks

Does your data collection method matter? Investigating the differences in palaeoecological reconstructions from published and citizen science data

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Citizen science initiatives provide valuable data across ecology, but are less well explored for palaeoecology. One example is the FossilBlitz project that ran in 2015, 2016 and 2017, where participants counted and identified Lower Jurassic fossils that they found within 50 cm by 50 cm quadrats placed randomly on beds exposed on the foreshore. The palaeontology of Lyme Regis, UK, has been extensively studied for over 100 years, so the FossilBlitz data is uniquely placed as a trial for how citizen science data compare to published and unpublished palaeoecological data from the same bedding planes in the same location. We have statistically compared the FossilBlitz data to published palaeoecological data and additional unpublished data, to test whether three different data collection methods pick out the same palaeoecological trends. We explore whether the datasets have comparable diversity metrics for the same beds, whether the citizen science effort records rarer taxa due to higher counts, and ultimately whether the 'scientist-collected' and 'citizen scientist-collected' field data are similar enough to integrate.

Examining the morphological response of marine calcifying taxa to extreme environmental change during the Cretaceous–Palaeogene mass extinction in Southern Ocean shelf, open-ocean and deep-sea ecosystems

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The Cretaceous–Palaeogene (K–Pg) boundary at 66 Ma coincides with the most recent of the 'Big Five' Phanerozoic mass extinctions. The extinction was driven by rapid and extreme environmental changes, which included global cooling, surface ocean acidification, and productivity decline, following an extra-terrestrial impact at Chicxulub in the Gulf of Mexico. The excellent global fossil record of the K–Pg extinction and recovery provides an opportunity to examine how severe environmental perturbations affect organisms and ecosystems across different oceanographic settings. Combining samples from the expanded stratigraphic section on Seymour Island, Antarctica, and IODP sites 690 and 1135, we present new quantitative morphometric and µ-computed tomography data from large collections of well-preserved calcifying macro- and microfossil taxa (benthic molluscs, planktonic and benthic foraminifera) across the K–Pg boundary in the environmentally sensitive high latitudes of the Southern Ocean. Due to their accretionary growth, measuring morphological parameters in these organisms permits examination of common traits such as body size, growth rate and reproductive mode. These data allow us to directly compare and quantify the morphological response of different marine calcifiers to rapid and extreme environmental changes associated with this major mass extinction event in shelf versus open-ocean and deep sea settings for the first time.

How to become a crab: phenotypic constraints on a recurring body plan

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At least five cases of convergent evolution of the crab-like body plan (with a wide and flattened shape, and a bent pleon) are known in brachyuran and anomuran crustaceans as 'carcinization'. The repeated loss of this body plan has been identified as 'decarcinization'. Here we aim to resolve the history of crab evolution from multiple angles. We synthesize our recent molecular phylogenetic approaches to crab relationships, comparing the use of carefully vetted fossil calibrations to automated sampling of hundreds of fossil occurrences, and the appropriate way to model the inclusion of these fossils in divergence time inference. We also quantify carcinization and decarcinization using micro-computed tomography to build 3D models of exemplar crab taxa that will span the disparity of body forms. A suite of landmarks and semi-landmarks are applied to describe the shapes of the carapace and pleon, with the goals of determining if instances of convergent evolution occupy the same areas of morphospace, and if the evolution of carapace and pleon shape are phenotypically integrated. Together these data will provide a backbone to assess the pattern of crab shape evolution, and potentially the predictability of phenotypic evolution from ecological and/or genomic 'rules'.

talks

Palaeontological heritage as a powerful resource to promote the understanding of ecology and evolution concepts at schools in a project-based learning initiative

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Project-based learning (PBL) is a scholar method which engages students into reasoning around a certain topic. Likewise, researchers may use PBL to study students' previous misconceptions, encourage critical thinking, and facilitate the incorporation of complex concepts. Fossils are exceptional resources for transmitting how life has evolved, past biodiversity and extinction events. Within the 2020–2021 school year, five educational centres in rural areas of Cuenca, Spain, participated in a project that proposed the comparison between current micromammal adaptations to the ones observed in the local eutriconodont fossil *Spinolestes xenarthrosus* (129 Ma), studying different structures (teeth, bone remains, hair) experimentally. Most students changed their first hypothesis about *Spinolestes*, usually misinterpreted as a rodent, many using ecological and evolutionary reasoning effectively to explain a greater teeth analogy to insectivores. Yet only 60 % of the teachers identified that the project facilitated the understanding of evolutionary concepts, mostly explained through the variation of teeth morphology and diets. Therefore, the relationship of explicit concepts to the theory of evolution needs to be strengthened. Still, the engagement of both students and teachers to the scientific method was excellent. Students were aware of their palaeontological heritage and proud to show their neighbours the exhibition of their results.

Abstracts: Lightning Talks

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

Floral diversity, disparity and turnover at the Siluro–Devonian boundary: palynological evidence from the Anglo-Welsh Basin, UK

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Few successions have contributed as much to our understanding of late Silurian – Early Devonian land plants as the Lower 'Old Red Sandstone' of the Anglo-Welsh Basin, UK. The nearly continuous fluvial deposits of the basin straddle the Siluro–Devonian boundary, a key moment in time for embryophytes. Here, the >40 Ma long 'slow-fuse' evolutionary stasis of primitive cryptospore-producing land plants ends with an explosive radiation of tracheophytes and their immediate progenitors as they diversify and dominate terrestrial ecosystems. An in-depth appraisal of the dispersed spore record from the latest Ludlow to middle Lochkovian (late Silurian – Early Devonian) of the Anglo-Welsh Basin, building on previous work, has revealed a striking radiation amongst dispersed cryptospores and miospores. Here we present a temporal and spatial quantitative analysis of diversity and disparity (morphological diversity) change amongst the trilete miospores and cryptospores, alongside exploring floral turnover across several coeval, environmentally variable sites. Our findings suggest that not only did trilete spores see immense changes in diversity and disparity across the Siluro–Devonian boundary, but cryptospores also exhibit their own adaptive radiation. The environmental differences between coeval sites may also hint at palaeoecological preferences for certain dispersed spore species and their parent plants.

talks

Bryophytes in the fossil record: two examples from non-amber preservational contexts

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The bryophyte fossil record is sparse and understudied. While most Mesozoic and Cenozoic bryophytes are preserved in amber, bryophyte fossils are also preserved in other depositional contexts. For example, Early Cretaceous (Valanginian, 136 Ma) permineralized plant assemblages on Vancouver Island, Canada, preserve abundant and diverse bryophytes in marine carbonate concretions. A newly-discovered moss type, represented by several branched gametophytes with gametangia borne on short branches,

adds to the diversity of tricostate mosses, a diverse Mesozoic group now extinct. The leaves are densely arranged on the stems, lightly plicated at the base and adaxially concave distally, they have unistratose lamina and three costae 3-5 cells thick: a central costa and two symmetrical lateral costae. Lack of cellular preservation at the centre of stems suggests the presence of a central strand with thin-walled cells. Another example is found in the upper Barremian (129 Ma) limestones of Las Hoyas, Spain, where thalloid liverworts preserved as carbonaceous compressions possess unistratose thalli with multistratose midribs and archeogonia similar to those of extant simple thalloid liverworts. Morphometric and taphonomic analyses suggest that these liverworts were adapted to relatively dry habitats with low sunlight exposure. Both occurrences add significantly to the sparse bryophyte fossil record.

Uncovering the true diversity of the Wealden iguanodontians

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The iguanodontians were a diverse and widespread group of ornithopod dinosaurs including some very well-known taxa, yet their taxonomic history is convoluted. Initial isolated finds assigned to Iguanodon by Gideon Mantell would not be considered valid for the erection of a new genus today. Further nineteenth century finds from the Wealden Group of the UK were often assigned to Iguanodon with little appraisal, resulting in it becoming something of a 'wastebasket taxon'. Valanginian deposits in the UK display a lack of iguanodontian diversity when compared to contemporaneous formations in North America. The historic lumping of specimens together into 'hypodigms' masks true diversity and causes some specimens to be overlooked. The relatively fragmentary nature and often poor preservation of these specimens further exacerbates confusion around their relationships. These issues have led to a full review of the Valanginian material at the Natural History Museum, London. Holotype material and the referred specimens of all genera have been critically reassessed for autapomorphies and shared features resulting in new definitions being produced. Hypselospinus has been suppressed, *Barilium* and *Kukufeldia* remain valid, *Sellacoxa* has been revived, and at least one new taxon has been recognized, indicating that the diversity of the Wealden is greater than previously thought.

Diversity of shield morphologies in crabs of the group Carcinidae – a quantitative approach

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Carcinidae is a younger group of true crabs (Eubrachyura), the invasive European shore crab being its most famous representative. Recent molecular analyses expanded the species richness of Carcinidae, interpreting more lineages as being part of the group. This increase also resulted in an expansion of known fossil representatives of Carcinidae, allowing new conclusions for the group's evolutionary history. Here we analyse the diversity of shield morphologies within Carcinidae through time and ontogeny. We use elliptic Fourier analysis to investigate shield outlines. Furthermore, we combine morphological and molecular character matrices to create an up-to-date phylogeny that includes fossil species for a reconstruction of ancestral states of the group. These are then used for a disparity analysis through time. We find that the ancestral shield form for Carcinidae probably was a quasi-hexagonal shield type, suggesting an epibenthic lifestyle of the earliest representatives of Carcinidae. The group underwent a strong radiation in the Oligocene leading to a significant increase in diversity of the shield forms. We also find that the shield outline can be used to separate the ontogenetic stages of Carcinidae. This fact may be used in the future for a more quantitative interpretation of ontogenetic stages in fossil specimens.

Comparative taphonomy of anurans from lacustrine-hosted Cenozoic Lagerstätten

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Anurans have a highly conserved body plan and are abundant components of many Cenozoic lacustrine Konservat-Lagerstätten. Fossil frogs, therefore, readily lend themselves to investigation of variations in preservation through time and space. We systematically analysed the skeletal taphonomy of 168 anurans from Geiseltal (Eocene, Germany) and compared the results with published data on anurans from Libros (Miocene, Spain) and with new observations on the taphonomy of anurans from Enspel (Oligocene, Germany), Bechlejovice (Oligocene, Czech Republic) and Messel (Eocene, Germany). The results reveal three shared taphonomic patterns common to anurans from all five biotas: a proximal-distal trend in completeness in the limbs; high completeness in the torso, but with preferential disarticulation or loss of bones in the pelvic girdle; and specific articulated body units (*e.g.* tibiale-fibulare). These taphonomic trends are controlled by the size and location of bones in the body, the 3D configuration of joints and stomach rupture. These shared patterns are superimposed by a suite of biota-specific features, *e.g.* near-complete phalanges for Bechlejovice specimens. The ultimate controls on the preservation of anurans in lacustrine-hosted Cenozoic settings relate to the skeleton (bone size, configuration, location), soft tissues (decay rate, recalcitrance) and depositional setting (water temperature, depth and bottom currents).

Appendicular and axial modular change reveals different routes taken by secondarily aquatic mammals and reptiles

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Distinct functional and morphological differences separate secondarily aquatic clades at the onset of their transitions, particularly between mammals (*e.g.* cetaceans, pinnipeds, *etc.*) and reptiles (sauropterygians, mosasauroids, *etc.*). These differences span the axial and appendicular skeleton with, for example, the presence and absence of certain bones, vertebral orientation and movement, and limb posture. Secondarily aquatic groups evolved locomotor morphology suited to the aquatic realm via predominantly axial or paraxial (appendicular-driven) swimming. To determine if these terrestrial functional differences may have impacted secondarily aquatic locomotion evolution we sought to test the degrees to which the appendicular and axial modules changed relative to one another between

secondarily aquatic clades and their terrestrial ancestors. We created morphological matrices of discrete and continuous characters of the axial and appendicular modules linked to locomotor function (*e.g.* relative length of the humerus, number of caudal vertebrae). We estimated terrestrial ancestral states using the Claddis R package and compared the distance by which each clade transformed in their axial and appendicular modules. Cetaceans and mosasaurs exhibit both high and similar degrees of axial change, despite having different ancestral terrestrial states, pinnipeds and sauropterygians have the least axial change, and all clades greatly modify their appendicular modules.

The oldest hurdiid radiodont in China known from complete specimens

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The Qingjiang biota is a recently described Burgess Shale-type (BST) fossil Lagerstätte from South China, preserving an early Cambrian community characterized by cnidarians, kinorhynchs, sponges, algae and nektobenthic arthropods. Here we describe the first known radiodont from the Qingjiang Biota, based on articulated specimens. It has a body bearing wide lateral flaps and dorsal setal blades, and a head consisting of stalked eyes, a tetraradial oral cone, and a pair of frontal appendages bearing five elongated endites. Details of the digestive track, the nervous system and the circulatory system are visible. Phylogenetic analyses identify the Qingjiang radiodont as a hurdiid. It has a unique head organization, with a single dorsal carapace covering three prominent head segments, and is also distinct in having both glands and ceca in the mid gut, and a body termination consisting of a central spine flanked by two rounded tail flukes. Hurdiids are rare in Cambrian Series 2, known only from isolated carapaces and frontal appendages. The Qingjiang radiodont thus greatly expands our knowledge of early hurdiid evolution and allows for comparison of its detailed anatomy with other contemporaneous radiodonts in China, and with the abundant and diverse hurdiids that are globally distributed in younger strata.

