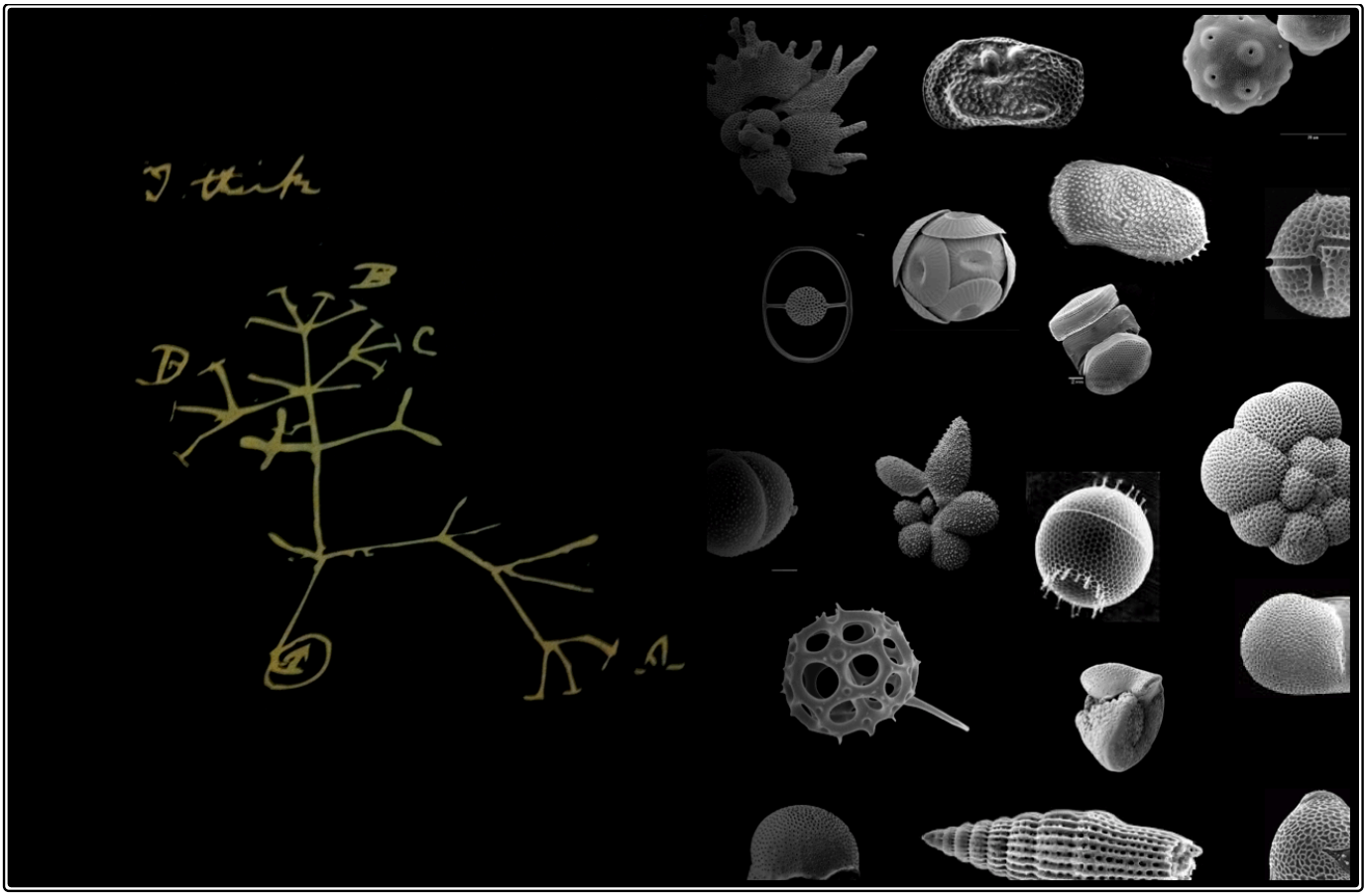
The Micropalaeontological Society

http://www.tmsoc.org

Micropalaeontological phylogenies and their applications



19th – 20th November 2014

Oxford University Museum of Natural History

UNIVERSITY OF OXFORD

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petrostrat applied stratigraphy

Museum of Natural History

The Micropalaeontological Society
3rd Annual Meeting

Oxford University Museum of Natural History

19th – 20th November 2014

Convenors: Tracy Aze (University of Leeds)
& Paul Smith (University of Oxford)

Arrival

By air: London Heathrow and Gatwick airports are linked to Oxford by The Airline coach service, which operates a direct frequent service 24 hours a day (http://airline.oxfordbus.co.uk; T: +44 (0)1865 785400).

London Stansted airport is linked to Oxford by the National Express 757 coach service, running every two hours (http://www.nationalexpress.com; T: +44 (0)8705 747777).

By train: A direct service operates between Oxford and London Paddington (approximately every 30 minutes), and between Oxford and Birmingham New Street. Other services operate from the north via Birmingham New Street; from the South via Reading; and from the west via Didcot or Reading. For information contact National Rail Enquiries (http://www.nationalrail.co.uk; T: +44 (0)8457 484950).

The railway station is located around one mile from the museum (see map overleaf). Taxis are available (c. £5 depending on the traffic), but it is often as quick to walk.

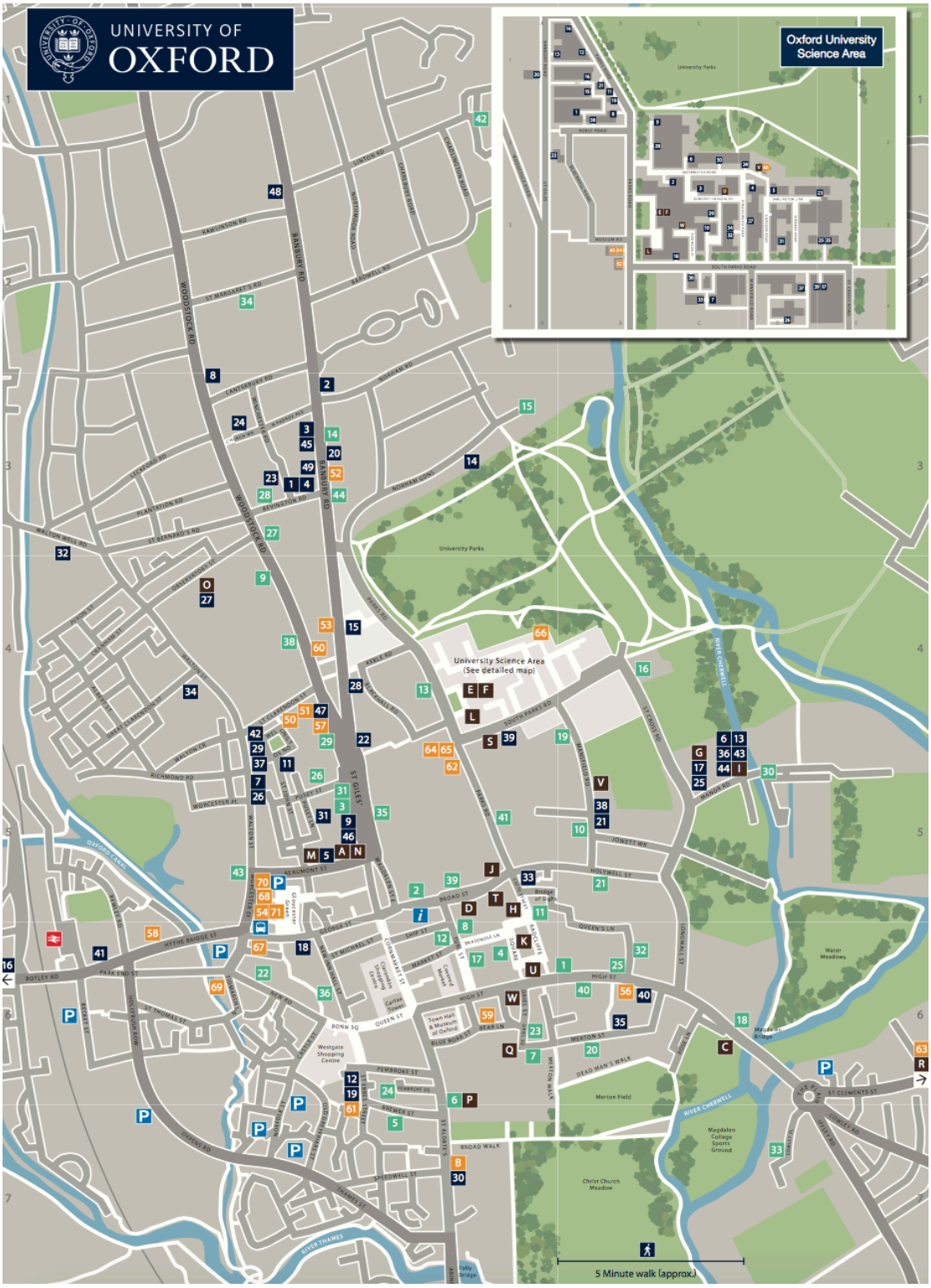
By bus: Fast and frequent 24-hour direct services connect Oxford with London (at peak times every 10-20 minutes).

