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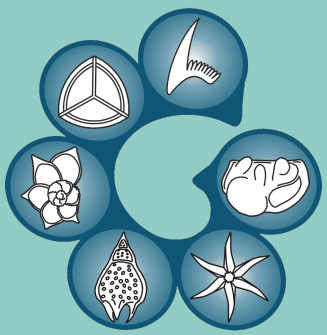
The Micropalaeontological Society Annual Conference 2022

The microfossil record of ecosystem response to global change



9–11 November 2022, Bremen, Germany

The Micropalaeontological Society

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Organizing committee:

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- Dr Raphaël Morard
- Prof. Dr Michal Kučera
- Jana Nitsch
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Programme

*All times are given as Cenral European Time (CET). Please adapt accordingly if you reside in a different time zone, e.g. using https://www.timezoneconverter.com.

Wednesday, 9 November 2022

Time*	Programme
	Workshops
9:00–12:00	Workshop for early career researchers
9:00–12:00	Workshop data analysis with R
12:00–13:30	Lunch break
	Workshops
13:30–15:15	Workshop for early career researchers
13:30–15:15	Workshop data analysis with R
13:30–15:15	Workshop PAM Fluorometry
13:30–15:15	Workshop taxonomy of modern planktonic Foraminifera
15:15–15:45	Coffee break
	Workshops
15:45–17:00	Workshop for early career researchers
15:45–17:00	Workshop data analysis with R
15:45–17:00	Workshop PAM Fluorometry
15:45–17:45	Workshop taxonomy of modern planktonic Foraminifera
17:45– . . .	**Ice Breaker**

Thursday, 10 November 2021

Time*	Programme
8:30–8:45	**Introduction by the Organizing Committee**
8:45–10:30	Talk Session 1
10:30–12:00	Coffee and Poster Session
12:00–13:30	Lunch break
13:30–15:30	Talk Session 2
15:30–17:00	Coffee and Poster Session and **TMS Annual General Meeting**
17:00–18:00	Talk Session 3
19:00– . . .	**Conference Dinner**

Friday, 11 November 2021

Time*	Programme
8:45–10:30	Talk Session 4
10:30–12:00	Coffee and Poster Session
12:00–13:30	Lunch break
13:30–15:30	Talk Session 5
15:30–17:00	Coffee and Poster Session
17:00–18:00	Talk Session 6

Contents

Part I

Annual Conference 2022—Keynotes

Monsoon strength, productivity, and coccolith export in the Bay of Bengal over the Late Pleistocene

Clara T. Bolton[1], Phyo Wai Thant[1], and Luc Beaufort[1]

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The South Asian monsoon (SAM) is the world's largest hydrological phenomenon, and its seasonal winds and precipitation impact the livelihood of billions of people on the subcontinent. Understanding its variability in the past is therefore of paramount importance for the prediction of monsoons in the future. The interplay between monsoon winds and precipitation, ocean carbon cycle feedbacks, and climate forcing mechanisms remains poorly understood. The Bay of Bengal is in the core convective region of the SAM, resulting in spatially heterogeneous physical, chemical, and biological oceanography. Tracing coccolithophore productivity and calcification is a powerful tool with which to reconstruct changing oceanographic conditions and carbon cycling. Here, we present new high-resolution records from the International Ocean Discovery Programme (IODP) Site U 1446, in the Mahanadi Basin in the northwest Bay of Bengal, a region strongly influenced by freshwater runoff from India. This runoff, which reaches a maximum during the late summer-early autumn following monsoon rains, influences upper water column structure and induces strong stratification, with impacts on marine primary productivity. Using records of coccolith mass, assemblages, and accumulation rates from Site U 1446 sediments over the late Pleistocene, we investigate the relationship between monsoon strength and runoff, coccolithophore productivity, and coccolith morphology and carbonate accumulation. During the last glacial maximum when monsoon runoff was lower, productivity and coccolith carbonate export were enhanced relative to the Holocene; the opposite pattern to that ex-

pected due to stronger monsoon wind-driven mixing. Lower photic zone species thrived under stratified conditions. We integrate our results with other regional records to better understand the net effect of the SAM on productivity and carbonate burial in the Bay of Bengal.

Adaptations of Foraminifera to oxygen depletion, their role in marine nutrient cycling, and related implications for the palaeo-record

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Benthic Foraminifera are ubiquitous marine protists that inhabit environments from the deepest part of the ocean to saltmarsh meadows. Various species of Foraminifera have specific adaptations to environmental conditions in their ecological niche. Their high abundances and metabolic adaptations in O_2-depleted environments make them key players in marine nutrient cycling.