Documenting diagenetic alteration of an aragonitic Miocene giant clam (*Tridacna* sp.) with implications for strontium isotope stratigraphy (SIS)

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Strontium isotope stratigraphy (SIS) uses the Sr isotope ratios preserved in marine sediments to date their age with a numeric algorithm. The 87Sr/86Sr ratio of sea water throughout geological time is well documented and has changed due to the input of varying proportions of Sr derived from isotopically different continental *vs.* upper mantle sources. This study examines a Miocene *Tridacna* sp. from East Borneo, which – despite being aragonitic and visually well-preserved – shows noticeable diagenetic alterations as infilled cracks and an outer calcitic rim. Magneto- and biostratigraphy, as well as spatially resolved LA-ICPMS Sr isotope analysis, place the age of this sample at ~15 Ma, however a bulk powder TIMS SIS analysis of the aragonitic sample indicates an age of ~17 Ma. We investigated the source of this striking age difference via a combination of SEM imaging and elemental analysis by LA-ICPMS and EPMA. The Sr concentration in the diagenetically produced infilling was as high as 45 wt.%, compared to only ~0.2 wt.% Sr in the pristine aragonite. This pilot study highlights that great care needs to be taken when sampling *Tridacna*, as alteration can lead to contrasting Sr-isotope signatures and, hence, to SIS age offsets even for seemingly well-preserved aragonitic fossil material.

A brief history of the "Age of Barnacles"

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Charles Darwin once quipped that we live in the "Age of Barnacles", on account of the global abundance of shallow marine acorn barnacles. Darwin used the cirripedes as a model organism with which to study evolution but was limited by the paucity of fossil material available at the time. A renaissance in the study of barnacles has resulted from the integration of molecular phylogeny and study of abundant new fossil material. This permits reconstruction of a time-calibrated phylogeny through the Mesozoic and Cenozoic and provides evidence of the precise origin of all extant groups. The main features of this history include a transition from phosphatic to calcite shells in the Early Jurassic, diversification and global abundance in the Late Jurassic, and the progressive appearance of modern groups through the mid- and late Cretaceous. Sessile barnacles evolved in the Cretaceous and the balanomorphs (acorn barnacles) radiated dramatically through the Cenozoic. Evolution of barnacles was characterized by extensive homoplasy, most importantly repeated paedomorphic reduction in plate numbers, clearly demonstrated by molecular phylogeny. Fossils also provide evidence for the recurrent evolution of a sexual strategy involving dwarf males living inside large female individuals.

Variscan deformation: the driving force in bone alteration of the Jarrow tetrapods

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The Jarrow Assemblage is a Pennsylvanian Lagerstätte containing a diverse fauna of tetrapods preserved in the bituminous shales of the Leinster Coalfield, Ireland. A unique feature of Jarrow is the way in which bone material has undergone alteration and coalification, making specimens difficult to distinguish from the surrounding matrix. Bone alteration has traditionally been linked to early diagenesis. Here a combination of X-ray scanning electron microscopy, cathodoluminescence, micro-computed tomography and laser ablation quadrupole inductively coupled plasma mass spectrometry are applied to study the nature of bone alteration seen at Jarrow. Original bone morphology is no longer present, being replaced by bituminous material and sphalerite surrounded by tabular apatite. CT-data show alteration varies between specimens and even within specimens. In recrystallized apatite, U-Pb dating, zonation in halogen elements, variably positive and negative Eu-anomalies and depletion in LREE suggest an influence of hydrothermal fluids sourced during the maturation of the Leinster Coalfield. Alteration of bone is here considered to primarily be a result of Variscan deformation with apatite being dissolved and then recrystallized as tabular crystals in a void followed by the mineralization of sphalerite and bituminous material within the bone, giving the Jarrow assemblage fossils their unique appearance.

Cabinet of curiosity: a fungal community in Late Devonian *Callixylon newberryi* wood from the University College Dublin historical slide collection

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Studies of fungi and fungal activities in fossil wood are relatively rare, although silicified wood is one of the most common plant fossils. Signs of fungal degradation are frequently encountered in fossil wood, and many fungus-affected woods contain also evidence of the causative agent in the form of hyphae, spores, *etc*. Documented evidence of late Devonian wood-fungus interactions is exceedingly sparse and limited to a few reports in *Callixylon* spp., a Devonian wood attributed to archaeopteridalean progymnosperms. This contribution provides new information and examples of fungi in *Callixylon newberryi* from the New Albany Shale, southern Indiana, USA, based on thin sections from a historical set of slides on loan from the University College Dublin, Ireland. It is unclear whether all thin sections were prepared from the same wood specimen, but there are abundant fungal remains in all slides. Based on the abundance of fungal remains in the *C. newberryi* samples, several distinct distribution patterns and interaction types can be reconstructed. This study provides a new data set for considerations on the coevolution between early woody plants and fungi that can be used in molecular clock calibrations and as proxies for (palaeo)ecosystem cycling and functioning.

talks

Insect decline in the last 100 million years investigated with quantitative morphology: the example of lacewing larvae

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Loss of biodiversity and especially insect decline is a widely recognized phenomenon in modern ecosystems. This decline has an enormous impact, as insects occupy crucial positions in the food web, but are also of economic importance due to the role of insects as pollinators, to mention just one example. When investigating changes in biodiversity, a view into the past can provide important insights. One group of insects, for which a significant decline over the last 100 million years has often been postulated, is Neuroptera, the group of lacewings. Many adult lacewings are pollinators, while the larvae are mostly predators, which becomes very obvious from their prominent stylet-like mouthparts. During recent years, the fossil record of neuropteran larvae increased significantly, providing a sound basis for biodiversity studies through time. We investigated the fossil record of larvae of all neuropteran lineages as well as a large share of extant neuropteran larvae. Based on these, we performed outline analyses of the entire body, of the head with stylets, or the stylets alone. These morphological analyses provide for the first time a quantitative frame for recognizing the decline of lacewings since the Cretaceous, indicating also a severe loss of ecological roles.

Stratigraphic completeness in phyletic evolution: insights from astronomically paced carbonate platform successions

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Fossil evidence reveals how ancient life changed over time and in space. Therefore, palaeontologists reconstruct long-term processes at temporal and geographic scales that are inaccessible to experimental biologists. However, gaps in the stratigraphic record are hard to detect and complicate an accurate estimate of the pacing of evolutionary processes (*e.g.* stasis, drift, selection). The resolution and precision of absolute and relative geological dating methods is usually too coarse for high-resolution rates approaching those acting at microevolutionary scales. To alleviate this problem, we detect astronomical rhythms driving sediment production and deposition and use them to constrain the timing and distribution of gaps at the submillennial time scale. We use models of carbonate deposition informed by orbitally driven insolation curves to constrain the completeness of carbonate platform strata. Thereby, we quantify to what extent stratigraphic gaps affect the preservation of phyletic evolution. We determine the environments and sedimentary conditions under which the mode of evolution can be identified correctly. Analogously, we assess which environmental conditions are conducive to systematic distortions. Our observations offer the possibility to resolve evolutionary rates in fossil successions and overcome the limitations of the incompleteness of the stratigraphic record.

talks

Anatomy and phylogeny of a close relative of the chondrichthyan *Cladoselache* from the Devonian of Morocco

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Like other vertebrate groups, chondrichthyans diversified during the Devonian. Although mostly known from their teeth, some conservation deposits like the northern American Cleveland Shale or the northern African Thylacocephalan Layer yield complete skeletons of early chondrichthyans. Based on several nearly complete skeletons and some 3D crania, we describe a new taxon, which is uniquely similar to the slightly younger *Cladoselache* from Ohio. The new taxon differs from other early chondrichthyans in the broad nasal capsules, the shape of the telencephalon, the scapulocoracoid and the anterior fin spine. It is one of the few early chondrichthyans preserving the complete neurocranium including the nasal capsules. Based on the rich materials, we reconstruct the animal and analysed its phylogenetic position. According to maximum parsimony and Bayesian inference analyses, the new taxon is either sister to *Cladoselache*, to all symmoriids or all holocephalans with symmoriids.

Revising taxonomy using a collaborative tool (Xper3) with an example from Early Triassic conodonts

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Taxonomy and systematics are the very first steps that allow naming and classifying objects to study them afterwards. For extant and extinct taxa, these are determinant for further investigation because they allow defining units of study. However, as new specimens are regularly discovered, classifications are modified through time by creating new or merging pre-existing taxa (splitting *vs*. lumping) that are described in different publications. Then, it is a dynamic scientific field that must be kept properly updated to get a broad overview of the classification of any taxonomic group. We propose to use Xper3, a free, online and collaborative tool that creates databases of descriptive knowledge. First, diagnostic characters and taxa are listed separately. Second, listed taxa are described using the listed characters. Then, Xper3 creates a determination key and suggests synonyms among taxa that are too similar. The main benefits of Xper3 are gathering taxonomic information from different sources and suggesting an objective opinion of lumping or splitting taxa. It can be applied to any biological model for which diagnostic characters can be listed. We will present the first results of a revision of Early Triassic conodonts using taxonomic information from published articles.

Untangling the web of arachnid systematics: using confocal microscopy to image Devonian trigonotarbids

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Trigonotarbids are an extinct order of armoured arachnids, with fossils ranging from the late Silurian to early Permian. Comprising some seventy species, trigonotarbids are characterized by the partitioning of their opisthosomal tergites into discrete median and lateral plates. As prominent predators, these extinct spider-like arachnids played a critical role in the earliest terrestrial food webs. However, the phylogenetic position of trigonotarbids relative to extant arachnids remains disputed. In this study, we use confocal laser scanning microscopy (CLSM) to image some of the earliest known land-dwelling arachnids in 3D. A re-examination of the mouthpart morphology of the Lower Devonian (~408 Ma) trigonotarbid, *Palaeocharinus*, from the Rhynie Chert of Scotland, yields an unprecedented level of morphological detail crucial to untangling arachnid systematics. By comparing the Rhynie trigonotarbids to new CT scans of their closest extant relatives, we aim to adjudicate between the two competing hypotheses for the sister group of trigonotarbids, the ricinuleids (hooded tick-spiders) or tetrapulmonates (spiders, whip scorpions and whip spiders). The Rhynie Chert trigonotarbids demonstrate the power of confocal laser scanning microscopy in the elucidation of fossils and their phylogenetic placement.

Description of *Helmetia expansa* and phylogenetic analyses of concilitergans

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Concilitergans are a group of non-biomineralized trilobite-like euarthropods distinguished by a well-developed anterior sclerite and tergites that only overlap along the axis. *Helmetia expansa* was originally named by Charles Walcott in 1918, but it has not been formally described despite being included in multiple phylogenetic analyses and the discovery of other similar trilobitormophs. Here we present the first formal description of *H. expansa* and a phylogenetic analysis of the group with new characters focused on resolving their relationships in order to better understand concilitergan evolution in the context of other trilobitomorphs. *Helmetia expansa* is a large (sag. 154.6 mm average) leaf shaped euarthropod from the Wuliuan Burgess Shale known from over 30 specimens housed at the Royal Ontario Museum and Smithsonian Institution. In addition to the dorsal exoskeleton consisting of the cephalon with an anterior sclerite, thorax with six-freely articulating tergites, and large pygidium, undescribed specimens also show previously unknown features, including ventral sternites, short antennae, biramous appendages and serially repeated gut glands. The biramous appendages are homonomous, completely covered by the dorsal exoskeleton, and show similarities to those known from artiopods.

The Las Hoyas (Serranía de Cuenca, Spain) fossil biases reveal a constantly changing ecosystem during the Barremian

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The study of the over 30,000 fossils recovered from Las Hoyas locality has allowed the description of different fossil associations related to a changing environment that underwent climatically driven cyclical oscillations in water level, within the framework of a seasonal, subtropical, inland wetland. Apart from variations in drier versus wetter season associations, partly due to the differential growth of microbial mats, the fossil assemblage shows other interesting biases. For example, there is a divergent taphonomic selection between body fossils and ichnofossils, whose records are not coupled. Vertebrate and invertebrate traces are not commonly associated with body fossils, but coprolites are. Additionally, isotopic analyses of coprolites indicate that most were produced by omnivorous organisms, whereas vertebrate bioturbation are biased towards omnivorous-carnivorous animals, and invertebrate traces correspond to sedimentivorous-detritivourous organisms. From a stratigraphic point of view, the presence of seismites indicates a constant extensive tectonic activity during the sedimentation of the basin, which could have caused disruptions in the interface zone between the soft sediment and the water sheet, generating disturbances in the palustrine ecosystem, affecting water chemistry and the living conditions of organisms. Altogether, these biases integrate substantive information on the biodiversity and ecosystem dynamics to model an upper Barremian wetland.

How to build a Lagerstätte: new taphonomic and sedimentological insights into the preservation of exceptional Ediacaran fossils at Spaniard's Bay, Newfoundland

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Southeastern Newfoundland, Canada, is home to the oldest Ediacaran fossils in the world and is dominated by the Rangeomorpha. A fossiliferous surface in Spaniard's Bay exhibits unique three-dimensional preservation of Ediacaran fronds, without the associated volcanic deposits or microbial-mat preservation seen elsewhere in the Avalonian assemblage. Previous taphonomic models have tried to explain this preservation by invoking unique conditions resulting from the interaction of erect organisms and turbidites. However, many structures previously identified as stems are actually longitudinal sedimentary ridges, contradicting an important factor of the current model. Additional observations show a level of ecological tiering not previously documented from the site, alongside evidence for the burial and exhumation of many of the organisms prior to preservation. The cross-cutting of rangeomorph fronds by holdfasts suggests the preservation of two communities, one of entombed erect/reclined organisms and a later community of erect organisms, the generation of erosive scours around the latter exhuming the former. Our new model explains the processes leading to the preservation of this complex community,

incorporating previous and recent observations to explain the fossils present. We also note the preservation of both sides of many rangeomorphs, which will improve our understanding of morphological variation within this poorly understood group.