The X90 service includes Victoria Coach Station, Grosvenor Gardens, Marble Arch, Baker Street/Gloucester Place and Hillingdon (http://x90.oxfordbus.co.uk; T: +44 (0)1865 785410).

The Oxford Tube service includes Grosvenor Gardens, Marble Arch, Notting Hill Gate, Shepherd's Bush, and Hillingdon (http://www.oxfordtube.com; T: +44 (0)1865 772250).

For information on coaches to other major cities and airports contact National Express (http://www.nationalexpress.com; T: +44 (0)8717 818178). Coaches arrive at Gloucester Green Coach Station in the city centre.

By car: Parking in the centre of Oxford is a challenge at the best of the times, but the centre is currently undergoing major road works that are causing severe congestion. Many Oxford streets are closed to traffic, or are restricted by temporary traffic lights, and parking is severely limited, so you are strongly advised to make use of the extensive Park & Ride facilities instead.



Map of central Oxford. The Museum of Natural History is building E in grid square G4, on the east side of Parks Road opposite Keble College. The museum is 15 minutes, or a short taxi ride, from the railway station.

Park & Ride: Park & Ride bus services operate between the city centre and parking areas on the outskirts at Pear Tree, Woodstock Road (north); Water Eaton (north); Seacourt, Botley Road (west); Redbridge, Abingdon Road (south); and Thornhill, London Road (east).

Please note that Thornhill and Seacourt are often full. We therefore recommend that drivers coming to Oxford from the east (including London), the south and the west use the Redbridge Park & Ride, while drivers arriving from the north can choose between Pear Tree and Water Eaton.

Programme

The entire conference will be held in the Museum of Natural History, including the posters, AGM, wine reception and dinner. The lectures and AGM will be held in the lecture theatre, which is accessed from the first floor gallery. The museum is situated on Parks Road (OX1 3PW), opposite Keble College.

Lunch is not included in the registration but local facilities include the museum café, the Lamb & Flag (Lamb & Flag Passage), the King's Arms (Parks Road), the Eagle & Child (St Giles) and Taylor's café on St Giles', all with good food (and the pubs have decent beer).

Wednesday 19th November
Registration in the Museum open from 12.00

Thematic symposium: Micropalaeontological phylogenies and their applications
Co-chairs – Tracy Aze & Paul Smith

14.00–14.30 **Combining fossil and genetic data to understand the radiation of modern planktonic foraminifera**
Michal Kucera

14.30–15.00 **The beautiful world of fossil nannoplankton**
Samantha Gibbs

15.00–15.30 **Phylogeny of the family Sonneratiaceae based on the fossil pollen record**
Robert Morley

15.30–16.00 Tea & coffee

16.00–16.30 **Evolution and phylogeny of the *Hantkenina* lineage**
Helen Coxall

16.30–17.00 **Origin and early history of ostracods: cautioning the interpretation of the shell-based record**
David Siveter

17.00–18.30 AGM and prize-giving

18.30–19.30 Drinks reception, Museum of Natural History

19.30–22.00 Annual Dinner in the Court of the Museum of Natural History

Thursday 20th November

9.00–10.30 **Poster breakfast, Upper Gallery of the Museum of Natural History.** Poster presenters please stand by your posters.

Oral presentations – open session
Chair – John Gregory

10.30–10.45 **Photoautotrophic symbiotic foraminifera record multimillion-year evolutionary (speciation-mass extinction) cycles**
Martin Brasier

10.45–11.00 **Forams and phylogeny: where do fossils fit in?**
Susan L. Richardson

11.00–11.15 **Disentangling synergistic climate drivers on the extinction of the planktonic foraminifer *Globoconella puncticulata***
Anieke Brombacher*, Paul A. Wilson, Ian Bailey, Thomas H.G. Ezard

11.15–11.30 **Spatiotemporal correlation of different facets of diversity**
I.S. Fenton*, P.N. Pearson, T. Dunkley-Jones & A. Purvis

11.30–11.45 **Ontogenetic lability as an evolutionary driver in planktonic foraminifera**
Thomas H.G. Ezard

11.45–12.00 **Progress in understanding Late Cambrian radiolarian biodiversity dynamics and palaeobiogeographic distribution**
L. Pouille & T. Danelian*

12.00–13.00 Lunch

Oral presentations – open session
Chair – Sev Kender

13.00–13.15 **Palaeoenvironmental analysis of a Mesolithic-Neolithic sedimentary sequence from Queens Sedgemoor, Somerset**
Tom Hill*, John Whittaker, Martin Bell, Richard Brunning & Keith Wilkinson

13.15–13.30 **The BP Palaeo-GIS project: the reappraisal of previously unused microfossil data from the former British Petroleum Collection at The Natural History Museum, London**
Stephen Stukins*, Tom Hill, Giles Miller & Kelly Smith

13.30–13.45 **Applying micropalaeontology to biosteer the oldest and deepest wells – the Permian carbonates of Saudi Arabia**
G. Wyn Hughes

13.45–14.00 **Global response in calcareous nannoplankton to the climatic change across the Eocene–Oligocene transition**
Cherry Newsam*, Tom Dunkley Jones & Paul Bown

14.00–14.15 **Lower Jurassic foraminifera from the Mochras Borehole; biozonation, classification and phylogeny**
Philip Copestake & Ben Johnson

14.15–15.00 **Ostracods from Middle Pleistocene lake sediments at Marks Tey, Essex**
Anna March*, David J. Horne, Jonathan Holmes & Simon G. Lewis

15.00–15.15 **Quaternary holoplanktic gastropods from the Mediterranean Sea**
Deborah Wall-Palmer*, Christopher Smart, Richard Kirby & Malcolm Hart

15.15 Closing remarks – TMS President, John Gregory

Abstracts for oral presentations

Photoautotrophic symbiotic foraminifera record multimillion-year evolutionary (speciation – mass extinction) cycles

Martin Brasier
Department of Earth Sciences, University of Oxford, South Parks Road Oxford OX1 3AN & Oxford University Museum of Natural History, Parks Road, OX1 3PW, UK

Twelve evolutionary cycles can be traced within c. 40 lineages of benthic agglutinated and calcareous foraminiferan skeletons preserved in tropical marine limestones. Each cycle involves speciation and radiation of skeletons ('tests') within a single lineage. These were adaptive radiations that generated new (species-to-family) taxa. My database comprises a literature survey that involves >10,000 samples. Each cycle (Palaeozoic to Cenozoic; mid-Devonian (400 Ma) through mid-Miocene (20 Ma)) lasted from 30 to 110 million years. Evolution (diversification and geographical dispersion of new taxa, primarily genera and species) invariably was followed by extinction. Trends of increase occur in (a) diameter, towards large size (<15.0 cm), (b) wall translucency, (c) number of shell subdivisions, and (d) numbers of lines of communication. Decrease is seen (e) in length of lines of communication within the shell relative to its volume. These trends typify extant carbonate-shelled foraminifera that, in reef ecosystems, cultivate intracellular photosymbionts: chlorophytes, rhodophytes, dinomastigotes or diatoms. Speciation-extinction cyclicity in the foraminiferal fossil record of reef ecosystems seemingly correlates with prolonged periods of global environmental stability. Tropical benthic heterotrophs that evolve greater dependence upon their internal symbiotic photoautotrophs are selected for in the marine environment under lowering nutrient conditions. Evolution cycles in these protoctists terminate with other well-documented mass extinction episodes due to intrinsic system instabilities. It is suggested that communities and ecosystems finely tuned towards greater obligate phototrophy-heterotrophy in relatively predictable environments become intrinsically vulnerable to collapse and extinction in response to changes in geological conditions (i.e., extrinsic disturbances). This hypothesis requires palaeontological investigations beyond photosynthetic benthic foraminifera.