Here I will review recent advances in understanding those adaptations. Several Foraminifera from O_2-depleted environments are able to denitrify and, thus, an important sink for oceanic reactive nitrogen. Some species even show a metabolic preference of NO_3^- over O_2 as an electron acceptor. Recent advances in genetic methods facilitated a growing number of studies on the anaerobic metabolism of benthic Foraminifera. Several enzymes for foraminiferal denitrification are transcribed by eukaryotic RNA. These denitrification steps are executed by the Foraminifers themselves and use enzymes that are known from bacterial denitrification. Still, the foraminiferal denitrification pathway is incomplete. Recent studies indicate that previously un-described enzymes or bacterial symbionts might be responsible

for the missing steps.

In addition, there is a widespread occurrence of intracellular phosphate storage in benthic Foraminifera from the deep Pacific to the German tidal flats. These Foraminifera encode genes required for a creatine phosphate metabolism. Dephosphorylation of creatine phosphate to regenerate ADP to ATP likely is another adaptation to O_2 depletion. The high intracellular phosphate storage in Foraminifera has previously been overlooked in benthic phosphorous cycling. It constitutes an important mobile reservoir in benthic ecosystems and facilitates phosphogenesis in some environments. Finally, I'll give an outlook, how we can apply our knowledge about these adaptations to palaeo-records and show examples of O_2 and NO_3^- reconstructions using the porosity of denitrifying and O_2 respiring Foraminifera.

A review of radiolarian research

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Radiolarian research has undergone many, sometimes sweeping changes. After initial 19th century biological studies, the group was nearly forgotten. The field was revived by the biostratigraphical–paleoceanographical study of Caenozoic deep sea sediments after Wordl-War II. Research shifted mostly to Mesozoic and Palaeozoic material in the 1980s to 2000s, but is now renewing a biologic focus. These trends have been driven by factors such as radiolarian fossils' scarcity in oil well sections, their use in provenance studies of tectonic terranes, and opal's poor value as a source of geochemical proxies.

Molecular biology has recently dramatically improved our knowledge

of living plankton, revealing the high abundance, diversity and relative ecological importance of radiolarians in the microzooplankton. It is also providing a first solid basis for radiolarian higher level systematics, a subject plagued until now by a lack of sufficient homologous characters and rampant speculation.

Rapidly developing artificial intelligence (AI) automatic specimen identification will greatly increase the palaeontological importance of all areas of micropalaeontology, but may in particular benefit Caenozoic and living radiolarian studies. Here, automated methods may allow for the first time routine, reasonably complete census data of radiolarian diversity, which can be as high as several hundred species in single samples. The diverse ecological and evolutionary signals of these species' occurrences should allow vastly improved studies of (mostly Caenozoic–recent) plankton evolution, palaeoecology, and palaeoceanography; particularly in climate critical polar regions and upwelling systems.

The future is exciting! Major challenges, however, include properly supporting the highly incomplete study of, and creating image libraries of, radiolarian species-level taxonomy (needed for AI methods); and improved, well supported databases, plus new analytical methods, to hold and analyse the coming flood of AI imagery and census data.

Among the living: The significance of marine protist resting stages for palaeo-environmental studies

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The formation of resting stages that can undergo long-term dormancy is

a common feature in the life cycle of marine protists. Microfossil records from the tropics to the poles and across the geological record contain resting stages, such as diatom spores and dinoflagellate cysts, that are routinely used in micropalaeontology. Over the past decade(s), resurrection ecology, single-cell approaches, and eDNA investigations have revealed the potential of resting stages as 'time capsules' that may preserve biological and genetic material under optimal conditions allowing us to directly gain information from historical populations.

In this keynote, I will present an overview of our understanding of marine protist resting stages and their potential. I will provide examples of studies and applications focusing on (1) the ecological significance of resting stages and how they may help constrain interpretations based on microfossil records; (2) the evolutionary significance of resting stages, and how they may offer insights into intraspecific level responses to environmental change; and (3) the potential significance of resting stages for the emerging field of marine sedimentary ancient DNA.

The living record of marine protists is a powerful and yet under-explored natural archive. Our understanding of ecosystem responses to global change can thus be greatly improved by combining insights from the microfossil and living records of marine protists.