An exceptional Jurassic fern with biotic interactions from southern Sweden

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A remarkably well-permineralized fern rhizome preserved in a Lower Jurassic lahar deposit of the central Skåne volcanic province, Sweden, reveals preservation of anatomical features down to the level of organelles and chromosomes. The anatomical details enable not only precise systematic placement of the fossil (to *Osmundastrum pulchellum*), but reveal the likely absence of polyploidy in this lineage for over 180 million years. Integrating molecular divergence with age calibrations provided by fossils and through geological time provides a revised timeline for Osmundales evolution including an apparent radiation of Osmundaceae after the end-Permian extinction event. In addition, a range of exotic fossils entombed within the root mantle of the permineralized fern rhizome indicate biotic interactions between the fern and oribatid mites, epiphytic lycopsids and fungi.

Palaeobiology's next top model: combining evidence from morphology and stratigraphy

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For most groups of extinct animals establishing evolutionary relationships relies on a small number of morphological characters, limited to 30 characters or less for many datasets. Recent developments in phylogenetic modelling – in particular, the introduction of the fossilized birth-death process – allow us to leverage evidence from both morphology and the stratigraphic record simultaneously within a statistically coherent framework. This presents renewed opportunities to examine the role of time in phylogeny. Using Cambrian echinoderms as a case study, we assess the impact of temporal evidence and models of character evolution in testing hypotheses about the origins of the animal body plan.

A novel interpretation of the Ediacaran rangeomorph *Culmofrons plumosa* as a reclining organism

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Memorial University of Newfoundland, Canada

The Ediacaran of Newfoundland, Canada, reveals the oldest fossil evidence for complex ecosystems hosting macroscopical multicellular life. Among them, the Rangeomorpha represents the most diverse and most represented clade. The group morphology is characterized by a 'frond' of more or less regularly bifurcating branches, often associated with a 'stem' and 'holdfast'. Despite their abundance, little is known about the palaeoecology of the rangeomorphs and their phylogenetic relationship with other eucaryotic taxa. *Culmofrons plumosa* is known from several Newfoundlandic localities, including the

Konservat-Lagerstätte MUN surface. Due to its typical stemmed frondose appearance, *C. plumosa* has been traditionally interpreted as being erected in the water column. In this work, we offer a re-interpretation and statistical analysis of the morphological appearance of *C. plumosa* and we suggest new growth and lifestyle models. Based on its morphological similarity with other rangeomorphs (cf. *Fractofusus*, *Beothukis*, *Bradgatia*), we suggest that in life *C. plumosa* was reclining on the seafloor, possibly trophically relying on a symbiotic relationship with sulfur-oxidizing bacteria. The description of reproductive propagules and a novel growth model based on branching structures are consistent with an epibenthic habitus. The reclining lifestyle is further supported by taphonomic evidence for microbial smothering of parts of the organisms during life.

Frontal appendages from the Fezouata Biota (Morocco) reveal high diversity and ecological adaptations in radiodonts during the Early Ordovician

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The Fezouata Shale Formation (Early Ordovician, Tremadocian) of Morocco yields exceptionally-preserved remains of marine organisms that highlight the transition between the Cambrian Explosion and the Great Ordovician Biodiversification Event (GOBE). This Lagerstätte is rich in arthropods, especially in remains of radiodonts (informally known as anomalocaridids). Frontal appendages are the anatomical part of the radiodont body with the highest preservation potential, and these appendages provide both taxonomic identification and palaeoecological information on feeding behaviour. Study of 104 specimens in the collections of the Musée Cantonal de Géologie de Lausanne and the Yale Peabody Museum identifies three new species (including one new genus) and allows for the revision of the genus Aegirocassis and the family Hurdiidae. *Pseudoangustidontus* is also confirmed to be a hurdiid radiodont. This assemblage highlights a high species diversity in the radiodont community with different feeding strategies. The most represented feeding strategy is suspension feeding with 95 specimens, whereas there are only nine sediment sifters. This may be linked to the 'Ordovician Plankton Revolution', which saw a huge radiation in plankton diversity during the GOBE. The study also points to the decline of active raptorial predation in radiodonts, as suggested by their absence in the Fezouata Shale Formation.

talks

Anatomy and phylogeny of the first macraucheniid (Mammalia: Litopterna) from the Neogene Bahía Inglesa Formation (late Miocene), Atacama Region, Northern Chile

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During much of the Cenozoic, South America was isolated from the other continents, which promoted the independent evolution of South American ungulates (SANUs). Among SANUs, litopterns were the second most diverse order, ranging from the middle Palaeocene to late Pleistocene. Macraucheniidae is a family of medium- to large-sized litopterns,

with long necks, three-toed feet and a reduced nasal region, and ranged from the late Eocene to the late Pleistocene. Macraucheniidae is usually grouped into two subfamilies: Cramaucheniinae (Eocene to middle Miocene) and Macraucheniinae (late Miocene to late Pleistocene). Here we describe SGO.PV.21700, a macraucheniid discovered in the coast of the Atacama Desert, northern Chile, that represents the first macraucheniid (and SANU) from the Mina Fosforita Member of the marine Bahía Inglesa Formation (middle Miocene to Pliocene). The postcranial anatomy of SGO.PV.21700 is consistent with terrestrial and cursorial locomotion, which suggests an allochthonous preservation of the specimen. Parsimony and Bayesian phylogenetic analyses show that SGO.PV.21700 is a member of subfamily Macraucheniinae. We estimated the body mass of SGO.PV.21700 to be ~ 100 kg, which make it the smallest member of its subfamily. This finding increases the anatomical and taxonomic diversity of Macraucheniidae during the late Miocene

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Why the eyes of phacopid trilobites look the way they do

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As true arthropods, trilobites possess compound eyes. These eyes show a trade-off between size (sensitivity) and number (acuity) of facets. Many trilobites are endowed with densely packed facets, as are modern diurnal arthropods. Normally these units (ommatidia) consist of a lens, focusing the light through a transparent cellular area onto a central light-guiding structure, which is part of the underlying sensory cells, arranged in a rosette. Because all signals inside the field of view of any facet are summed up on this light guide, the total image seen is mosaic-like, each facet contributing one pixel. This system is typical for modern diurnal insects and crustaceans, but in principle already present in lower Cambrian trilobites with so-called holochroal eyes. Phacopid eyes are most different: here the lenses are relatively large, and far apart (schizochroal), obviously wasting space for collecting light. The reason lies in their structure. Several ommatidia lie combined under each of the large lenses and build a hyper-compound eye. Neighbouring facets probably coalesced to form one system each, leaving behind blind interspaces in between. The advantage is still not clear, but a higher sensitivity by pooling-processes and sophisticated cooperation of these subsystems are possible.

Current issues with conodont tissues: using multi-analytical methods to unravel the conodont conundrum

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Conodonts are a highly diverse group of chordates that thrived in prehistoric oceans from the late Cambrian to Late Triassic and are widely known from their isolated skeletal remains. The ecology of this animal has puzzled scientists for years, as the majority of studies are based upon information solely obtained from these teeth known as elements. This is further complicated due to the rarity of soft body remains that are often applied as the only analogue for all conodont taxa. These elements grew by lateral accretion of enamel-like hydroxyapatite throughout the animal's life, which provides a somewhat continuous record of growth, potentially storing information about the life of the animal itself within these tissues. Here we attempt to answer the question "How much information about an animal's mode of life can one obtain from an isolated tooth?". With a combination of scanning electron microscope techniques, we can analyse the chemistry, crystallography and growth, unlocking this invaluable information. These methods, when used in combination, have been used to quantify an animal's ontogeny, growth rates, ecology, function, and even the level of control on biomineralization that drove the evolution of the first teeth.

Terrestrial vertebrates from Triassic caves of south-west Britain: older than we thought

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Triassic cave fills in Carboniferous limestone outcrops across southwest Britain have yielded rich and diverse terrestrial vertebrate faunas, including dinosaurs. Dating has proven problematic since none of these taxa have been found in normal bedded successions, but palynomorphs and marine microvertebrates suggest a Rhaetian (latest Triassic) age for some sediment at a few sites. A now widely-held view maintains that these caves, and their contents, are all Rhaetian in age, formed through mixing corrosion at a marine-freshwater interface, but this model is untenable on geomorphological and palaeotopographic grounds. The mutual exclusion of terrestrial vertebrate taxa from the cave fills and from the well-studied Rhaetic bone beds of the region also casts considerable doubt on their supposed contemporaneity. New radiometric dates from stalagmites in two Triassic caves, in Gloucestershire and south Wales, prove that they formed more than 30 Ma before the Rhaetian, probably during the humid Carnian Pluvial Episode. Many elements of these terrestrial faunas have been interpreted as evolutionary relics that were isolated on Rhaetian islands. The reality is that they are actually much older and, for some (dinosaurs and lepidosaurs), are among the very earliest representatives of their clades anywhere in the world.

Gondwanan araucariaceous genus related to *Wollemia* was restricted to the southern high latitudes

***Miriam A. Slodownik and Robert S. Hill**

University of Adelaide, Australia

The fossil assemblage of the Macquarie Harbour Formation in Tasmania, Australia, represents a near-polar forest during the early Eocene climatic optimum (~53-50 Ma) just before the final breakup of Gondwana. The new specimens of the extinct *Araucarioides linearis* (Araucariaceae) presented here include near-complete leaves, female cone scales, a seed and abundant associated araucariaceous pollen (*Dilwynites tuberculatus*). Thus we present the first reproductive organs of *Araucarioides*. The new characters reveal the close relationship to the extant, monotypic *Wollemia*. *Araucarioides*' generic diagnosis is emended, adding important characters to differentiate the genus from *Wollemia*. Furthermore, the phylogenetic placement is assessed through parsimony analyses. The palaeogeographical distribution of *Araucarioides* is restricted to the polar and subpolar regions in southern New Zealand in the Late Cretaceous and southeast Australia in the early Eocene. Adaptations to seasonal environments likely facilitated the survival of *Ar. linearis* through the end-Cretaceous impact winter and photosynthetic crisis while the

talks

continuing northwards movement of the continental plates of Australia and New Zealand likely caused its extinction.

A 300-million-year record of ecosystem change – what conodonts can tell us

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As abundant and diverse macrophagous vertebrate predators with varied diets, conodonts were critical components of Palaeozoic and Triassic marine ecosystems. Couple this with their excellent fossil record and global distribution, and conodonts provide unparalleled opportunities for analysis of ecosystem function over 300 million years of Earth history. Until recently conodonts could not fulfil this potential because we lacked knowledge of their ecological roles, but our recent work demonstrates that dental topographic metrics allow them to be categorized into dietary guilds. Applying this approach reveals that the full diversity of functional ecologies and inferred diets evolved early in the Ordovician. The early Palaeozoic was dominated by conodonts adapted to consume soft prey, but these were displaced by taxa capable of processing tougher and harder foods. Conodonts with sharp blade-like teeth proliferated through the Triassic, indicating specialization on soft prey. Negligible changes in the relative importance of different guilds across mass extinction events indicates swift recovery of dietary diversity and ecosystem function. Analysis of the end-Devonian Hangenberg event reveals these changes at an unprecedented temporal resolution. These studies demonstrate the power of the conodont fossil record as a palaeobiological dataset for analysis of functional ecology and ecosystem function throughout the Phanerozoic.

Study of decay in the branchiopod crustacean *Triops* in sediment using micro computed tomography

***Madeleine Waskom, Sarah R. Losso and Javier Ortega-Hernández**

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Exceptional preservation of animal body fossils requires a balance of microbial decay and rapid abiotic mineralization, but many questions about the conditions and timeline of fossil formation remain unanswered. Experimental decay studies typically do not recreate natural environments where fossilization takes place. Furthermore, most taphonomic experiments exploring exceptional preservation in laboratory settings are destructive and do not allow tracking the processes of decay and mineralization continuously, which is critical given that sediment may influence pathway and rate of microbial decay. We followed the decay of *Triops* in organic-poor sediment inoculated with sulfate reducing bacteria. We used micro computed tomography as a non-invasive and non-destructive method to investigate the timeline of decay and fossil formation in three dimensions. Vials were scanned over four months, allowing us to track mineral precipitation and density loss caused by specimen decay. Macroscopic concretions of quartz, hematite, albite and gypsum started precipitating within a four weeks. We demonstrate that although *Triops* carcasses completely disarticulate within eight weeks when solely immersed in water, they maintain their overall integrity when buried in sediment, and that even delicate structures (*e.g.* appendages, caudal furcae) can be resolved past 21 weeks of decay.

talks

Abstracts of poster presentations

* indicates a poster eligible for the Council Poster Prize.
Underlined author denotes designated presenter.