Disentangling synergistic climate drivers on the extinction of the planktonic foraminifer *Globoconella puncticulata*

Anieke Brombacher[1*], Paul A. Wilson[1], Ian Bailey[2], Thomas H.G. Ezard[1,3]
[1]*National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, European Way, Southampton, SO14 3ZH, UK*
[2]*Camborne School of Mines, University of Exeter, Penryn Campus, Cornwall, TR10 9FE, UK*
[3]*Centre for Biological Sciences, University of Southampton, Life Sciences Building 85, Highfield Campus, Southampton, SO17 1BJ, UK*

Evolutionary biology typically considers selection on single traits as responses to individual climate factors. However, evidence from mass extinctions implies that large scale evolutionary processes might be better explained when the multi-faceted nature of climate change is taken into account. Is the same true, however, for within-species (anagenetic) microevolution? The deep-sea microfossil record is sufficiently complete that multivariate climatic and multivariate morphological trait data can be obtained from the same samples. Here we present morphological data from the planktonic foraminifera species *Globoconella puncticulata* deposited in mid-latitude North Atlantic Ocean sediments (Integrated Ocean Drilling Program Site U1313) from a mid-ocean site over 500,000 years before the species'

extinction at 2.44 Ma. Test height, width, area and aspect ratio were measured and compared to records of sea surface temperature, productivity and aeolian input determined from analysis of the same sediment samples. We report a reduction in test size by a factor ~2 during marine isotope stage (MIS) G6. Over the subsequent 200,000-year interval leading up to extinction average test sizes remained small, and aspect ratios increased. Multivariate statistical methods were employed to study and assess the combined effects of the various climatic variables on trait changes. Although MIS G6 is characterized by peaks in productivity and aeolian input and low sea surface temperatures, correlations between size, aspect ratio and the environmental parameters are absent over the total studied interval. We propose that species-internal biotic processes act as the primary regulator of morphological change, with abiotic factors playing a secondary role.

Lower Jurassic foraminifera from the Mochras Borehole; biozonation, classification & phylogeny

Philip Copestake[1] & Ben Johnson[2]
[1]*Merlin Engery Resources Ltd*
[2]*Aberdeen Stratlab Ltd*

The presentation introduces the key contents of a significant new paper published in 2014 on British Lower Jurassic foraminifera from the Llanbedr (Mochras Farm) Borehole, North Wales, the thickest known British section. A diverse foraminiferal fauna, comprising 270 species and subspecies, is described and illustrated in detail in the publication, including three new genera, 19 new species and 10 new subspecies.

The typical European Boreal Atlantic foraminiferal fauna is dominated by members of the Lagenida, with the Ceratobuliminoidea, Miliolida, Spirillinina, Involutinina, Buliminida and Textulariida as important accessory groups. The Ceratobuliminoidea and Miliolida are unusually diverse, with *Reinholdella* and *Ophthalmidium* being abundant. The presence of the Family Oberhauserellidae is significant.

A foraminiferal biozonation scheme for the Lower Jurassic of northern Europe, comprising 16 biozones and tied to the standard ammonite-based chronostratigraphy, is proposed. This is the first foraminiferal zonation of international applicability to be erected for the Lower Jurassic. The original ammonite records from the borehole are placed into the modern ammonite chronozone scheme.

The principles and historical development of foraminiferal classification are reviewed. A revised classification is proposed for the Order Lagenida based on the principle that chamber arrangement is the most important taxonomic character and recognises the fundamental phylogenetic trend from coiled to uncoiled forms.

In addition, data are included in the publication from many other previously unpublished Lower Jurassic sections, at outcrop, from boreholes and from hydrocarbon exploration wells.

Ontogenetic lability as an evolutionary driver in planktonic foraminifera

Thomas H.G. Ezard[1,2]
[1]*Centre for Biological Sciences, University of Southampton, Life Sciences Building 85, Highfield Campus, Southampton SO17 1BJ, UK*

[2]*Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, European Way, Southampton, SO14 3ZH*

Life is a journey. Nevertheless, as biologists or stratigraphers, we are often fixated by the final state that organisms obtain: adult body size is a ubiquitous phenotypic trait; palaeontological taxonomic decisions focus predominantly on characters expressed in the final chamber. Often, such decisions are borne out of pragmatism but environmental change during life affects ontogenetic development. One of the most striking aspects of planktonic foraminifera is the overwhelming variation among individuals, but how much of this variation is determined by within-individual development, and does it affect fitness? Combining survival, reproduction and growth data in *Globigerinoides sacculifer* from laboratory experiments and Synchrotron-equivalent Leica X-Radia scanning microscopy, I'll construct an integral projection model of life history evolution for this species and show the fundamental influence of growth as a fitness determinant. I'll then use this model to make the theoretical prediction that the extensive variation among individuals is evolutionarily adaptive. This prediction contradicts the demographic buffering hypothesis, which states that the traits most important for fitness should be canalized against variation to ensure that the organism remains on track to obtain the expected final state. In stochastic environments, the ability to flexibly alter ontogenetic trajectories (lability) demands we study development within individuals to gain a better understanding on microfossil life history evolution. I'll describe the first steps developing a semi-automated algorithm to extract size and shape data from each chamber during development, which pilot studies suggest will accelerate processing time of individual specimens from months to minutes. In so doing, it will permit comprehensive empirical testing of the integral projection model predictions and the role of lability in microevolution, speciation and extinction.

Spatiotemporal correlation of different facets of diversity

I.S. Fenton[1,2*], P.N. Pearson[3], T. Dunkley-Jones[4] and A. Purvis[1,2]
[1] *Department of Life Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK*
[2] *Department of Life Sciences, Silwood Park Campus, Imperial College London, Ascot, Berkshire, SL5 7PY, UK*
[3] *School of Earth and Ocean Sciences, Cardiff University, Cardiff CF10 3YE, UK*
[4] *School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK*

Biodiversity has many aspects, all of which can provide information about a study system. Many measures have been proposed to describe the diversity of a system. In this study, measures of species richness, species evenness, functional and phylogenetic diversity are used to quantify multiple aspects of the diversity. The relationship between these different aspects can provide information on the structure of a community. The detailed fossil record of the planktonic foraminifera allows investigation of this relationship through the Cenozoic. This study focuses on the diversity at two time intervals: the Eocene, a period of global cooling, and the Recent. Data were collated from the literature and cruise reports from sites across the world's oceans. Multivariate analyses of the different diversity measures at each site can identify correlations observed between these measures. We investigate how the covariation between different facets of diversity has changed through time.

Palaeoenvironmental analysis of a Mesolithic-Neolithic sedimentary sequence from Queens Sedgemoor, Somerset

Tom Hill[1*], John Whittaker[1], Martin Bell[2], Richard Brunning[3] & Keith Wilkinson[4]
[1]*Department of Earth Sciences, The Natural History Museum, Cromwell Road, London, SW7 5BD, UK*
[2]*Department of Archaeology, School of Human and Environmental Sciences, University of Reading, Whiteknights, PO Box 227, Reading RG6 6AB, UK*
[3]*Somerset County Council Heritage Service, Somerset Heritage Centre, Brunel Way, Norton Fitzwarren, Taunton, TA2 6SF, UK*
[4]*Department of Archaeology, University of Winchester, Winchester, SO22 4NR, UK*

A sediment core extracted from Queen's Sedgemoor, located on the Somerset Levels, has undergone high-resolution radiocarbon dating and subsequent directed micropalaeontological (palynological, diatom and calcareous microfossil) analyses. To date, the project has focussed on the sedimentary sequence associated with the Mesolithic and early Neolithic periods. This talk summarises the radiocarbon results and associated multiproxy analyses for the sedimentary sequence. Radiocarbon dating has identified a sequence dating back to the Mesolithic period (7.6 ky BP). Microfossil evidence indicates hydroseral succession has taken place, with the initial establishment of a freshwater lake, prior to undergoing terrestrialisation and eventually developing into a raised bog. Holocene sea-level change also influenced the sedimentary archive. Due to a rise in relative sea level c. 6.7 ky BP, subsequent coastal inundation and estuarine sedimentation took place, here associated with the Lower Wentlooge Formation of the Somerset Levels. Whilst pollen preservation was found to be relatively poor within the section associated with the Mesolithic-Neolithic transition, the analyses undertaken to date provide clear picture of landscape change preserved within the sedimentary archive. Microfossil and microscopic charcoal evidence is indicative of landscape modification by humans since the late Mesolithic. The sedimentary sequence also provides a valuable archive worthy of further palaeoenvironmental potential, due to the exceptional preservation and abundance of other micro/macrofossil groups encountered during the initial assessment (Mollusca, plant macrofossils, Coleoptera, testate amoebae, chironomids etc.).

Applying micropalaeontology to biosteer the oldest and deepest wells – the Permian carbonates of Saudi Arabia

G. Wyn Hughes
Applied Microfacies Limited, Tan-Y-Gaer, Llanbedr DC, Denbighshire LL15 1UT, UK; Department of Earth Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK; King Fahd University of Petroleum & Minerals, PO Box 5061, Dhahran 31261, Saudi Arabia

Underbalanced Coiled-tube Drilling (UBCTD) is used to increase gas and condensate production/flow rates from the Khuff Formation C carbonate reservoirs in the southern Ghawar Field of Saudi Arabia. As the 2 5/8" diameter coiled-tube inhibits access of full-suite drillstring logging tools for conventional high-resolution, log-based geosteering, the only source of stratigraphic control is micropalaeontological analysis gathered while drilling, referred to as biosteering. Rigsite-based coiled-tube biosteering uses rapid thin-section production with micropalaeontological and petrographic analysis of cuttings samples. Stratigraphic position is achieved by reference to a local biozonation based either on core or cuttings samples from the mother bore or adjacent wells. Although of shallow marine origin, Khuff C depositional palaeoenvironments are highly variable, both vertically and laterally over short distances, it is therefore necessary to establish a nearby, core-based, reference biozonation. Thin-sections of foraminifera, calcareous algae and associated microfossils are

used, all of which are small enough to be identifiable within ultra-small cuttings. Their extreme sensitivity to minor shallow marine sea level changes suits them perfectly for biosteering, and has enabled recognition of high-frequency microfacies variations. Stratigraphic control is possible to within 2ft vertical accuracy, and enables near real-time critical instructions to the directional driller. On average, the results are at least 15 minutes ahead of gamma data and reduce the need for expensive corrective drilling. As the "eyes" of the drill, this technique has enabled maintenance of the bit within the target reservoir resulting in significant increase in gas and condensate production.

Ostracods from Middle Pleistocene lake sediments at Marks Tey, Essex

Anna March*[1], David J. Horne[1], Jonathan Holmes[2], Simon G. Lewis[1]
[1] *School of Geography, Queen Mary University of London, London, UK*
[2] *Department of Geography, University College London, London, UK*

The lacustrine sedimentary succession at Marks Tey comprises the most complete record of the Hoxnian interglacial (MIS 11c) in Britain (Ashton *et al*., 2008). Although the sequence contains some hiatuses, it potentially records the entire interglacial and the transition to the following glacial stage. Not only is the succession largely complete, but it offers high-resolution: much of the >30 m thickness of sediment is laminated and in some intervals, laminations are considered annual (Turner, 1970; Candy *et al*., 2014). It is therefore an ideal site at which to investigate abrupt climate changes. Current research is focused on exploring how the palaeoclimate and palaeoenvironment changed throughout the interglacial to glacial transition, using a multiple-proxy approach to studying ostracods.

This paper will present preliminary results that demonstrate the presence of abundant, well-preserved, *in situ* ostracod assemblages at most levels sampled so far, dominated by freshwater lacustrine species (eg *Cytherissa lacustris*, *Limnocythere inopinata*, *Limnocytherina sanctipatricii*, Candonidae) but including the putative brackish-water indicator *Cyprideis torosa* at several levels as well as reworked Mesozoic marine ostracods and foraminifera (Horne *et al*., 2014). Preliminary ostracod-based palaeotemperature reconstructions hint at a cold-warm climatic oscillation after the Hoxnian interglacial.

Global response in calcareous nannoplankton to the climatic change across the Eocene Oligocene transition

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The Eocene-Oligocene transition (EOT) was a profound climatic interval marking the culmination of the long-term shift from a 'greenhouse' to an 'icehouse' world. Marine and terrestrial environments underwent physical, chemical and biological changes. Global environmental disruption during the EOT included extreme cooling, continental ice sheet growth on Antarctica, sea level fall, >1 km deepening of the calcite compensation depth, increased ocean alkalinity and significant marine biotic disturbance, with elevated levels of plankton extinction and turnover, within planktonic foraminifera, radiolarians and calcareous nannoplankton. The Eocene-Oligocene boundary, lying within this transition, is

marked by the extinction of the planktonic foraminifera family Hantkeninidae. Calcareous nannoplankton appear to have been the dominant oceanic phytoplankton group in the early Palaeogene, up until the EOT, where this group declined in diversity and underwent prominent shifts in assemblage structure. Calcareous nannoplankton data has been documented from individual sites across the EOT, yet we know little of the overall global population response to this extreme climatic change.

Here we present calcareous nannofossil data from a range of global sites, varying in latitude and oceanographic setting, to try and quantify the extent of the global response in calcareous nannoplankton populations to the changing climatic conditions across the EOT. Semi quantitative data and simple abundance counts highlight diversity change, species extinction events, originations and acmes as well as major shifts in abundance patterns. Determining the precise timing of these events at widespread localities allow us to examine the relationship between calcareous nannoplankton evolution and the strongly shifting palaeoclimatic/palaeoceanographic conditions.

Progress in understanding Late Cambrian radiolarian biodiversity dynamics and palaeobiogeographic distribution

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In spite of their importance in understanding Early Palaeozoic bursts in marine diversifications, the fossil record of polycystine Radiolaria is still very fragmentary. New data from Canada (Newfoundland) and Australia improve our understanding on the clade's biodiversity and biogeographic distribution during the critical Cambrian/Ordovician transitional interval, highlighted by a "revolution" in plankton communities.
Well-preserved and diverse faunal assemblages were obtained from pelagic carbonate sequences in western Newfoundland. Three different assemblages, including a total of 5 families, 8 genera and 22 species, are recognized in several sections situated on a palaeobathymetric profile. The various recognized assemblages are compared with previous studies conducted on the Cow Head Group; they improve considerably our understanding of the pattern of changes in radiolarian diversity during the Cambrian-Ordovician transition. The radiolarian biotic record of western Newfoundland unveils a two-step faunal change across the Cambrian-Ordovician transitional interval: one situated at the base of the uppermost Cambrian Stage 10 and the second at a poorly constrained interval situated towards the top of the same Stage 10. These biotic changes consist of genus-level selective extinctions, as well as within-clade species faunal turnover (i.e. *Echidnina*, *Paleospiculum*), decrease of species abundance, species extinction and within-clade episodes of species diversification (i.e. *Protoentactinia*, *Parechidnina*).

A well-preserved radiolarian assemblage found in the Upper Cambrian Chatsworth limestones of northwestern Queensland is very similar to the *Subechidnina* assemblage described in Newfoundland, suggesting the presence of a coherent tropical radiolarian bioprovince, as in the modern ocean.

Forams and phylogeny: where do fossils fit in?

Susan L. Richardson
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Molecular systematics has revolutionized our understanding of where Foraminifera fit on the Tree of Life; however, molecular phylogenies depict crown clades only, and thus cannot evaluate the evolutionary relationships of extinct taxa to modern species. This study presents the results of a cladistic analysis of 121 fossil and Recent foraminiferal taxa, including representative species from Palaeozoic Lagenina, Palaeozoic Fusulinacea, and Mesozoic Involutinina. A cladistic analysis of a data matrix comprising 121 foraminferal taxa and 170 characters (both binary and multistate) discrete characters was analyzed in TNT (Tree analysis using New Technology, Goloboff *et al.* 2003) using the New Technology search option. The search returned two trees with a best score of 688 after 15,014,536 rearrangements. The resulting evolutionary relationships of the fossil foraminiferal groups mentioned above as revealed by this analysis are as follows: (1) Fusulinacea is a monophyletic clade that branches within the more inclusive clade Globothalamea as the sister group to Textularida (orange); (2) Involutinina (pink) is a monophyletic clade that branches as the sister group to the clade Tubothalamea; (3) "Lagenida" is a polyphyletic group comprised of: a monophyletic clade of two-chambered undivided tubular Palaeozoic lagenids (red) that is more closely related to the clade Tubothalamea, and a monophyletic clade of multi-chambered septate Palaeozoic "lagenids" (green) branches as the sister group to the modern multi-chambered lagenids. The clade Globothalamea is the sister group to a more inclusive clade comprised of the multi-chambered Palaeozoic "lagenids"+Recent "lagenids".

The BP Palaeo-GIS project: the reappraisal of previously unused microfossil data from the former Briti sh Petroleum Collection at The Natural History Museum, London

Stephen Stukins*, Tom Hill, Giles Miller & Kelly Smith
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*s.stukins@nhm.ac.uk

The British Petroleum Micropalaeontological Collection was acquired by The Natural History Museum, London, in 1992. It contains microfossil, palynological and nannofossil material from a global coverage of over 3, 800 drilled wells, in addition to 800 outcrop successions.

The new project is a three-year pilot study on the North-west European region. The aims are to extract palaeoenvironmental information from the microfossil/palynological assemblages, which will then be applied to a previously established GIS tectonic framework. This involves the re-assessment of the reference collections, well material and original company well/biostratigraphy reports.

The project is in its first phase, during which time focus has been on the taxonomic reappraisal and subsequent digitisation of the entire North-west European Foraminifera Reference Collection. However, this initial phase of work has already thrown up some interesting questions in terms of taxonomy and biostratigraphy. In addition, MSc students at the University of Birmingham have had funds available to complete their final projects on material associated to this project. This last year, two students successfully completed projects looking at the Jurassic palynology of wells from Dorset and the Beatrice Field, Inner Moray Firth.

The next phase of the project will focus on analysing selected wells with the aid of a 2-year post-doc position, NHM staff and potential MSc students. It is hoped that the final deliverable of the pilot study will be a web-based, interactive GIS package showing the NW European area through a selected time period. Assuming that the pilot study is successful we aim to expand the project globally covering other regions previously examined only for their commercial potential.