On the shoulders of mammals: the potential of the scapula in understanding the locomotor behaviour of extinct mammals

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The mammalian scapula has the potential to provide great insights into posture and locomotion due to its roles in weight-bearing and forelimb excursion. Owing to its relative fragility compared to long bones, the scapula is under-utilized as a tool in reconstructing the locomotory habits of extinct mammals. To address this knowledge gap, we have undertaken the first extant mammal-wide study of scapular functional morphology using 3D geometric morphometrics. We have designed configuration of 72 landmarks (including both true and semilandmarks) to capture the overall shape and anatomical features of the scapula. This configuration, which is repeatable across morphologically diverse mammalian taxa, has been used in a preliminary order-level study containing one specimen from each currently recognized extant mammalian order (28 specimens). The results show a wide diversity in mammalian scapula shape and reveal links between scapular morphology and locomotor behaviour that have never before been demonstrated across the entire class, notably in the isolated spine and glenoid regions. Following the success of this preliminary work, we intend to continue this study at higher resolution (including one specimen from every mammalian family and subfamily) in order to clarify the form–function relationship in this skeletal element.

Seeing red: discerning the Siluro–Devonian boundary and a Přídolí (Late Silurian) spore assemblage biozone for the Lower ‘Old Red Sandstone’ of the Anglo-Welsh Basin, UK

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The near continuous fluvial succession of the Siluro–Devonian Lower ‘Old Red Sandstone’ of the Anglo-Welsh Basin, UK, yields, *inter alia*, abundant vertebrate and plant remains alongside diverse and well-preserved dispersed spores. Previous workers succeeded in erecting regional and global biostratigraphic zones using these fossils, especially in the Early Devonian where the globally important *Emphanisporites micrornatus – Streelispora newportensis* (MN) spore assemblage biozone and subzones have been utilized since the 1980s. The latest Silurian and earliest Devonian ‘pre – MN’ zones (Pridoli – earliest Lochkovian) have, however, remained problematic given the paucity of suitable sampling horizons. We have carried out an investigation of the palynological record from this time slice, revealing a diverse and well-preserved assemblage of dispersed cryptospores and miospores, comprising some 200 species in 43 genera, from several sites across the Welsh

posters

borderlands and south Wales. These sites shed new light on the problematic earliest Devonian and Pridoli pre-MN *Apiculiretusispora* sp. E and *Aneurospora* spp. spore biozones and go some way towards constraining the Siluro–Devonian boundary of the region. However, problems persist with suitable sampling horizons in some areas, neatly encapsulated in one borehole by some 700 m of red, unsamplable mudstones, leaving a considerable portion of the Pridoli unexamined.

The affinity of embryo-like fossils: new evidence from Mongolia

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The timing of the origin of animals remains unresolved, largely due to inconsistencies between the fossil record and molecular clocks. Animal embryo-like fossils pre-date the appearance of animal body fossils and have the potential to provide the first evidence for metazoans but their taxonomic affinity is unclear. The embryo-like fossils of the Ediacaran Weng'an biota have been the subject of greatest scrutiny, showing differences in preservation to unequivocal animal embryos from the Cambrian Kuanchuanpu biota. Do these differences occur due to biology or taphonomy? To begin to answer this question, we have characterized animal embryo-like fossils from the Ediacaran–Cambrian boundary of Mongolia using synchrotron X-ray tomographic microscopy (SRXTM). Initial results from the Mongolian assemblage reveal a broad range of preservation states, from decayed and collapsed outer membranes, through to cellular – but not subcellular – level preservation. This is comparable to the lower end of the preservation spectrum in both the Weng'an and Kuanchuanpu biotas, suggesting a common suite of preservation states. This similarity, however, may reflect shared primitive characteristics of multicellular eukaryotes rather than providing evidence of a common animal affinity.

Ontogenetic bias in the preservation potential of the marine shrimp *Palaemon varians*: a long-term experimental study from embryo to adult stages

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The arthropod lifecycle in the fossil record is highly biased towards the later ontogenetic stages of their development, with larvae and other early post-embryonic stages being rarely preserved. Amongst the Burgess Shale-type (BST) Lagerstätten, only the Haiyan locality in China and the Fezouata Shale in Morocco yield abundant early developmental arthropod stages. Similarly, the Orsten biota yields almost exclusively larval and juvenile euarthropods, without preserving the later developmental stages. Such ontogenetic data offer invaluable information about the evolution of the development of metazoan clades, but the taphonomic biases controlling preservation of juvenile forms remain poorly understood. Here we conducted long-term taphonomic experiments to investigate the preservation potential of the common marine shrimp *Palaemon varians* at six stages of its development, from eggs in an ovigerous female, through larval stages up to the juvenile, and adult. Individual developmental stages showed differential preservation in line with other studies, with morphologically-informative characters being lost through decomposition. Disarticulation patterns appear markedly distinct especially between larvae and adult specimens. These experimental results provide important information on the relationship between ontogeny and taphonomy, allowing us to begin outlining the taphonomic conditions that are necessary for the preservation of early developmental stages.

The eyes and vision of ichthyosaurs

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Ichthyosaurs were dolphin-like marine reptiles that inhabited the world's oceans for most of the Mesozoic. Famously, ichthyosaurs had incredibly large eyes, even rivalling those of the giant squid in size – considered to be the largest in the animal kingdom. However, the function of these large eyes has remained unclear, with suggestions they either increase low-light sensitivity at depth or improve acuity. We use CT scans of two three-dimensionally preserved sclerotic rings from the early Toarcian (Lower Jurassic) Strawberry Bank Lagerstätte, referred to *Hauffiopteryx typicus*, to create the first complete model of an ichthyosaur eyeball. We demonstrate that *H. typicus*, and likely other ichthyosaurs, had asymmetrical eyeballs with flattened outer corneal portions. With this, we calculate minimum f-number estimates – a measure of the light-gathering capabilities of an optical system – for *H. typicus* and 20 other ichthyosaur species. We find that f-numbers were more variable in the Triassic (0.93–4.43 at 55 % aperture diameter), then decreased in the Jurassic (0.99–2.51 at 55 % aperture diameter). This follows a pattern of decreasing morphological disparity and ecological focus across the boundary as a result of open water specialization, supporting both the sensitivity and acuity hypotheses.

Using elephant bird brains as insights into their diversity and ecology

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Elephant birds (Aepyornithidae) were amongst Madagascar's largest Quaternary vertebrates and played important roles in the regulation, structure and function of its diverse ecosystems. Studying the biology and behaviour of these species is of interest to conservation scientists seeking to understand the consequences of their recent extinction for the current health of Madagascar's biomes. In this study, we use computed tomography data to create endocasts of 12 aepyornithid specimens in order to determine neuroanatomical variations between different morphotypes and to better understand their sensory abilities and provide clues to the ecology of Quaternary life. We achieve this by comparing the relative sizes of the Wulst and olfactory bulbs via surface area and volume measurements of specific regions related to eyesight and olfaction. Using the measurements from our endocasts, we can further resolve their taxonomic diversity through variation in neuroanatomy and better understand how these giant extinct island animals interacted with their environment.

Spatial discrepancies in the palaeorotation of fossil data impacts the reconstruction of deep-time macroecological patterns

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The Earth is a dynamic system constantly evolving. Plate rotation models aim to reconstruct the evolution of tectonic plates over geological timescales, including their origin, demise and relative position on the Earth's surface. These models are vital for palaeobiologists to reconstruct the geographic position of life remains at the time of deposition. However, numerous plate rotation models exist, and may differ in their construction and approaches. Spatial discrepancies between models, and their impact on reconstructing past macroecological patterns, has so far not been quantified. Here we used an equal-area grid and two case studies of climatically-sensitive organisms (corals and crocodiles) to measure differences between four widely-used plate rotation models. Our results indicate that discrepancies between models increase with time, and that areas of uncertainty are largely spatially clustered in complex tectonic zones. In addition, we highlight that depending on model choice, the latitudinal limits of a taxa could vary by more than 10º, having significance for reconstructing macroecological patterns, as well as palaeoclimatic conditions based on proxy data. Our findings suggest that incorporating palaeogeographic uncertainty is vital to better constrain our understanding of life and climate in deep time.

Testing the casing model: the evolutionary implications of melanosome chemistry and formation

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The two types of melanin found in vertebrates – eumelanin and phaeomelanin – occur in organelles termed melanosomes. Previous research has characterized the chemistry of melanin and the abundance of melanin types in different tissues in fossil and modern vertebrates. The spatial distribution of melanins in individual melanosomes, however, remains largely unknown. The casing model predicts that melanosome internal structure comprises a phaeomelanin core surrounded by a eumelanin shell, but there is limited evidence for the presence of both types of melanin within a single melanosome, and for whether the core or shell forms first. Resolving this issue will inform on the biosynthesis of melanin and will enhance our understanding of melanin evolution. To approach this issue, we studied melanosomes from European sea bass (*Dicentrarchus labrax*) retinal pigmented epithelium using synchrotron-X-Ray fluorescence nanoprobe analysis. We mapped melanosomes at nanoscale resolution to study the distribution of the melanin-chelated metals Zn, Ca and Cu in these organelles. Our results show a Zn- and Ca-rich core and variable distribution of Cu in the melanosomes, with some melanosomes showing enrichment in all three metals. These results support the coexistence of both types of melanin within an individual melanosome, but clear evidence for a eumelanin-rich shell was not detected.

CT scanning as a non-invasive visualisation technique for sediment-based decay experiments

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Decay experiments provide insights that can aid with the interpretation of soft bodied fossils and allow for investigation of variables that may impact patterns of decay. Many experiments seek to utilize sediment in their design, however, collecting data is usually difficult due to the exhumation process, and any disturbance of the carcasses may potentially lead to data loss. Here we present a novel application of computed tomography (CT) scanning during a decay experiment performed on zebrafish buried in sediment, as a proof of concept to test the effectiveness of non-invasive visualization techniques as a sampling methodology for taphonomic investigations. To determine whether exposure to X-rays would impact decay rates, we CT scanned decaying carcasses buried in sand at the initiation of the experiment and once again after 50 days. We compared the acquired 3D models with those of zebrafish that were only CT scanned after 50 days and with control specimens (via traditional dissection). Our preliminary results show that exposure to X-rays from CT scanning has little to no impact on decay rate or sequence of character loss. Our preliminary results confirm the effectiveness of this approach, and future work will focus on refining our methodology.

Taphonomy of a unique assemblage of putative early chordates from the Lower Devonian of Belgium

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The Lower Devonian of the southernmost part of Belgium, known as the Neufchâteau Synclinorium, recently yielded numerous enigmatic organisms during a field campaign in June 2021. The latter followed the rediscovery of one fossil formerly identified as a cephalochordate, during a visit of local museum collections in 2020. The fossils were collected in slates of Pragian age and are associated with various invertebrate taxa (cephalopods, echinoderms, arthropods). The putative early chordates are preserved as thin reflective films, likely carbonaceous, with only a medial elongate structure (a probable notochord) showing some relief. Most specimens are extensively pyritized with pyrite crystals obscuring details of the anatomy. Scanning electron microscopy and elemental spectroscopies suggest the presence of different sulphide minerals, including cubic pyrite and polydisperse grains of chalcopyrite, Ni-rich pyrite and sphalerite, the distribution of which follows, to some extent, particular anatomical features. Future analyses will focus on the chemical characterization of the films, but also of the depositional and burial environments in order to trace the taphonomic history of these mysterious early chordates and identify potential preservation biases that could affect their interpretation.

Characterization of internal and external melanin within fish

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Melanins are pigments that are present in almost all eumetazoans, synthesized in cell-bound organelles termed melanosomes. Occurring in integumentary and internal body tissues, they have putative functions in UV protection, crypsis, mechanical stiffening, thermoregulation, anti-predator defence, metal homeostasis and immunity. While our current understanding of the geometry, anatomical distribution and function of melanin derives largely from studies on higher vertebrates, characterization of melanin in lower vertebrates and their close relatives is considerably more limited. This has constrained our understanding of the origin of melanin and its functional evolution in the vertebrate clade. Of particular interest is the internal melanin of bony fish, with purported function in immunity and evidence of synthesis *in situ* in extracutaneous tissues. Here we resolved these issues by sampling ten tissues in twelve species of extant fish, comprising a wide phylogenetic spread of early-diverging vertebrates. By applying SEM, HPLC-AHPO and synchrotron-XRF analyses, we will identify the trends in melanosome chemistry, morphology and anatomical distribution of fish tissues. This new dataset will be tested against known trends in these melanosome characters in extant amphibians and reptiles, informing on the role of melanin across the transition to life on land.

Is *Pohlsepia mazonensis* a cirrate octopus? A reassessment of a controversial Carboniferous fossil

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Pohlsepia mazonensis Kluessendorf & Doyle, 2000 is a controversial coleoid cephalopod from the Late Carboniferous (Pennsylvanian) Mazon Creek Lagerstätte, Illinois, USA. Originally, it was described as a member of the Cirrata, a suborder within the Octopoda. Living members of this suborder are characterized by a pair of fins on their mantle, internal shell, large web between the arms, arm cirri, and lack of ink sac. *P. mazonensis* is known from a single specimen found within a siderite concretion and has a combination of (contentious) derived crown-group morphological characters including a round body (with no clear demarcation between mantle and body), two fins, a small number of poorly defined arms, a possible radula/ink sac, and two eye spots. Reassessment of *P. mazonensis* is vital – recent molecular clock analyses and fossil evidence suggest that octopods originate during the Triassic/Jurassic; however, if *P. mazonensis* is an octopod, then this would indicate that this group originated during the Early Carboniferous. Here we present new interpretations based on preliminary data acquired from our investigation using scanning electron microscopy, X-ray microtomography and synchrotron X-ray fluorescence to re-examine this enigmatic fossil.

First *in situ* spatially resolved micro-X-ray fluorescence imaging analysis of fossils from Messel preserved in different media using a large area micro-XRF scanner

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The Messel Pit fossil site in Germany (48 Ma) is a UNESCO World Heritage Site renowned globally for yielding fossil vertebrates preserving soft tissues, including various melanosome-rich tissue types (*e.g.* integument and internal organs). These specimens are prepared via resin transfer or kept in the original sedimentary matrix that is usually immersed in water or glycerine. The impact of the various conservation methods on the chemistry of the melanosome-rich soft tissues was never investigated before. The study of the elemental chemistry in fossils preserved in liquid media is challenging since the specimens must remain submerged during analysis. Here we use a Bruker M6 Jetstream micro-X-ray fluorescence (XRF) spectrometer to investigate the trace element chemistry of taxonomically diverse fossil vertebrates from Messel (*n*=13), including specimens preserved in resin, water and glycerine. Our preliminary results reveal that tissue-specific trace element signals can be detected in all specimens, even those preserved in glycerine. For example, Ti is particularly abundant in feathers; Cr, Ni and Ti in the hair, and finally Cu, S, Ti, Zn are often found associated with the soft tissues in the abdomen. The M6 spectrometer was shown to be a promising tool for high-resolution imaging on specimens that otherwise cannot be analysed.

Using computational fluid dynamics to investigate aquatic specialization in ancient whales

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Significant change occurred in the aquatic locomotion of stem cetaceans (archaeocetes), evolving from early quadrupedal surface paddlers to the submerged oscillatory swimming style of modern cetacea. During this transition, the primary propulsive surface changed from the limbs to the tail, with external hindlimbs eventually lost completely. With very little fossil material definitively indicating the presence of a fluke (enlarged surfaces at the end of the tail) in archaoecetes, it is difficult to determine when this change occurred. Using computational fluid dynamics, we sought to use the more extensively preserved archaeocete hindlimb fossils to investigate significant changes in hydrodynamic performance across the land-water transition. We produced 3D reconstructions of the feet of a range of archaeocete species spanning the transition. These models were virtually sculpted around digitized fossils, using previously established regression equations to inform volumetric reconstruction. Water flow was simulated around each model, in order to approximate their effectiveness in providing propulsion during swimming. We estimated the coefficients for drag and lift produced by the feet at a range of angles of attack, imitating the angles observed in potentially analogous extant swimming mammals. Our results demonstrate significant changes in drag and lift coefficients over time related to increased aquatic specialization in archaeocetes.

Bioturbating ecosystem engineers and their sedimentary biogeochemical impact: a case study from the lower Cambrian Deep Spring Formation, California, USA

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Bioturbating macrofauna are key ecosystem engineers due to their influence on resource availability in marine ecosystems. Bioturbators rework sediments, thereby modifying substrate rheology, food availability and geochemical redox gradients, which in turn control ecosystem structure and function. Thus, the evolution of complex bioturbation behaviours around the Ediacaran–Cambrian boundary has long been implicated in the subsequent radiation of marine life during the Cambrian. However, different bioturbation behaviour and ecosystem engineering functional groups have been demonstrated to have varying impacts on benthic ecosystem functioning. Currently, the differential evolution and geochemical impact of these functional groups around the Ediacaran–Cambrian boundary is poorly understood. We document the occurrences of different ichnogenera and their respective bioturbation and ecosystem engineering functional groups from two localities in the lower Cambrian Deep Spring Formation, California, USA. We use micro-XRF to create maps of key elements across burrow structures to investigate the impact of each functional group on sedimentary biogeochemistry and redox gradients. We find an abundance of shallow-tier, biomixing deposit feeders, and fewer, more isolated semi-infaunal, bioirrigating suspension feeders – two functional groups that have differential impacts on sediment biogeochemistry. Ultimately, these results will help us constrain the role of bioturbators as ecosystem engineers during the Cambrian Explosion.

Terrestrial and marine ecospace dynamics across the end-Triassic mass extinction event

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Constructing trends in functional diversity dynamics across mass extinction boundaries is a key component of understanding how life responded to global environmental perturbations. Ecospace analyses that categorize marine animals into functional groups based on tiering, feeding and motility have proven useful in investigating how the ecological structure of marine ecosystems changed during mass extinction events. However, no analogous ecospace methodology has been developed for terrestrial ecosystems, thus limiting our ability to understand how global functional diversity has changed throughout Earth history. Here we present a novel tiering-feeding-motility ecospace cube for terrestrial ecosystems and its applications to the end-Triassic mass extinction. Utilizing the Paleobiology Database, we compare changes in terrestrial and marine ecospace dynamics. Each fossil genus was assigned to a tiering-feeding-motility functional group to construct terrestrial and marine functional ecology datasets from which we calculated functional

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diversity curves, extinction magnitudes, and stage-level ecological dissimilarity. We find that taxonomic and functional richness are more strongly coupled in the terrestrial than in the marine realm. Additionally, early Jurassic terrestrial ecosystems exhibit higher degrees of dissimilarity to each other than do the marine, suggesting a delayed development of terrestrial ecosystem stability in the wake of the mass extinction.

Re-investigation of *Stauroxylon beckii*, an early Carboniferous plant with progymnosperm affinities

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Seed plants are a clade appearing during the late Devonian and include the gymnosperms and angiosperms that dominate today's floras. The identity of their sister group has long been debated, but the candidates belong to the progymnosperms (Aneurophytales and Archaeopteridales) and the Stenokoleales. Phylogenetic analyses have not given a clear answer yet and have recently added more complexity by showing that the relationships among these groups vary significantly with taxon sampling. Discovering and adding more taxa can thus be a way to clarify these relationships. In this study, we re-investigate *Stauroxylon beckii*, an anatomically-preserved plant first described in 1970. *Stauroxylon* has been found in the early Carboniferous (Tournaisian) Lydienne Formation, France, and shows similarities with the progymnosperms, Stenokoleales, and seed plants. It possesses: a cross-shaped stele with protoxylem strands at the centre and the tips of the arms; pycnoxylic secondary xylem; and a unique pattern of lateral trace emission. We included *Stauroxylon* in the latest phylogeny of early seed plants and related groups. The results suggest that *Stauroxylon* belongs to the Aneurophytalean progymnosperms. When using continuous characters, the Archaeopteridalean progymnosperms appear as sister group of the seed plants and the Steneokoleales as a basal grade.

Anatomy and function in the mouth of the Early Devonian heterostracan *Rhinopteraspis*

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Heterostracans are a morphologically diverse group of heavily armoured, jawless stem-gnathostomes that were a major component of Laurussian ecosystems in the Silurian and Devonian. The functionality of heterostracan feeding systems is, however, poorly understood, obscured by a lack of data on their articulated oral regions. Here we use computed tomography to describe the articulated oral region of the Early Devonian pteraspid heterostracan *Rhinopteraspis dunensis*. The mouth of *Rhinopteraspis* is bordered ventrally by a post-oral cover, laterally orbital plates, and dorsally by bounded by a plate separate from the rostrum, with a row of tubercles marking the oral boundary. Thirteen imbricated oral plates articulate with a sulcus in the post-oral cover; these plates are varied in form and characterized by marked hooked processes. By retrodeforming and reconstructing this model, we show that the oral plates would have met the anterodorsal

plate, suggesting that it was functionally the upper boundary of the mouth. This observation appears to rule out previous interpretations that it was the roof of a prenasal sinus and supports the idea that the nasohypophyseal duct opened inside the mouth. This provides an anatomical framework on which future inferences for the functionality of feeding in heterostracans can be based.

Reinvestigating the late Devonian plant bearing localities of Co. Kerry and Co. Wexford, Ireland

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Our understanding of vegetation changes around the Devonian–Carboniferous boundary remains limited by the scarcity of plant-yielding deposits close in age to the boundary. In this context, we have started to reinvestigate Devonian–Carboniferous localities of Ireland, with an initial focus on those from which Matten and collaborators described late Devonian plants in the 1980s. Several outcrops around Kerry Head (County Kerry) have yielded plant adpressions but the most remarkable locality remains Ballyheigue Beach. The horizon initially studied by Matten contains anatomically-preserved seed plants cupules, petioles, stems and rhizomes. Vegetative organs are often in connection, providing information on the habit of the plants. The base of larger woody axes (*c.* 10 cm in diameter) was also observed in 2019. Underlying horizons have yielded a different assemblage, including adpressions of *Archaeopteris* foliage and casts of large lycopsid stems. At Hook Head (County Wexford), the historical locality of Sandeel Beach has yielded spores, adpressions and anatomically-preserved plants. The latter correspond to stems of the lycopsid *Wexfordia* at different stages of development and to at least one other woody plant. Prospections around the Hook Head peninsula have revealed other plant-bearing horizons that will be investigated in future field-trips.

The effects of wave processes on arthropod taphonomy: implications for Lagerstätten and small carbonaceous fossils

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Actualistic experiments using analogue organisms provide some of the best ways to study the likelihood of certain organisms being fossilized and any biasing factors that might be having an effect. We aim to conduct taphonomic experiments using a wave flume tank to answer the questions of, what are the effects of: the duration of exposure to waves; wave velocity and frequency; and grain size, on the decay, disarticulation and patterns of microwear for the arthropod *Ligia oceanica*. In this study, *Ligia oceanica* is being used as an analogue for segmented, multipodous marine arthropods such as trilobites. Our results will comprise an atlas of taphonomic grades of the state of bodily damage for *Ligia oceanica* under different experimental treatments, and a statistical analysis to identify the key wave processes and sedimentary characteristics that can affect their

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preservation. The outcomes of our experiments will be applied to evaluate arthropod fossils within Lagerstätten and the remains of small carbonaceous fossils. This study will help with identifying and elucidating the key taphonomic factors that may be biasing what is preserved in the fossil record, and impacting our understanding of the diversification of arthropods and how the group reached its present-day biodiversity.

Enrolment in *Strenuella polonica* facilitates exoskeleton moulting

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Enrolled individuals of the ellipsocephalid trilobite *Strenuella polonica* are numerous in the Cambrian Series 2 of the Holy Cross Mountains, Poland. Enrolment is considered a protection mechanism from predation, particularly in spinose trilobites like *S. polonica*. Partial enrolment in trilobites has also been suggested as a biomechanical moulting aid. Both enrolled moults and carcasses of *S. polonica* juveniles and adults are preserved (>70 specimens), enabling exploration of the extent of enrolment associated with moulting. Moults are identified by disarticulation of the librigenae and occasionally cranidium, with otherwise minor exoskeleton fracturing. Moults and carcasses are assigned an enrolment category: outstretched; pygidium flexure; cranidium flexure; semi enrolment; or full enrolment. We found that moults of *S. polonica* are more often preserved with only pygidium or cranidium flexure, and moults with greater enrolment are usually small. Carcasses are more often semi or fully enrolled, and rarely outstretched. These results are consistent with minor enrolment being used as leverage and/or partial protection during moulting, compared to the more complete enrolment required to direct the dorsal spines outwards and protect the ventral surface from attempted predation. The commonality of enrolment in both moults and carcasses indicates its dual-purpose importance for survival and growth in *S. polonica*.

Chitinozoan biostratigraphic advances in the type area of the North American Maysvillian Stage (Katian, Upper Ordovician)

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The Upper Ordovician strata and fossils of the Cincinnati region (USA) are world-renowned for their exceptional preservation and exposure. However, the broad range of depositional environments and provincial faunas have impeded efforts to establish highly refined regional biostratigraphic correlations and high-confidence utilization of global chronostratigraphic schemes in the North American Cincinnatian Series. To fully utilize this interval for the study of the Late Ordovician Mass Extinction, our group launched an

integrated bio- and chemostratigraphic initiative utilizing many new subsurface collections. Here we present the results of an extensive chitinozoan biostratigraphic study of the MY-14 core (Maysville, Kentucky, USA) from the type area of the Maysvillian Stage. This ~240 m core spans several lithofacies packages assigned to at least eight lithostratigraphic units (Lexington Ls to Elkhorn Fm). Sixty-six samples were processed through the entire core length and yielded abundant, diverse, and exceptionally well preserved chitinozoan specimens. Assemblages of chitinozoan species typically found in the lower Katian (*e.g. Acanthochitina cancellata*, *Belonechitina robusta*, *Hercochitina duplicitas*) and upper Katian (*e.g. Hercochitina longi*, *Tanuchitina* spp., *Eisenackitina ripae*) are present and provide the foundation for a refined US midcontinent chitinozoan biostratigraphic zonation with ties to global zonations.

A new taphonomic model from the Eocene Geiseltal Konservat-Lagerstätte (Germany)

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The Geiseltal Konservat-Lagerstätte (Eocene, Germany) is represented by *c.* 50,000 fossil specimens. Early studies of the vertebrates reported remarkable (sub)cellular details of muscle, cartilage, blood vessels, feathers, hair, reptile scales and bacteria. The mode of preservation was reported as three-dimensional silica replacements, which is unknown from other vertebrate Konservat-Lagerstätten. These claims of cellular fidelity, however, have not been verified using modern techniques. Here we tested these claims by analysing soft tissues from five anurans and seven fish from Geiseltal using SEM, EDS, FTIR and Raman spectroscopy. Our results show that soft tissues occur as layers of carbonaceous melanosomes and phosphatized residues; there is no evidence for silica in association with the preserved soft tissues. The preserved melanosomes exhibit tissue-specific geometries in both fish and frogs. In frogs, the Eberth–Katschenko layer of the dermis is preserved in calcium phosphate and nervous tissue is defined by euhedral aragonite. Our analysis reveals phosphatization rather than silicification as the preferred mode of soft tissue replacement for Geiseltal vertebrates. These features – carbonaceous melanosome films and phosphatized soft tissues – recur in other Konservat-Lagerstätten through space and time. This recognition sheds new light on the taphonomic pathways available for preservation of vertebrate soft tissues in the fossil record.