Quaternary holoplanktic gastropods from the Mediterranean Sea

Deborah Wall-Palmer[1,2,*], Christopher Smart[1,2], Richard Kirby[2] & Malcolm Hart[1,2]
[1] *School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth, PL4 8AA, UK*
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Living holoplanktic gastropods (pteropods and heteropods) are a common component of the zooplankton at all latitudes and are highly sensitive indicators of environmental changes. Despite having a fossil record that extends from the Paleocene (and potentially from the mid-Jurassic), their delicate aragonitic shells are rarely used in biostratigraphy owing to their susceptibility to dissolution. However, in well-preserved sediments, fossil holoplanktic gastropods can contribute valuable information for stratigraphical correlations and palaeoenvironmental reconstructions. Here, we demonstrate these applications using an extremely well preserved ~130 ka marine sedimentary record from the western Mediterranean Sea. Climatic events within the Mediterranean Sea tend to be amplified due to the semi-enclosed nature of the basin, leading to significant changes in the assemblage of holoplanktic gastropods that provide reliable stratigraphical markers. In the western Mediterranean Sea, the gastropods proved to be more sensitive to changes than planktic foraminifera, with two distinct groupings of holoplanktic gastropods identified using cluster analysis.

This study also reveals new ecological information about the shelled heteropods, suggesting that they are more abundant and have a wider geographical distribution than previously thought. This highlights the need for increased research on holoplanktic gastropods. The threat that current global changes pose, means that some species may become extinct in our oceans before they have even been fully ‘discovered’.

Abstracts for poster presentations

Relative impact of sea level change and sediment supply on shallow offshore Niger delta margins from palynodebris and lithofacies data during the late Quaternary

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The concept of using palynodebris (palynomacerals) associated with pollen data offers additional information in the interpretation of climate, eustasy and palaeoenvironmental analysis during the last deglaciation period across the Niger Delta margin. Non-palynologists usually utilise the term 'junk' owing to their lack of awareness of the usefulness in reconstructing palaeoenvironmental change in areas where non-biostratigraphic tools (fauna, seismic, wireline logs, etc.) are biased.

This research involves a multi-proxy study based upon three gravity cores of just under 3 metres length each. These materials (Late Pleistocene to mid-Holocene in age) have been collected from the seabed (approx. 40 mbsf) from offshore locations of the Niger Delta, and have been sampled at every 2 cm implying a high-resolution study.

The palynological and lithofacies component results suggest that assemblages of palynodebris (translucent phytoclasts, opaque phytoclasts and amorphous organic matter) associated with the 5-15 micron sieved fraction, were deposited under different environmental conditions. The littoral vegetation and associated palynodebris distributions dominate over the hinterland vegetation as a result of turbidity flow, oxidation and mangrove sediment trapping mechanism restricted to the proximal settings of Niger Delta. Evaluation of palynodebris integrated with palaeovegetation, lithofacies and trace elements components have led to the recognition of palaeoenvironmental change from deltaic marginal marine through to continental shelf settings.

Mudstones with dominant mangrove pollen were deposited in the anoxic palaeoenvironments during humid climate period can be suggested to be associated with an abundance of translucent phytoclasts characteristic of estuary / tidal flats settings. Conversely, hinterland pollen and very fine sand and siltstones have been deposited during dry climate periods, in association with an abundance of opaque phytoclasts and Amorphous Organic Matter (AOM) indicating delta plain and lagoonal palaeoenvironmental settings. Palynodebris, integrated with the aforementioned proxies allowed the interpretation of depositional settings especially in this case of limited deltaic floral diversity.

Palaeoecology inferred from LA-ICPMS depth profiles of Eocene planktonic foraminifera

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Differences in planktonic foraminiferal ecology, such as depth habitat, cause species to have geochemical offsets. Since geochemical proxy data are used to infer deep-time palaeoceanographic conditions (e.g. Mg/Ca for sea surface temperatures), it is important to constrain the palaeobiology of extinct species in order to improve our understanding of the validity of the proxy signals obtained.

The palaeoecology of many Cenozoic planktonic foraminiferal species has not been determined. Eocene sediments were recovered from Ocean Drilling Program Leg 174AX, Bass River, New Jersey, USA (Miller *et al., 1998*). This study focuses on the interval from 56 – 39.8 Ma, covering a time of dramatic climatic change from peak warmth during the early Eocene climatic optimum and subsequent temperature decline. The sediments contain extremely well-preserved, glassy planktonic foraminifera with very diverse middle Eocene assemblages, allowing multispecies geochemical analyses to reconstruct marine temperatures and thermocline carbon isotope gradients.

Trace element/Ca ratios of individual chambers of various species of surface and deep dwelling planktonic foraminifera (including *Pseudohastigerina wilcoxensis, Acarinina pseudotopilensis,* and *Morozovella formosa)* were obtained by slow depth profiling, utilising laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) as an analytical technique capable of achieving (sub)µm vertical spatial resolution.

Results show minor offsets between different species consistently through time. Concentrations also vary between each foraminiferal chamber. Changes in trace element/Ca ratios with size will be presented. Data obtained in this study will be useful to compare to other sites of exceptional preservation, and for reconstructing sea surface temperature gradients in the Eocene greenhouse.

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

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The Holocene reconnection of the Black Sea to the Mediterranean has provoked debate on several issues including Black Sea salinity prior to the establishment of the present two-way flow through the Bosphorus Strait. Fossil ostracod analyses in sediment cores from the south-western shelf of the Black Sea facilitate a qualitative reconstruction of past salinity levels.

Ostracod preservation is good throughout and often excellent, with occasional soft-part preservation. Taphonomic analyses show that most of the significant taxa are *in situ* (with suites of adult and juvenile moult stages) and show little evidence of post-mortem transport, mixing or size-sorting. Before the reconnection, 'caspi-brackish' assemblages including *Amnicythere olivia* (Livental, 1938), *Amnicythere quinquetuberculata* (Schweyer, 1949),

Candona schweyeri Schornikov, 1964, *Euxinocythere bacuana* (Livental, 1929) and *Loxoconcha lepida* Stepanaitys, 1962 are present, indicative of low-salinity brackish water. There is no evidence for freshwater as has been claimed by some authors; indeed there is marked absence of typical freshwater ostracods such as are common in surrounding areas today as well as in the Holocene. After reconnection, assemblages typically include marine species with Mediterranean affinities such as *Carinocythereis carinata* (Roemer, 1838), *Cytheroma marinovi* Schornikov, 1967, *Hiltermannicythere rubra pontica* (Dubowksi, 1939) and *Palmoconcha agilis* (Ruggieri, 1967).

Mediterranean sea surface temperatures during the Younger Dryas stadial in the Late Pleistocene based on planktonic foraminiferal assemblages: Preliminary results

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Planktonic foraminiferal assemblages from the Mediterranean Sea have been used extensively to reconstruct the significant changes in sea surface temperatures (SSTs) in our recent glacial/interglacial past. Techniques such as Artificial Neural Networks (ANN) have been developed to accurately reconstruct spring, summer and annual SSTs for the Last Glacial Maximum (LGM). In this study, we will use ANN to reconstruct the SSTs of the Younger Dryas (YD) cold period in comparison to similar studies of the LGM.
Consensus has not yet been reached in the literature on definitive dates for the YD in the Mediterranean region. To obtain a reliable age range for the Younger Dryas, a review of published calibrated ^{14}C dates from marine data was conducted and an average of the start and end dates was determined (11,600 – 12,800 kyr).

A desktop study of dated, >150 µm planktonic foraminifera from published and unpublished marine sediment cores was undertaken. Complete faunal counts from samples within +/- 50yrs of the defined YD age were collated from 29 cores (to-date) and analysed using ANN to determine the SSTs during the YD period. The resulting SSTs are presented in comparison with the LGM. In addition, faunal distribution maps of key species during the YD allow visualisation and interpretation of the spatial ranges of species, from which we can infer possible temperature and salinity preferences, as well as the influence of ocean circulation and global climatic teleconnection patterns between the Western and Eastern Mediterranean basins.