Illuminating the evolution of bioluminescence in sharks

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The evolutionary context in which shark bioluminescence originated is poorly understood, despite it being critical to uncovering influential factors in the evolutionary history and diversity of living chondrichthyans and the mechanisms of deep-water colonization by vertebrates. This study provides the first joint reconstruction of the habitats, lifestyles and occurrence of bioluminescence in the evolution of squalomorph sharks using ancestral state reconstruction to resolve the timing and tempo of deep-sea colonization, the evolutionary origin of bioluminescence and the ancestral ecologies of this group. The results suggest

that most squalomorphs originated in neritic environments from where they colonized deep waters on several independent occasions, predating most of the previous estimates of the timing of this event. The colonization of the deep sea took place through the benthic zone, in contrast to the view that an intermediate mesopelagic stage occurred during this transition. Finally, the analyses accounting for uncertainty of the presence of bioluminescence strongly support that this trait evolved once among sharks in a bathydemersal ancestor. This study reveals that shark bioluminescence evolved in a complex scenario that combines elements of several previous proposals, and enriches our perspective on the sequence of events that characterized the vertebrate conquest of the deep sea.

Documenting diagenetic alteration of an aragonitic Miocene giant clam (*Tridacna* sp.) with implications for strontium isotope stratigraphy (SIS)

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Strontium isotope stratigraphy (SIS) uses the Sr isotope ratios preserved in marine sediments to date their age with a numeric algorithm. The 87Sr/86Sr ratio of sea water throughout geological time is well documented and has changed due to the input of varying proportions of Sr derived from isotopically different continental *vs.* upper mantle sources. This study examines a Miocene *Tridacna* sp. from East Borneo, which – despite being aragonitic and visually well-preserved – shows noticeable diagenetic alterations as infilled cracks and an outer calcitic rim. Magneto- and biostratigraphy, as well as spatially resolved LA-ICPMS Sr isotope analysis, place the age of this sample at ~15 Ma, however a bulk powder TIMS SIS analysis of the aragonitic sample indicates an age of ~17 Ma. We investigated the source of this striking age difference via a combination of SEM imaging and elemental analysis by LA-ICPMS and EPMA. The Sr concentrations in the diagenetically-produced infilling was as high as 45 wt.%, compared to only ~0.2 wt.% Sr in the pristine aragonite. This pilot study highlights that great care needs to be taken when sampling *Tridacna*, as alteration can lead to contrasting Sr-isotope signatures and, hence, to SIS age offsets even for seemingly well-preserved aragonitic fossil material.

Testing hypotheses on heterostracan feeding using computational fluid dynamics (CFD) and finite element analysis (FEA)

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Teeth constitute a key innovation underpinning the evolutionary and ecological development of jawed vertebrates. As the earliest jawed vertebrates already possess teeth, we must study tooth-like structures in stem gnathostomes to learn more about their

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evolutionary origin of teeth. Heterostracans are a group of extinct, jawless vertebrates, that possess tooth-like structures (oral plates). These have been hypothesized to perform a diversity of functions, from filter-feeding to predation. We tested the suspension-feeding hypothesis using computational fluid dynamics (CFD). We compared flow patterns of models with forward-facing denticles to alternative models with rear-facing denticles. Independent of denticle orientation, similar velocity and turbulence patterns develop. Therefore, we reject the hypothesis that the forward-facing oral plate denticles are an adaption to suspension-feeding. To test the predation hypothesis, we used finite element analysis (FEA) and microstructural analysis to test whether they are adapted to a mechanical function. FEA stresses in the shaft of the oral plate are negatively correlated with bone volume fraction. The anterior part of the oral plate shows the highest bone volume fractions. This indicates a specific adaption of the microstructure to a mechanical function. Thus, we reject a filter-feeding function, instead concluding that heterostracan oral plates performed a mechanical feeding function.

The putative anostracan crustacean *Gilsonicaris rhenanus* Van Straelan, 1943 is a polychaete annelid

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Gilsonicaris rhenanus Van Straelan, 1943 is a 16-mm-long segmented organism from the Lower Devonian (Lower Emsian) Hunsrück Slate in Germany, originally described as an anostracan crustacean ('fairy shrimp') based upon the identification of a cephalon followed by 11 segments bearing appendages and 8 segments without appendages. This fossil, known by a single specimen housed at the Royal Belgian Institute of Natural Sciences, is only slightly younger than the stem-group anostracan *Lepidocaris rhyniensis* Scourfield, 1926 from the Lower Devonian (Pragian) Rhynie Chert (Scotland), suggesting the presence of modern-looking anostracans as early as during the Emsian. However, significant doubts have been cast on the affinities of *Gilsonicaris*. Rolfe (1967) proposed an alternative interpretation as a possible juvenile of the arthropleurid myriapod *Bundenbachiellus minor* Broili, 1930, a suggestion that has not been followed up by later work on *Bundenbachiellus*. Recent works on fossil anostracans pointed out that *Gilsonicaris* does not possess any anostracan synapomorphies beyond a seemingly homonymous trunk. X-ray micro-computed tomography of *Gilsonicaris*, performed only over 214° due to the extremely flat nature of the specimen, unveils a pair of scolecondonts associated with the mouth orifice, unambiguously identifying *Gilsonicaris* as a polychaete annelid.

Bioerosion on Mesozoic marine reptile bones: the evolution of a niche ecology

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Invertebrate assemblages from large vertebrate falls have been described in the Cenozoic and in the present day from whale carcasses. These whalefall communities are highly specialized for exploiting the nutrient influx produced by a large vertebrate fall. A few instances of organisms occupying this type of environment have been described from the

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Mesozoic in marine reptiles, and it is likely that marine reptile falls provided a similar environment to modern-day whalefalls for specialist invertebrate taxa. These faunas have not, however, been explored or inventoried in depth in the Mesozoic. In this study, marine reptile fossils from three major UK collections were examined for traces of bioerosion on the bone surfaces. A variety of borings and surface traces were identified in these fossils. This preliminary identification of ichnotaxa present in Mesozoic marine reptiles lays the groundwork for describing and identifying taxonomic assemblages associated with marine reptile dead falls. Further work will be done on specimens in the context of surrounding sediments and preserved invertebrate fossils. This study and those that follow will provide a snapshot of the invertebrate taxa present at a Mesozoic marine reptile fall and inform us on the ecological niche occupied by these specialist taxa through deep time.

Tibia scaling in kangaroos: large extant species are the odd roos out

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The common wisdom is that tibia length scales with positive allometry in kangaroos. A longer tibia reflects a longer Achilles tendon for elastic energy storage, an important component of locomotor energetics in larger (>3 kg) hoppers. Here we show that the observed positive allometry is an artifact of extremely elongated tibiae in the largest extant kangaroos, species of *Macropus* and *Osphranter* (M&O), all over ~30 kg in body mass. When M&O are excluded, tibia length scales with isometry in extant kangaroos (less the short-legged tree-kangaroos). Isometry is maintained when extinct larger kangaroos are included (again excluding M&O). Larger kangaroos have lower tendon safety factors, and may require thicker tendons in order to avoid rupture. The extremely long tibiae, and hence long Achilles tendons, of large extant kangaroos may help to counteract this thickening, ensuring the storage of sufficient elastic energy for energetically efficient hopping. The relatively shorter tibiae of extinct large kangaroos, sthenurines and the macropodine *Protemnodon*, concur with previous inferences that they may not have been hoppers; however, the basal sthenurine *Hadronomas* (which retains the fifth digit) had a relatively long tibia, as did the gigantic extinct *Macropus ferragus*, which approaches the theoretical weight limit for hopping (~150 kg).

Niche characterization is biased by limited and heterogeneous spatial sampling

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Ecological niche modelling is applied broadly in ecology to model a species' niche and map suitable habitat. The approach links species' occurrences with environmental predictors to statistically derive response curves. Although commonly applied to study extant taxa, ecological niche modelling is an emerging method in palaeobiology, providing opportunities to test ecological hypotheses regarding extinct taxa. However, the extent to which the approach can be applied to fossil data remains unconstrained. The fossil record is inherently incomplete and biased by heterogeneous spatial sampling. Consequently, the complete geographic distribution of a species, and its occupation of environmental space, is often unknown. These limitations can bias niche characterizations, leading to potentially erroneous conclusions about niche dynamics through time. Here we use a virtual species approach to quantify information loss when using fossil data to estimate species' climatic niches and geographic distributions through time. We focus on the Late Cretaceous fossil record to quantify the completeness of species' niches after sampling virtual species by the 'known' spatial sampling window. Our results suggest niche characterizations are often incomplete and biased towards a limited range of climatic conditions. Consequently, statistically-derived response curves can be misleading in some cases, resulting in erroneous predictions of suitable habitat.

Evolutionary changes in the cranial topology of pseudosuchians

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We compared cranial organization and organizational modularity in 50 pseudosuchian taxa and three non-archosaurian archosauriform taxa with the aim to closely explore cranial topological changes as a potential driver for evolution. Although pseudosuchians are more topologically similar to each other when compared to modern birds, we find that the number of bones and their topological arrangement can discriminate early-diverging pseudosuchians, non-crocodyliform crocodylomorphs, non-crocodylian crocodyliforms and crocodylians. We could also differentiate extant modern crocodilians from extinct crocodilian species, and could track the first appearance and the pattern of fusion (*i.e.* unfused, partially fused, or completely fused) of the left and right frontals and parietals across crocodyliform phylogeny. There is a clear progression in skull bone reduction from non-archosaurian archosauriforms to Crocodyliformes and further divergence of cranial bone arrangement within the Crocodyliformes. Using one basal pseudosuchian (one extinct subadult-adult pair) and six eusuchian ontogenetic pairs (two late-staged embryo–adult pairs, three extant juvenile–adult pairs and one extinct juvenile–adult pair), we also found that ontogenetic pairs are topologically similar and they tend to form a more densely connected and more integrated skull during development. Thus, we show that the phylogenetically-dependent pseudosuchian cranial reorganization could be traced as early as the late embryonic stage or early juvenile stage.

MoultDB: an interdisciplinary database for arthropod moulting data

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When moulting, arthropods replace their exoskeleton, which allows for growth and sometimes repair of damage or metamorphosis. A new collaboration between bioinformaticians, geneticists and palaeontologists at the University of Lausanne and Hebrew University of Jerusalem seeks to investigate the broad trends in moulting characteristics and evolution within Euarthropoda. MoultDB is an online database (<**https://moultdb.org/**>) currently under construction containing interdisciplinary moulting data from extant and extinct arthropods. Information on exoskeleton moulting methods, related characteristics (anatomical features associated with moulting), and ontogenetic

data will be collected for extant and extinct representatives of major euarthropod groups. Novel genomic and transcriptomic data on moulting pathways will also be collected for extant arthropods. Moulting methods and ontogenetic series are well known for trilobite groups throughout their fossil record. For other arthropod groups, such as crustaceans or chelicerates, this information still needs to be gathered and compiled from the fossil record. This information will help elucidate the relationships between morphology, ecology, evolution and different moulting strategies. MoultDB is in its early stages of development. In later stages, interested experts and researchers will be invited to contribute to building this database, and to use it as an open-access resource.

Foraminiferal response to Oligo–Miocene climate change on Malta

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Climate change has multifaceted consequences for marine ecosystems. Marine communities alter due to shifts in species composition and abundance resulting from environmental change. Foraminiferal communities in particular have been shown to shift rapidly. However, the precise ecological restructuring is poorly understood. Here ecological consequences of cooling and warming regimes on foraminiferal turnover are described from the Oligo–Miocene stratigraphy of Malta (27.8-7.2 Ma). Diagnostic indicator species were used to reconstruct the changing palaeoenvironments in Malta. Environmental change, including modification in carbonate production and sea-level, was shown to result in the local extinction of many specialized species. Foraminiferal evidence also supports marine eutrophication, as a result of climate-driven phosphogenesis. Punctuated abundance of dysoxia-tolerant and opportunistic foraminiferal species such as *Bolivina reticulata* and *Bolivina spathulate* were found throughout the stratigraphy. Conversely, oligotrophic and oxic-regimes were identified via *Cibicides rhodiensis* and *Cassidulina laevigata*. Additionally, our findings indicate that prolonged ecosystem stress may result in productivity failure. As a fundamental trophic base, it is essential that productivity in the foraminifera remains stable, otherwise there will be severe consequences for the whole ecosystem. This study demonstrates the potential consequences of contemporary climate change and the increasing abundance of dysoxic marine environments.

Micro-CT scanning of tiny fossils: giving shape to forams and conodonts

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Micro-computed tomography is now ubiquitous in palaeontology, though it is more commonly used to study macro-fossils. Alternative approaches, utilizing synchrotron or nano-CT equipment, are often preferred for the scanning of smaller (<5 mm) materials, due in part to the higher potential resolution that can often be achieved. Access to such methods is not always possible, however, and can also be both time-consuming and expensive per sample imaged. Here we present our method for micro-CT scanning multiple tiny (<1 mm) fossils using a Nikon XTH 225ST micro-CT scanner with foraminifera and conodonts as an example. Forams mounted using a modified pipette tip and double-sided tape facilitates scanning 10–20+ individual forams in a single scan at voxel sizes

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of 2.5-3.0 µm in as little as 25 minutes. Conodonts mounted similarly, but on carbon SEM stubs with carbon tape and a modified nylon rod, allows for 4–10 elements per stub at voxel sizes of 3.0-5.0 µm in 52 minutes. One day of scanning can produce data for upwards of 160 forams or 60 conodonts with high enough image quality for many aims including chamber counts, volumes, developmental trajectories and 3D morphology.

Enigmatic 'mattress'-like structures associated with Lower Ordovician graptolites

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We describe graptolites from the Tremadocian, Lower Ordovician Than Sa Formation of northeast Vietnam that are intimately associated with enigmatic, three-dimensional 'mattress'-like structures. The structures effectively encase the entire length of the graptolite and have transverse 'ribs' that align with the spacing of the thecae on the ventral side, and which also extend outwards from the dorsal surface of the graptolite. Various lines of evidence suggest a biotic rather than an abiotic origin, especially the close alignment of the 'ribs' with the thecae, the preservation as a continuous three-dimensional structure, and the textural contrast between the 'mattress' and the surrounding sediment. We review various possible interpretations for these structures, including microbial interactions with the graptolite on the seabed.

Using geotrails and palaeontology to increase public interest in geosciences

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The decline in geoscience interest across the UK and many other countries has been considerable in recent years. The reasons for this are multifaceted; however, much stems from a lack of exposure to the subject. One of the few areas of geoscience still attracting individuals is palaeontology, helped by a long-standing integration of palaeontology into modern culture. Whilst exposure is high for children, it declines with age. This doesn't have to be the case. Geoparks are globally becoming more common. These are great, but often attract geo-partial individuals. It is possible, however, to increase exposure in a more inclusive way. Here we present a series of proposed geotrails on Gozo, Malta. Research by undergraduate students over the past six years has revealed a wealth of geologically interesting localities. By grouping these locations together along existing walking routes, public exposure can be increased by engaging those not predisposed to the subject area. To increase public engagement, we also argue that palaeontology is a theme which should run throughout the trails. Palaeontology draws on pre-existing cultural exposure, and aids visualization of and relatability to palaeoenvironments and events. Visualization and relatability are often key to sparking interest and engagement in a subject area.

The effect of stoloniferous reproduction on resource competition and species co-existence in the Ediacaran

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Competition and reproduction are two of the most fundamental mechanisms of evolutionary theory, but their effects on early animal evolution are not well understood. For Ediacaran Avalonian early animal communities (572–560 Ma), reproductive and competitive processes can be reconstructed using spatial analyses, with stoloniferous reproduction indicated by anisotropic clusters (non-uniform directionality) and constrained dispersal clusters, and resource competition by spatial segregation. In this study, the presence, strength and spatial scale of intra-specific competition, dispersal cluster size and anisotropy were quantified in 20 taxa populations across nine Avalonian communities. Binomial regressions found anisotropy was a predictor for the presence of intra-specific competition ($p=0.041$) and general linear regressions found anisotropy and normalized cluster size were negatively correlated with strength intra-specific competition ($R2=0.5157$, $p=0.0021$). These regressions suggest that stoloniferous reproduction inhibits intra-specific competition. Furthermore, comparisons of the spatial scales of intra- and inter-specific competition found heteromyopic interactions, whereby inter-specific competition occurs at smaller spatial scales than intra-specific competition. Heteromyopia enables co-existence of sub-optimal competitors because the dispersal-limited dominant species cannot inhabit all of the optimal habitat, enabling the co-existence of weaker competitors within the same community. Thus, this heteromyopic co-existence demonstrates a reduced selection pressure on these Avalonian organisms, likely inhibiting evolutionary rates.

Suspicious minds: a molecular taphonomic approach to preservation of the central nervous system in the fossil record

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Over 390 putative neural tissues have been identified in fossils as old as the Cambrian Period, providing unique insights into the palaeobiology and evolutionary history of extinct taxa. However, decay experiments suggest that the central nervous system (CNS) is amongst the first organs to decompose post-mortem, and there is no known pathway to fossilization accounting for its exceptional preservation in the absence of other, more decay-resistant soft tissues. This project, the first of its kind, adopts a multi-omics approach to unravel how and why the brain persists when other organs perish. The unique molecular composition of the CNS itself may play a key role: an unusually high protein-lipid ratio and abundant biogenic iron might render neural tissues amenable to fossilization by intermolecular crosslinking or mineralization. To explore these hypotheses in parallel, we unite experimental taphonomy with molecular characterization; the former marries metagenomics and environmental metabolomics to investigate microbial communities colonizing the decomposing CNS, while the latter exploits proteomics and lipidomics to probe tissue transformation through geological time. Resolving the processes by which the CNS preserves will ensure we can interpret fossilized neural structures with confidence, and maximize recovery of the molecular and morphological information they harbour to inform evolutionary history.

Exceptions to the temperature-size rule? Body size patterns in end-Permian ostracods (Crustacea) (Aras Valley, NW Iran)

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Marine ectotherm body size is often negatively correlated with ambient temperature, including in many clades during the hyperthermal crisis of the end-Permian mass extinction (~252 Mya). However, in the case of ostracods, size changes during ancient hyperthermal events are rarely quantified. Partly, we suspect that this is due to their complex life history, which complicates fossil analyses. In this study, we evaluate the body size changes of ostracods in the Aras Valley section, northwest Iran, at three taxonomic levels (class, order, species) in response to the drastic warming during the end-Permian mass extinction. Preliminary results suggest that individual ostracod species of the Aras Valley section do not show dwarfing as an adaptation to the temperature stress during the end-Permian crisis. Instead, the warming triggers a complete species turnover in the ostracod assemblage, with very large, newly emerging species dominating the immediate post-extinction assemblage for a short time. This may indicate that ostracods migrated or became regionally extinct in response to intense environmental stress instead of adapting physically.

Examining the population structure, orientation and implications of *Fractofusus* on two Ediacaran fossiliferous surfaces in Newfoundland

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Fractofusus lived in marine benthic environments during the Ediacaran period and belonged to the extinct clade Rangeomorpha, a group of frondlike soft-bodied organisms. The purpose of this study was to statistically analyse morphometric and orientation data of *Fractofusus misrai* (E surface) and *Fractofusus andersoni* (H14 surface) specimens and compare to previous population structure and palaeoecological studies. Various analyses were performed using the statistical software R, notably: the clustering algorithms of MCLUST used to determine numbers of clusters in the data (age and shape classes), and the Mann-Whitney test used to determine any significant differences in shape class orientation. This study found similar results to previous population structure studies with one age class of *F. misrai* and two of *F. andersoni*, possibly indicating each species had a different reproductive mode. Previous studies have described a random arrangement among *Fractofusus*, with specimens not aligned with a NE contour current or SE turbidity flow. Contrastingly, a recent study suggested the existence of a SE background current. Our analysis discovered orientation trends based on specimen shape, suggesting that in the presence of a SE background current *Fractofusus* may have achieved optimal security and nutrient uptake when having their widest point perpendicular to the current.

Functional 'islands' in a three-dimensional trilobite morphospace

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Trilobites are a diverse group of extinct arthropods that lived in Palaeozoic oceans, in environments ranging from inshore to the deep sea, as well as some in brackish estuaries. Members of this group utilized a variety of feeding modes, including predators, scavengers, sediment feeders and filter chamber suspension feeders. While most lived on or close to the sea floor, a free-swimming lifestyle evolved convergently in many families. This broad range of lifestyles were facilitated in part by the disparity of exoskeletal shapes employed by different taxa. However trilobite exoskeletons were also under hydrodynamic controls, needing to minimize drag and generate appropriate lift coefficients for benthic or nektonic lifestyles. To test the adaptation of trilobite morphologies for different lifestyles, I quantified the morphological disparity of three-dimensionally preserved trilobite cephala, separated them into morphotypes, and used computational fluid dynamics to understand the hydrodynamic performance of morphotypes to different flow conditions. Identification and quantification of these functional 'islands' in trilobite morphospace, linked to particular ecologies, informs on evolutionary selecting pressures leading to convergence to particular morphotypes. Distance between functional 'islands' might also allow development of hypotheses relating to functionally continuous evolution between different ecologies.

Three-dimensional anatomy of derived South American cynodonts and homoplasy in the evolution of the mammalian jaw joint

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The acquisition of the mammalian jaw joint and middle ear was a key event in synapsid evolution. Previous research has described morphological changes to the jaw joint and postdentary bones across the cynodont/mammaliaform transition, but more recently discovered non-mammaliaform probainognathian cynodonts from South America have thus far not been integrated into comparative anatomical studies, despite being represented by numerous specimens including ontogenetic series. In this study, micro-CT data from nine specimens of *Brasilodon quadrangularis*, the sister taxon to mammaliaforms, and ten specimens of *Riograndia guaibensis* were segmented to produce an updated description of the jaw articulations of these taxa in three dimensions for the first time. Our findings indicate that the jaw joint of *Brasilodon* has more plesiomorphic traits than in previous interpretations, lacking a clear squamosal-dentary contact/articulation and instead relying on a main quadrate-articular joint. By contrast, *Riograndia* possesses a more developed squamosal-dentary contact to reinforce the plesiomorphic jaw joint, formed by a robust postdentary bone complex. These findings suggest that the dentary-squamosal jaw joint evolved convergently in separate cynodont lineages, and that the cynodont/mammaliaform transition was characterized by homoplasy, similarly to the independent acquisition of the definitive mammalian jaw joint and middle ear in Mesozoic mammals.

Global warming generates predictable extinction patterns of marine benthic invertebrates following a simple model of occupancy loss

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Anthropogenic global warming is expected to raise extinction risk and both warm- and cold-water organisms may be threatened. Extinction trends are observable in the fossil record but need correcting for sampling biases and regional climate variation. Here we relate extinction risk of ancient marine animals directly to seawater temperature estimates sourced from palaeoclimate models. We compare these patterns to simulated extinctions generated by simple geometric loss of thermal habitat. During times of rapid global warming, extinction trends deviate significantly from their usual form, imperilling marine invertebrates with preferences for habitats warmer than ~21°C and increasingly for habitats cooler than ~11°C. This bimodal latitudinal distribution of extinctions is congruent with simulated results, suggesting the spherical geometry of the globe alongside the temperature-latitude relationship causes an uneven loss of thermal habitat. Modern range shifts already indicate this mechanism. Following IPCC projections, cold-water habitats and their endemic species face annihilation within centuries.

Ancestral state reconstructions of the phloem anatomy of extant gymnosperms and angiosperms

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The phloem is vascular tissue in plants which transports sugars. Despite the phloem's importance to plant function, there are still many questions about the evolution of the phloem. A critical point of evolutionary history occurred when angiosperms and gymnosperms diverged, shaping the landscapes of Earth as we know them today. Researchers have found that angiosperm and gymnosperm phloem differ in many ways but little is known about the anatomy of the common ancestor of living angiosperms and gymnosperms as fossil phloem is rarely preserved. Using phloem anatomy data from extant species gathered by Liesche *et al.* (2016), ancestral state reconstructions were created for six traits of the phloem: sieve element length, sieve element radius, sieve area number, sieve pore number, sieve pore radius and end wall thickness. These reconstructions allowed us to predict phloem anatomy in the common ancestor of extant angiosperms and gymnosperms. Knowledge of the evolution of the phloem may allow scientists to determine how the phloem may continue to evolve in the future, as well as potentially allowing a deeper understanding of why angiosperms may dominate the Earth today.

Teeth growth pattern in the Middle Triassic capitosaur *Calmasuchus acri*

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In the Middle Triassic (Anisian) outcrops of the Montseny area located in the Catalan Coastal Ranges, northeast Iberian Peninsula, several osteological remains providing crucial information of the palaeobiodiversity in equatorial Pangaea have been recovered in the last two decades. The faunal assemblage is consistent with the record from higher latitudes of Europe, denoting the presence of archosauromorphs, procolophonids and a large bonebed of capitosaur temnospondyls, represented by dozens of disarticulated elements of different-sized individuals attributed to *Calmasuchus acri*. Growing patterns in temnospondyls are interesting because of their wide range of body size. Previous works on this group showed that size and shape of the skull maintain an allometric relationship, at least in some taxa. The objective of this work is to determine if the number of teeth per measured unit changes with body size (teeth density). The size of the specimens was qualitatively assessed from the recovered dental temnospondyl remains, and each fossil was classified into one of three different size classes. Due to the fragmentary nature of the fossil remains, an error study was conducted on the measurements. Small individuals showed a statistically higher teeth density, while differences between medium- and large-sized individuals were not found.

The typicality of the Fezouata biota

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Despite its impact on our understanding of marine life during the early Ordovician, little is known about the ecology of the Fezouata biota of Morocco. Qualitative assessments suggest that Fezouata's assemblage composition is typical for an Ordovician open marine deposit. Here we quantitatively examined the similarity of the shelly fossils preserved in the Lower (Tremadocian) and Upper (Floian) Fezouata Formation relative to other early Ordovician, high-palaeolatitude localities (60°S and 90°S). We downloaded Ordovician age site-specific occurrence data for all biomineralizing taxa and corresponding palaeogeographic data from the Paleobiology Database. We find a positive relationship between assemblage dissimilarity and palaeogeographic distance, recapitulating distance–decay relationships seen in modern, marine ecosystems. The assemblage dissimilarities amongst the Lower and Upper Fezouata sub-localities are higher and lower than expected, respectively, when compared to general Ordovician palaeo-ecogeographic trends and other early Ordovician, high-latitude sites. Ordination and cluster analysis suggest a small, yet significant difference in assemblage composition between the Lower Fezouata, the Upper Fezouata, and other early Ordovician high-latitude sites. This suggests that even though the biomineralized assemblages of the Lower and Upper Fezouata are distinct from one another and other contemporary localities, the Fezouata biotas are broadly similar to that of other high-latitude, early Ordovician deposits.