Diatom assemblage variation and stable isotopes provide evidence for environmental change driving microevolution in Miocene sticklebacks (*Gasterosteus doryssus*)

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Exceptionally preserved three-spine sticklebacks (*Gasterosteus doryssus*) from the Miocene diatomite of the Truckee Formation of Nevada, USA, provide a rare fossil example of finely resolved, directional microevolution through an interval of ~20 ka. The stickleback

themselves have been subject to extensive study, but little has been done to investigate whether microevolutionary change correlates in any way with palaeoenvironmental changes in the lake where they lived. Here we test this hypothesis using microfossil data (diatom assemblages) and isotope ratios ($\delta^{13}C_{bulk}$, $\delta^{13}C_{diatom}$ and $\delta^{18}O_{diatom}$) as proxies for environmental and climatic change. Our analysis reveals that these proxies record a palaeoenvironmental trend towards increased evaporation, causing decreased lake-level and increased productivity. This interpretation is based on changes from a diatom assemblage dominated by planktonic forms to one dominated by benthic forms, supported by increasing $\delta^{18}O_{diatom}$ interpreted as a result of increased evaporation. This environmental trend correlates with the evolutionary changes in stickleback morphology, but the hypothesis that this reflects a causal relationship is difficult to test. We propose that a reduction in lake-level potentially drove stickleback microevolution by shifting predation pressures, linked to increasingly benthic habitats in a shallower lake. Such adaptive morphological responses to changes in predation pressure are well documented in extant stickleback but this may be the first evidence for comparable adaptive responses in the fossil record.

Understanding ocean-atmosphere teleconnections since the Last Glacial Maximum: micropalaeontological and isotopic reconstruction of sea surface temperature, benthic temperature and productivity offshore South Georgia, Southern Ocean

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To assess climate sensitivity and place recent environmental changes within a historical context it is vital to develop an understanding of how the Southern Ocean evolved during the transition from the Last Glacial Maximum to the present. This project will investigate how the fronts associated with the Antarctic Circumpolar Current (ACC), a potential source of atmospheric CO_2 during the last deglaciation, varied around South Georgia during this time period. South Georgia is of particular significance because it sits in the path of the ACC, between the Antarctic Polar Front (APF) and the Southern ACC Front (SACCF). Changes in the interaction of the SACCF with the South Georgia shelf, the primary nutrient source feeding the South Georgia bloom, the largest sink of CO_2 in the Southern Ocean will provide information about natural variability in the ACC through the Holocene and its sensitivity to the Southern Westerly Winds.

This study will produce micropalaeontological and geochemical proxy records of temperature, salinity, nutrient availability, productivity and water column structure, from suite of cores along continental shelf north of South Georgia. To produce these records the project will use a range of proxies including benthic foraminifera and diatom assemblages, stable isotopes, palynology, biogenic silica, grain size analyses, organic carbon, and C/N ratios. A multiproxy approach is critical for a robust reconstruction of palaeoenvironment and water column properties, and to allow comparison of these records with those from other Southern Ocean localities.

Priority research questions in morphology and micropalaeontology today

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Morphology is the most fundamental and longest established means of observing an organism. It is the basis for most systematic descriptions of life and is the main means for understanding evolutionary, physiological, ontogenetic and functional processes in organisms both past and present. In recent years there has been a resurgence in the popularity of morphometrics in micropalaeontology for two main reasons; (1) an increase in the relative ease and diversity of techniques now available to both image and analyse morphologies and thus, the range of questions that these datasets can address and (2) a motivation to understand the impact of anthropogenic climate change on marine organisms in the modern and future oceans, including identification of high risk species and areas, extinction precursors, quantification of species' adaptive potential and so on. Here we present the results from a one-day discussion workshop held at the Royal Netherlands Institute for Sea Research (NIOZ) on Texel in June 2014. The aim of this workshop was to bring together scientists with different backgrounds to produce a coherent synthesis of the priority research questions in micropalaeontological morphometrics, a field of study that spans multiple disciplines (e.g., molecular phylogeny, evolution, ecology, micropalaeontology and geochemistry) and timescales (modern to multi-million years). We present a summary of the priority questions that emerged from this process and outline how these may be used to drive forward new research agendas in micropalaeontology.

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The Mesozoic benthonic foraminifera of the Middle East

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The Iraq Petroleum Company (IPC) Collection of Palaeozoic, Mesozoic and Cenozoic foraminifera in the Natural History Museum, London, contains examples of approximately 254 genera and 586 species. Whittaker et al. (1998) provided a review of about 100 of the most important Mesozoic species in a book of limited availability, as it was specifically aimed at the petroleum industry.

An enormous amount of work has subsequently taken place through oil exploration throughout the Middle East, especially in countries that were not covered at all (or at best, hardly covered) by the IPC Collection, and this is particularly true for Saudi Arabia. As a

consequence, in collaboration with Wiley Blackwell, a major revision of the 1998 publication is being undertaken. This new book will substantially increase the number of species originally covered to include some 250 taxa from across the Mesozoic Middle Eastern realm. In addition, all the original content will be revised and updated and state-of-the-art biostratigraphic, lithostratigraphic and palaeoenvironmental information for each species will also be provided. A dedicated section to the use of foraminifera as a tool for sequence interpretations and palaeoenvironmental reconstructions will also be provided. The publication is expected to be in print in late 2015.

The purpose of this book is to provide a single source, ready-reference to enable fellow micropalaeontologists to identify ("larger") benthonic foraminifera from the Mesozoic of the Middle East and to evaluate their biostratigraphic and palaeoenvironmental utility. This will in turn provide a valuable adjunct to regional correlations, well-site biostratigraphy and reservoir reconstructions.

A new Jurassic micropalaeontological biozonation for the Saudi Arabian subsurface

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Micropalaeontological biozonation of the Jurassic of the Middle East, especially Saudi Arabia, has historically been poorly established, and shown to have limited regional and pan-Tethyan applicability. This difficulty was based on the inability to apply global schemes based on open marine forms, such as planktonic foraminifera and calpionellids, to the extensive and relatively shallow, often hypersaline carbonate platforms that persisted throughout much of the Jurassic. Intrashelf basins with restricted open marine access further inhibited the use of standard global tropical planktonic biozonations.

Pioneer fieldwork established chronostratigraphic constraint to the various Jurassic formations and members, using ammonite, nautiloid, brachiopod and limited foraminiferal stratigraphy of which the macropalaeontological schemes are impossible to use in subsurface-derived limited rock samples such as those from cuttings, sidewall cores and cores of lithified carbonates. A recently completed core-based thin-section micropalaeontological reassessment of the Saudi Arabian Jurassic has revealed a moderately refined benthonic foraminiferal and microfossil bioevent scheme that should assist age assignment, palaeoenvironmental interpretation and assistance towards identifying the various formations and members during exploratory drilling. In the absence of other disciplines, this scheme is intended to assist chronostratigraphic and lithostratigraphic assignment to "hot-shot" samples and single well interpretation and in addition provide calibrative and correlative support for multiwell single field and regional studies. Twenty informal biozones are proposed, and serve as an initial scheme for modification when additional events are encountered.

Investigating the benthic foraminiferal Stilostomellid Extinction and mid-Pleistocene phytoplankton evolution

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As global climate cooled during the Mid Pleistocene Transition (MPT, ~1.1–0.6 Ma), the last great extinction of benthic foraminifera occurred. The so-called 'Stilostomella Extinction' saw the disappearance of almost two families of elongated uniserial species with distinctive apertural architecture. The stepwise extinction consisted of a gradual disappearance at different water depths and ocean basins over successive glacials. Understanding the causes of this extinction has proven difficult, in part because ecological preferences are not well known, and because their extinction has not been documented in high resolution along with other palaeoenvironmental proxies. For instance, one hypothesis for the extinction is lowering bottom water temperature.

We present new high-resolution (~5 ka time step) benthic foraminiferal data from ODP Site 593 in the Tasman Sea (~1068 m water depth) through the MPT, and compare with new intermediate water temperature (benthic Mg/Ca) and surface water productivity proxies (nannofossil assemblages and sediment pigment analyses). Extinction group occurrences do not correlate with intermediate water temperature. There are, however, clear changes in surface water productivity associated with the final phase of the extinction, at ~0.85 Ma. Pigments increase in abundance, indicating elevated glacial productivity across the MPT. Coccolith assemblages shift towards small *Gephyrocapsa* spp., and extinction occurs within the *Reticulofenestra*, both of which are global events. Comparisons with the Pacific and Atlantic Ocean extinction data indicate 0.85 Ma as a critical time interval in the global Stilostomella Extinction. This evidence strengthens the hypothesis that changes in the type of organic carbon reaching the sea floor, driven by reorganization within marine phytoplankton communities, may have been linked to the disappearance of the extinction group.

A *Braarudosphaera* acme and phytoplankton dynamics at the Oligocene/Miocene Boundary (IODP Exp. Site U1405, NE Atlantic)

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Braarudosphaera-bearing oceanic sediments have been reported from various geological times and localities. As *Braarudosphaera* is a neritic genus, the cause of their open ocean occurrences has been questioned yet no completely satisfactory explanation has yet been provided. Recently, another *Braarudosphaera*-rich horizon of Oligocene/Miocene age was recovered by International Ocean Drilling Program Expedition 342 (Site U1405) near the J-Anomaly Ridge in the NE Atlantic Ocean. Quantitative nannoplankton data show that the acme event lasted around 4000 years, during which the relative abundance of *Braarudosphaera* increased from zero to 47.3%. Based on the abundance changes of other species within the population, oceanic conditions (temperature and productivity) did not change significantly during this time. Therefore, we can exclude major environmental change, such as upwelling, as explanations for the presence of Braarudosphaera at Site U1405. Instead, we suggest that abundant Braarudosphaera from the adjacent shelf area

were carried by surface currents, perhaps associated with Gulf Stream eddies that may have strengthened during the Mi-1 glaciation event.