Optimization of extraction techniques of non-pollen palynomorphs from Irish Quaternary peat deposits

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Irish Quaternary peat deposits have yielded a wealth of information to palynology studies; however, these studies are primarily based on pollen analyses. Studies of non-pollen palynomorphs (NPPs) have been shown to be useful proxies as palaeoecological indicators and provide additional insights into palaeoecology. NPPs are abundant in different sediment types throughout geologic time, but studies of NPPs in Ireland are rare. This study: investigated the presence of NPPs in Irish peat deposits from Liffey Head Bog, Co. Wicklow, based on a core section dated *c.* 1540 (33 cm)–1657 AD (25 cm); and aimed to optimize extraction techniques of NPPs. Peat samples were prepared using standard pollen extraction techniques and the application of acetolysis and no acetolysis steps were compared. Previous studies have shown that acetolysis can damage NPPs; however, NPPs were recovered from both treatments suggesting that acetolysis is not essential for NPP extraction. Preliminary results include over 100 examples of NPPs, such as Van Geel HdV-10 Type fungal spores, testate amoebae, tardigrade eggs, and copepod spermatophores. Further work on the study of NPPs from Irish peat deposits is greatly needed because their analysis is a powerful tool for reconstructing environmental changes over time.

Impact of palaeoenvironmental variation on the fossil assemblage of the Ballysteen Formation (Carboniferous, Hook Head, Ireland)

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The Lower Carboniferous Ballysteen Formation on the Hook Head Peninsula, Ireland, hosts a shallow marine carbonate ramp fauna within tempestites in a transgressive sequence. The fossil assemblage is characterized but the extent to which the fauna and its taphonomy are impacted by variations in palaeoenvironment has not been studied previously. Here the faunal assemblage in sixteen different horizons at four different localities is studied. Each of the eight fossil groups present – brachiopods, bryozoans, rugosan corals, tabulate corals, crinoids, echinoids, gastropods and vertebrate bones – was scored using a semi-quantitative system for taphonomic and palaeontological indices including abundance, mean and maximum size, fragmentation, disarticulation, and completeness as well as diversity. The results show significant differences in the diversity, maximum size, disarticulation of crinoids among the horizons. Variations in abundance of brachiopods and tabulate corals, maximum size of bryozoans are significant among horizons. These variations relate to changes in lithology and water depth. Limestones with greater mud content are associated with better preservation; brachiopods and tabulate corals are less abundant in deeper settings. There are no significant variations in any parameters with lithology for rugosan corals, echinoids, gastropods and vertebrate bones. Crinoids, brachiopods and tabulate corals are the best palaeoenvironmental indicators in the assemblage.

Palaeontology at the core of multidisciplinary approaches to identifying resilient woodland ecosystems in the lowland Anthropocene landscape of Leicestershire and Rutland, England

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Woodlands in the British landscape have been reduced to fragments and continue to decline in species diversity. Increasing woodland resilience is essential to protect these ecosystems and their ability to withstand future environmental change. Woodlands in Leicestershire have undergone various human disturbance over several millennia including extensive modification such as clear-felling in the twentieth century. Adopting a multidisciplinary approach, we aim to examine resilient, biodiverse woodlands in lowland Britain, using East Leicestershire and Rutland as a case study. Through the integration of information from the fossil pollen record, place-name evidence of past vegetation cover, LiDAR data and recent botanical surveys, the methodology aims to identify regions that have maintained long-term, stable woodland cover and to elucidate how ecosystems have recovered after natural environmental or anthropogenic disturbances, through the examination of vegetation succession and species diversity in past and present woodland ecosystems. In the future, the project aims to use this information to develop a spatiotemporal model for Leicestershire and investigate how resilient woodland ecosystems might be developed for the future, considering various UK climate projections, to inform rewilding and conservation efforts.

Trophic changes in marine ecosystems following the Pliocene megafaunal extinction event

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A marine extinction event at the end of the Pliocene (~2.5–3 Ma) saw significant losses in marine megafauna, notably *Otodus megalodon*, one of the largest apex predators ever to exist. The apparent relationship between extinction susceptibility and large-bodied homeotherms (species with high energy requirements) in this event is atypical among past extinctions, yet is similar to trends seen in current conservation research. However, the ecological consequences of losing megafauna from marine environments, particularly a globally dominant apex predator, is not well understood. Using a trait-based inference model, we reconstructed food webs to assess the impact of this Pliocene extinction event on North Atlantic trophic community structure and dynamics. The model distributes trophic links using rules based on foraging theory and functional traits assigned to every trophic species (*e.g.* body size, motility, metabolic control and feeding habit). Through analysing the differences in food web topology pre- and post-megafaunal extinction event we show

how trophic structure and feeding interactions were altered and identify the species that ‘replaced’ *O. megalodon* at the top of the food web. In addition to addressing questions in palaeoecology, these findings could be informative for conservation studies predicting the impact of future marine megafauna and apex predator losses.

The Sedimentary Geochemistry and Paleoenvironments Project

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The Sedimentary Geochemistry and Paleoenvironments Project (SGP) is an open, community-oriented, database-driven research consortium that seeks to address questions of environmental evolution across Earth history through statistical analyses of the sedimentary geochemical record. For decades, geologists and geochemists have generated data relevant to these important questions, and as results accumulated researchers have increasingly gravitated towards larger compilations and statistical tools. We aim to organize geochemical data and relevant context data into a central and accessible database, and develop new analytical techniques to analyse these data in group papers. The project is modelled after palaeobiological studies, where researchers have worked rigorously to understand the impact of sampling intensity and geological bias on their results, and community efforts in fields like genomics, where multiple research groups have combined their data for more statistical power. This poster serves as an introduction to the goals of SGP, presents descriptive statistics regarding our publicly available Phase 1 data release and search website, describes our goals for Phase 2, and provides information for researchers interested in being involved in the project.

Community development in the Ediacaran of Avalonia

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Community composition varies over time in response to differential patterns in biotic and abiotic variables. Pathways of succession in the benthic communities in the Avalonian Ediacaran (~580–560 Ma) have been suggested with certain taxa associated with different phases of community development, *e.g. Fractofusus* is often associated with early succession, whereas large frondose taxa are placed in later stages of community development. In order to investigate how Avalonian communities mature, we mapped out the position of specimens using laser-scan and photogrammetric data from ten bedding planes from Newfoundland, Canada. The *in situ* preservation of these sessile organisms provides a near census of communities at this time, enabling modern ecological methods to be used to investigate their community ecology. These maps were used to calculate species densities and aerial coverage, as a proxy for biomass. Rank abundance and k-dominance curves of abundance–aerial coverage comparisons were calculated to estimate relative levels of disturbance and community succession. Early successional communities are expected

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to show a steep biomass-density-based k-dominance relationship which becomes less steep later in succession. The W-statistic was applied to determine demonstrable differences between communities. These analyses enabled us to establish how community development contributes to observed variation in these Avalonian benthic communities.

Biogeographic estimates of temperature-dependent hypoxia responses in marine ectotherms

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The synergistic effects of ocean warming and deoxygenation are a key climate-related stressor for modern marine animals and are thought to have been a primary extinction driver through geologic time. The Metabolic Index, a quantitative framework describing how warming and deoxygenation constrain aerobic capacity in marine ectotherms, provides a methodological advance in linking animal physiology to ancient extinctions. The Metabolic Index enables palaeobiologists to model predicted extinction based on oceanographic models of ancient environmental change. These extinction models can then be compared to fossil data to test the role of climate-related stressors in ancient extinctions. Palaeobiological applications of the Metabolic Index have been parameterized based on experimental respirometry data from modern marine ectotherms. However, appropriate physiological data are relatively limited, especially for groups that are abundant in the fossil record but understudied by modern ecophysiologists. Here we demonstrate a biogeographic approach to estimating Metabolic Index parameters. We combine animal occurrence data from the Ocean Biodiversity Information System with oceanographic data from the World Ocean Atlas to calculate Metabolic Index parameters and associated uncertainty with dramatically higher throughput than respirometry approaches. These analyses provide a key advance in linking animal physiology to the fossil record based on taxonomy and functional ecology.

Phyllotactic diversity in earliest leafy plants, but absence of Fibonacci spirals

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The leaves of extant plants are produced at the shoot apical meristem in a regular pattern known as phyllotaxis. When phyllotaxis first evolved in plants and whether the earliest leaves developed in a similar arrangement to any living species is currently unknown. I investigated the phyllotaxis of the lycopsid *Asteroxylon mackiei* from the early Devonian Rhynie chert, a member of the Drepanophycales, the earliest group of plants with leaves. Using serial cellulose acetate peels of Rhynie chert blocks and SPIERS software, I created the first digital reconstructions of leaf-bearing *A. mackiei* axes. The leaf arrangement analysis of mature stems, fertile regions and shoot apices represented the earliest detailed investigation of phyllotaxis in the fossil record. These to-scale 3D models revealed previously undescribed phyllotactic diversity in the earliest leafy plant group and yet a lack of Fibonacci spirals, the most common phyllotactic pattern observed in land plants. These findings suggest a complex origin of phyllotaxis in land plants.

A novel method of soft sediment stabilization for taphonomic experiments

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Decay experiments are a powerful tool for ground-truthing hypotheses regarding exceptional preservation within Konservat-Lagerstätten. Typically, replicates of decayed organisms are exhumed from a substrate at specified time intervals, and characterized on the basis of observed mineralization and character state loss. However, exhumation of partially-decayed organisms results in trauma, with disaggregation of skeletonized tissues, damage to already-weakened labile tissues, disturbance of mineral growths, and mixing of the substrate, leading to loss of data regarding the spatial pattern of early authigenic mineralization around carcasses. While non-invasive techniques have been employed with some success, these do not yet allow quantitative mineralogical analysis of phases, and are limited to minerals with differential X-ray attenuation relative to the substrate. We describe a novel 'solid-state' method of sediment stabilization, wherein water is continuously replaced by anhydrous acetone; the molecular sieve-driven replacement of porewater leverages Le Chatelier's principle, permitting pore space impregnation with Paraloid B72. Experimental vessels investigating mineralization around the anemone *Actinia equina* were consolidated using this technique, with the spatial pattern of mineralization characterized via elemental mapping and petrography. Our method of sediment stabilization provides a viable alternative to classic taphonomic methodologies, producing stable specimens suitable for quantitative analysis, and for long-term accession within repositories.

Clumped isotope constraints on ammonite palaeoecology and latest Cretaceous climate variability in the United States Gulf Coastal Plain

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Geochemical records from well-preserved shell carbonate are used to reconstruct the palaeoecology and habitat of ammonoid cephalopods (ammonites) and the evolution of ancient marine ecosystems and climate. Carbonate clumped isotope (Δ47) analysis is a promising tool which does not rely on assumptions of ancient seawater composition that hamper 'traditional' stable isotope studies. We present a multi-taxon dataset from the Maastrichtian Owl Creek Formation, Tippah County, Mississippi, USA. This site contains an exceptionally-preserved molluscan fauna constrained by macro- and microfossil biostratigraphy to the final ~300 kyr of the Cretaceous. Fossils of three ammonite genera, infaunal bivalves and rare nautilids were systematically collected and sampled throughout a 9 m-thick section. Preservation was assessed using the SEM Preservation Index (PI). Clumped isotope palaeotemperatures and $\delta^{18}O_{Seawater}$ values reveal overlap in values and close agreement amongst all taxa. Ammonites and benthic bivalves thus secreted their shells in isotopic equilibrium with seawater of the same composition and probably lived in similar environments. We see no evidence that ammonites exhibit 'vital effects' with respect to their clumped isotope composition. These data provide new constraints on the

palaeoecology of extinct cephalopod taxa and marine climate evolution in the Gulf Coastal Plain immediately prior to the end-Cretaceous mass extinction.

Small shelly fossils from the Cambrian Series 2/Miaolingian transition of the High Atlas Mountains, Morocco

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Cambrian shelly fossils tell the story of the evolution of early skeleton-producing animals. We describe a suite of small shelly fossils from the Cambrian Series 2/Miaolingian transition in the High Atlas Mountains, Morocco. The fossils were recovered from the lowermost Brèche à Micmacca Member, Jbel Wawrmast Formation. The basal Brèche à Micmacca Member has been biostratigraphically dated to the *Morocconus notabilis* Zone (*c.* 508 Ma) in the Lemdad Syncline. It comprises a stratigraphically condensed unit of fossiliferous limestones similar to units of comparable age in Iberia, Avalonia and Baltica. The trilobite and hyolith faunas from here are well documented, and the helcionelloids partly documented, but many shelly fossils remain to be described in detail. Our sampling has recovered an incredible diversity of skeletal remains from at least five animal phyla, including many molluscs, brachiopods and echinoderms. Alongside readily recognizable taxa are a possible new species of the tommotiid *Tannuolina*, and a suite of phosphatic sclerites whose biological affinity remains uncertain. The shelly fossils from the basal Brèche à Micmacca Member shed further light on the diversity of skeletal taxa at the end of the Cambrian explosion and are indicative of how much remains to be discovered from this interval.

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