Globigerinoides ruber (w) morpho-specific response on past SSS and SST changes inferred from stable isotopes and geochemical proxies (Mg/Ca, Ba/Ca): A Gulf of Mexico Perspective

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Globigerinoides ruber (w) morphotypes have been shown to pose distinct $\delta^{18}O$ and Mg/Ca compositions. Application of this information to the sediment core JPC-26 in the Gulf of Mexico (GOM) shows the differential response of *G. ruber* sensu stricto (s.s) and *G. ruber* sensu lato (s.l.) during the last 21 kyr_{cal} B.P., regarding to changes in sea surface temperature (SST) and salinity (SSS).

For palaeotemperature reconstructions we measured Mg/Ca ratios on both morphotypes, with the difference in Mg/Ca-Ts (ΔT) of the "surface morphotype" and the "mixed layer morphotype" to be indicative of the upper water column stratification. For palaeosalinity reconstructions, we present a $\delta^{18}O_{SEA\ WATER}$ ($\delta^{18}O_{SW}$) record, reconstructed from Mg/Ca ratios and $\delta^{18}O$ measurements. Moreover, we also measured Ba/Ca ratios in *G. ruber* s.s. and *G. ruber* s.l., as a proxy for North American riverine discharge. Overall, the reconstructed SST and SSS patterns reveal notable amplitude variations between the two morphotypes, adding valuable insights to previously published *G. ruber* (w, mixed) GOM records. Especially during the deglacial GOM meltwater flooding events (GOMs), the sea surface freshening seems to be more pronounced than the SST reduction. The comparison between the two morphotypes also shows that Ba/Ca and $\delta^{18}O_{SW}$ of *G. ruber* s.l. appears to be more sensitive to river water influence, which potentially makes the s.l. morhotypes more opportunistic than the s.s. morphotypes during the largest low-salinity Mississippi flooding events.

Late Quaternary palaeoenvironmental reconstruction of South Evoikos Gulf (east – central Aegean Sea) by benthic foraminiferal assemblages

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The present study is aiming to track the palaeoenvironmental evolution of South Evoikos Gulf during the Holocene, utilizing benthic foraminifera microfauna. South Evoikos Gulf constitutes a shallow epicontinental basin, at the northern prolongation of the Cycladic Platform (Western Aegean Sea, East – Central Greece). The gulf is divided into two sub-basins: a southern deeper basin with a maximum depth of 160 m and a northern shallow one where water depth ranges from 20 to 70 m. The study area is located at the latter.
A gravity core of 150 cm total length which sedimentary record covers the last 13540+/-50 cal yr BP, was retrieved from 75.5 m water depth and a benthic foraminiferal analysis was

carried out on 88 samples. Relative abundances, cluster analyses, and faunal parameters, such as diversity indices, were performed in order to recognize significant variations in the assemblages and to trace the local palaeoenviromental conditions. The environmental interpretation of the results from the benthic foraminiferal analysis present strong evidence that a restricted, quite shallow, less than 30m deep, oligohaline lagoon was formed sometime before 13540 cal yr BP which maintained until 11065 cal yr BP. Subsequently, during the Holocene, an unrestricted communication with the sea was established and a marine coastal environment was formed.

A Diatom Record of Oceanographic and Sea Ice Variability from the Amundsen Sea

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Accelerated melting of ice-streams terminating in the Amundsen Sea Embayment over recent decades, with consequences for global sea level, has directed attention towards the cause(s) of these changes. The upwelling of relatively warm circumpolar deep water (CDW) has been implicated in increased basal melting, yet the long-term variability of regional ocean forcing and related sea ice dynamics remain poorly constrained. Using material from three mid-shelf sediment cores, this study presents a diatom assemblage record of surface water and sea-ice conditions since deglaciation of the embayment c. 14 ka. Multivariate statistical analyses (principal component analysis and cluster analysis) reveal three relatively distinct floral assemblages. Intense water column stratification is inferred during the late Pleistocene (c. 14-11 ka), followed by evidence of significant glacial meltwater production and increased deep-water influx in the early Holocene (c. 11-7 ka). A shift towards assemblages dominated by sea-ice associated taxa at c.7 ka suggests increased sea-ice presence since this time, with the decline of the late summer species *Thalassiosira antarctica* implying a shorter growing season from c. 3 ka. However, continuous diatom sedimentation and the sporadic occurrence of CDW-proxy species *Fragilariopsis kerguelensis,* particularly in the eastern sector, indicates that the influx of warm water was sufficient to sustain a seasonally productive water column throughout the record despite the southerly latitude and increased sea-ice coverage of the mid and late Holocene.

Two case studies in evolution: *Turborotalia* and *Hantkenina* (Eocene planktonic foraminifera)

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The fossil record of planktonic foraminifera (marine protists with calcite tests) is remarkably complete. A species can be continuously present in deep-sea cores in high abundance across millions of years – all the way from its first to last global appearance. We can address questions of speciation, evolution, and extinction that in other fossil groups are difficult because of incompleteness and sampling bias. As well as scientific opportunities, the record also forces us to confront some basic issues of terminology and methodology. What do we mean by completeness and continuity of record? If all in nature is flux, what do we mean by recognizing 'species' or 'lineages' as entities that persist through time? These themes are illustrated by two recently published case studies from the Eocene. In the first example, the

Turborotalia cerroazulensis lineage (Pearson & Ezard, 2014), 10,200 individual tests from 51 populations spanning 12 million years of geological time were individually picked, oriented, measured, and curated. Novel multivariate clustering statistics were used to test the hypothesis that a single evolutionary species was present across the entire time interval, despite substantial lasting morphologic change, with surprising results. In the second example (Pearson and Coxall, 2014) an active search was made for the origin of a distinctive genus, the tubulospine-bearing *Hantkenina*, previously upheld as an example of 'punctuated' or sudden evolution. By sampling the precise stratigraphic interval, a series of morphological intermediates was discovered, showing how and when tubulospines evolved, how long it took, and from which ancestor.

How gradual is gradual speciation? A morphometric assessment of planktic foraminifer speciation in the Pliocene

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The balance between anagenesis (gradual change within a lineage) and cladogenesis (lineage branching) in the evolution of planktic foraminifera is litigious, In light of molecular genetic evidence of 'cryptic' species (multiple genotypes) within modern single morphospecies, the validity and utility of fossil morphospecies is questioned. Although arbitrary morphospecies delimitation is a necessary facet of long-ranging fossil lineages that exhibit gradual morphological change, 'cryptic' events may be elucidated with high-resolution biostratigraphic and morphometric studies. To what extent do general anagenetic trends mask cladogenetic branching events?

The extant *Globigerinoides sacculifer* (with sac-like chamber) is a long-ranging morphospecies which gave rise to the morphologically bizarre *G. fistulosus* in the mid-Pliocene. By contrast with *G. sacculifer*, *G. fistulosus* is a short-ranging, extinct morphospecies with distinctive finger-like protuberances on the final chamber(s). The appearance of the protuberances has been previously described as an anagenetic trend, showing directional change towards progressively larger protuberances. Therefore the *G. fistulosus* speciation is apparently a 'pseudospeciation' event. The unmistakeable protuberance attainment provides an excellent opportunity to examine the role of anagenesis in this event.

High-resolution biostratigraphic and morphometric data are presented from ODP Site 1115 (SW Pacific) and will be compared to tropical Atlantic Site 926. Forms with incipient protuberances show a proportionate increase within *G. sacculifer* populations leading up to the appearance of *G. fistulosus* sensu stricto. However, these incipient protuberances are no larger than those observed in recent *G. sacculifer*, and the development of true protuberances appears to be a later cladogenetic event only revealed by high-resolution sampling.

Coccolithophore preservation and growth rate over the Eocene/Oligocene Transition in the Equatorial Pacific

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Using the Sr/Ca proxy, we have produced direct records of coccolithophore growth rates from the equatorial Pacific (IODP site U1334) across the Eocene/Oligocene transition (E/OT), ~34 to 33.5 Ma, from both individual coccoliths and bulk coccolith calcite. The E/OT is the most extreme period of climate change in the Cenozoic as the climate shifted from a 'Greenhouse' to an 'Ice House' within ~400 ky. The data reveal a significant shift in coccolithophore Sr/Ca (growth rate) over the E/OT, linked with changes in both $\partial^{13}C$ and $\partial^{18}O$. This shift may be associated with changes in nutrient cycling and/or ocean thermal structure due to changes in ocean circulation.

Due to their small size, coccoliths are often perceived to preserve poorly. Coupled with this, until recently, it has been difficult to obtain species-specific geochemical data for individual specimens. We demonstrate the preservation of primary coccolithophore calcite from the U1334 sediments supports the further use and interpretation of both coccolith trace element and stable isotope data as proxies for past environmental change. Using SIMS and TOF-SIMS (Time of Flight - Secondary Ion Mass Spectrometry) it has been possible to examine the distributions of different ions within individual coccoliths, demonstrating the presence of primary biogenic calcite, and identifying that the effects of diagenesis can often be overcome. The proportion of abiogenic to biogenic calcite further suggests that reliable results of coccolith geometry can be obtained from bulk samples.

Meet the ancestors: Exceptional insights into past coccolithophore communities using fossil coccospheres

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Coccolithophore coccospheres incorporate aspects of each individual cell's growth and life history. Exquisite fossil coccospheres from remarkably well-preserved Palaeogene sediments

uniquely capture information on size, growth, and levels of organic and inorganic carbon from cells that were living 65 to 23 million years ago. The cellular parameters recorded in each coccosphere enables direct comparison with modern cells, facilitating exciting new approaches that explore the physiology of ancient species. Many of these species have never been observed or imaged as coccospheres before. We present our observations of coccosphere architecture for many now-extinct species (approximately 40 species), some of which are ancestors of modern taxa, and quantify this through measurements of coccosphere geometry (coccosphere size, number of coccoliths per cell and coccolith length). While larger coccospheres are typically comprised of larger coccoliths, we also find that the number of coccoliths per cell can vary significantly both within and between species. We also observe coccolith poly- and varimorphism around individual coccospheres, as well as a variety of sphere shapes found in modern coccolithophores such as elliptical and ovoid. Understanding extinct coccosphere architecture gives us a unique means to reconstruct coccolithophore population size structure across the long-term and more rapid environmental changes of the Palaeogene, providing a cellular perspective to community and species evolution.

The former British Petroleum Northwest European Reference Collection

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The former British Petroleum Microfossil Reference Collection was acquired by the Natural History Museum in 1992 along with well material from over 3,800 global well successions. It consists of nearly 40 years of reference material selected by industry experts which relates to the exploration and production of the North Sea and surrounding areas. As part of a larger study into the stratigraphic and palaeoenvironmental reconstructions within this region through geological time, the NW European section of the reference collection has recently been re-imaged and re-identified using up-to-date techniques and classification. It is hoped that soon the information will be available online through the Natural History Museum's web portal and the reference collection is always available on appointment at South Kensington, London.

The re-analysis of the reference collection has shed new light on taxa originally described through the industrial practices in the North Sea that have since had a knock-on effect on today's academic understanding. An example of this is the British Petroleum reference slide for *Ammobaculites hockleyensis*. This particular taxon was originally described from the upper Eocene of Texas, USA (Cushman & Applin, 1926). The collection specimen, *Ammobaculites* cf.*hockleyensis* is from the Kimmeridgian of Dorset and has subsequently been referenced in literature without the cf. label. Therefore its current use as a North Sea marker is taxonomically incorrect.

All-in-all this is a resource that has been re-vitalised in view to offering a world-class reference to modern academics and industrial biostratigraphers alike.

Improved taxonomic classification of *'Globigerina praebulloides'* using a multivariate statistical clustering method

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Globigerina bulloides d'Orbigny is an abundant modern species of planktonic foraminifera, and is used extensively in palaeoceanography to reconstruct past environmental change. However, uncertainty exists over the taxonomy and habitat of supposedly ancestral forms from the upper Oligocene and Miocene that have often been included in *'Globigerina praebulloides'* Blow. While *G. bulloides* is commonly assumed to have evolved from *'G. praebulloides'* in the middle Miocene, foraminifera from the uppermost Oligocene have recently been described as being morphologically similar to modern *G. bulloides* (Pearson & Wade, 2009). It has also been suggested that these Oligocene forms may have hosted algal symbionts, unlike modern *G. bulloides,* and so had a different ecology (Pearson & Wade, 2009). For accurate interpretation of geochemical proxy records that use calibrations based on modern *G. bulloides*, a quantitative understanding of the relationship between modern and morphologically similar fossil forms is vital.

A suite of morphometric traits will be measured on individuals of *'G. praebulloides'* and related forms from the early Oligocene to middle Miocene, using exceptionally well-preserved material from IODP Expedition 342, and modern material for comparison. A multivariate statistical clustering method will be applied to these measurements (Ezard *et al.*, 2010). This will enable quantitative analysis of intra- and inter-species morphological differences (and similarities), thus enabling a robust statistical determination of the timing of morphological divergence to the point of taxonomic separation. SEM imaging of wall structures will allow further quantification of morphological differences, and stable isotope measurements will be used to investigate the relationship between morphology and geochemical proxy measurements.

Calcareous nannofossil assemblages of the Mossy Grove core, Mississippi, USA

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The Mossy Grove core, of Hinds County Mississippi, recovered 167.6m (550') of the late Eocene and earliest Oligocene (~38 to ~33 Ma; uNP17-21) Yazoo Clay. Here we present a study of the taxonomy and assemblage variations of the well-preserved calcareous nannofossils present throughout this core. Calcareous nannofossil assemblages are relatively diverse, dominated by *Reticulofenestra* species but with significant additional components from the Pontosphaeraceae, Helicosphaeraceae, Rhabdosphaeraceae, holococcoliths and nannoliths. Scanning Electron Microscope (SEM) imaging demonstrates that the quality of preservation is similar to that of other clay-rich continental margin facies, such as the early Palaeogene New Jersey margin, and the Cretaceous and Tertiary of coastal Tanzania. With inferred progressive cooling through the late Eocene, we document the increase in abundance of temperate to cool-water species, such as *Reticulofenestra daviesii* and *Isthmolithus recurvus* prior to the Eocene/Oligocene transition.

Deep water circulation in the Eocene greenhouse

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Over 46 years of international ocean drilling, deep-sea cores have revealed a discontinuous stratigraphic record which contain major hiatuses. These hiatuses provide valuable information on the deep-water circulation of ancient oceans. Furthermore, because the vigour of bottom-water flow and its erosive capability is governed by the amount of deep-water formation, hiatuses can be closely linked to climatic change. An interesting period in the study of past climate is the Eocene (~56 to 33.9 million years ago). This greenhouse world was characterised by a reduced equator-to-pole thermal gradient and an absence of permanent ice at the poles; for this reason, the nature of deep-water circulation and its role in the redistribution of heat is poorly understood.

Using core data from the ODP and IODP, the temporal and spatial pattern of hiatuses across the Eocene Atlantic and Indian Oceans are presented. Age-depth models, created using biostratigraphy and magnetostratigraphy, reveal the presence of six Eocene hiatus events. Mapping of these events demonstrate multiple ocean hiatuses during the Middle Eocene, whilst Early and Late Eocene events are more spatially restricted. Comparison with the palaeoclimatic/palaeoceanographic record reveal a shift in oceanic circulation around 40.5 Ma where deep water formation switched from a dominant Southern Ocean to a bipolar source. The Early Eocene was characterised by a sluggish oceanic circulation, ineffective in the transport of heat to high-latitudes. In comparison, the Late Eocene was characterised by a vigorous oceanic circulation. The transition at 40.5 Ma suggests an earlier influence of North Component Water than widely documented.

Late Jurassic to Early Cretaceous dinoflagellate cysts from the Eastern Gulf of Mexico: Facilitating future exploration and development activities in the basin

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The Late Jurassic to Early Cretaceous deposits of the Eastern Gulf of Mexico (EGoM) are one of the world's major hydrocarbon reserves. However, the Gulf of Mexico is a structurally complex area in terms of its tectonic setting. This unusual basin therefore requires establishment of a high resolution biostratigraphy to facilitate correlation and aid understanding of its sedimentary fill. Unfortunately there is a distinct lack of published studies on dinoflagellate cysts from these strata. This research project aims to fill that data gap by producing a high resolution dinoflagellate cyst biostratigraphy from data collected from three wells around the EGoM. 175 samples have been processed and analysed using light microscopy.

Rich assemblages of well-preserved palynomorphs, dominated by dinoflagellate cysts, have been recovered. These have been systematically described and quantitative occurrence/abundance data have been collected and analysed using the data storage and

analysis packages PAST and STRATABUGS. These data together with palynofacies information have been utilised in a detailed analysis of the biostratigraphy, palaeoecology, palaeoenvironments and palaeogeography of the deposits and in developing a robust high-resolution biostratigraphy. This will greatly facilitate upcoming exploration and development activities in this basin and ensure future energy security.