Micropalaeontology as time machine biology

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Abstract

Direct observations of marine ecosystems are inherently limited in their temporal scope. Yet, ongoing global anthropogenic change urgently requires improved understanding of long-term baselines, greater insight into the relationship between climate and biodiversity, and knowledge of the evolutionary consequences of our actions. Sediment cores and microfossils included there can provide this understanding by linking data on the responses of marine biota to reconstructions of past environmental and climatic change. Given continuous sedimentation and robust age control, micropalaeontological studies of sediment cores have the potential to constrain the state and dynamics of past climates and biodiversity on timescales of centuries to millions of years. I recently dub this line of research as 'Time Machine Biology'—a synthetic science with potential to illuminate the interplay and relative importance of ecological and evolutionary factors during times of global change. I will showcase several examples from recent studies from our lab.

Yasuhara bio

Moriaki Yasuhara is an associate professor of environmental science in the School of Biological Sciences and the Swire Institute of Marine Science at the University of Hong Kong. He has broad interests in integrating organismal biology (ecology and evolutionary biology), palaeontology, and

palaeoceanography/palaeoclimatology, especially by using highly resolved micropalaeontological records. His recent research has focused on the spatio–temporal dynamics of large-scale biodiversity patterns, the impact of climate on species diversity, and the controlling factor(s) of biodiversity pattern/change in deep-sea, shallow-marine, and pelagic ecosystems. He is also interested in microfossil-based conservation palaeobiology and palaeontology of the Ostracoda in general. Recently, Yasuhara has been developing a new research direction, deep-learning-based automation in micropalaeontology
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Part II

Annual Conference 2022—Talks

Benthic Foraminifera in the Arabian Gulf: Biodiversity and geographical trends

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Utilizing a 60-year history of studies of benthic foraminiferal species distributions in the Arabian Gulf, we applied a regional-synoptic approach to evaluate the total benthic foraminiferal biodiversity in the Arabian Gulf. By compiling, examining, and integrating available data, a conservative analysis yielded 753 benthic foraminiferal species and subspecies belonging to 236 genera, 99 families, 43 superfamilies, and 11 orders. These values are comparable to those reported in other basins and are unexpectedly high, considering the extreme conditions of the Gulf. Yet these figures likely represent an underestimation of total diversity, as some areas have been poorly sampled (i.e. south-western part of the Gulf), reference materials are lacking (i.e. a taxonomic atlas), and the difficulty in the identification of taxa at species level has resulted in frequent use of open nomenclatures. We contend that these conservative figures nonetheless reflect the actual benthic foraminiferal diversity of the Gulf and reduce the number of modern species left in open nomenclature. The diverse oceanographic, sedimentological, and environmental conditions that occur in the Gulf are well mirrored by geographical trends of diversity and in the composition of benthic fo-

raminiferal species. In addition, this paper helps to unify and resolve issues relating to the use of synonyms and taxonomic-name revisions that invariably affect species counts and result in misaligned datasets. This study is part of ongoing research endeavours to establish the much-needed comprehensive knowledge of benthic foraminiferal species and diversity worldwide in the context of a rapidly changing climate.

An online taxonomic database for Cretaceous to Caenozoic deep-sea benthic Foraminifera

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Benthic Foraminifera are excellent proxies for climatic and environmental change, and provide the best fossil record of deep-sea Meso–Caenozoic biota. The number of experts providing taxonomic training to the next generation is in sharp decline, and many challenges to locate taxonomic publications put the future of benthic foraminiferal studies at risk. The decline in taxonomic knowledge imperils the accuracy of geochemical studies on benthic Foraminifera, i.e. basic palaeoceanographical knowledge.

We are building a universally accessible, high-quality online taxonomic database of deep-sea Cretaceous–Caenozoic benthic Foraminifera. It will provide an invaluable taxonomic reference for species identification, to be used to train future generations of students and professionals, and stabilize

taxonomic concepts. The database will provide immediate online access to a wealth of information, images, and expert opinions. The database uses the same platform as the successfull databases for calcareous nannofossils (Nannotax) and planktonic Foraminifera (pforams@mikrotax). A main catalogue will contain all valid species names, starting with Caenozoic–Cretaceous taxa most commonly identified in deep-sea sediments, and used in palaeoceanographical research. In addition, an original description catalogue will include the species in the main catalogue (incl. synonyms, etc.), their original descriptions, illustrations of type specimens, Scanning electron micrographs of the primary types, and English-language translations of descriptions.

The database will have a simple (queries for a taxon name), as well as an advanced search with multiple options (e.g. age, taxonomic group, age, morphological features). These will facilitate species identification and access to information on biogeographic, palaeoenvironmental, and biostratigraphical distributions, and will assist future generations of micropalaeontologists, geochemists, and others interested in benthic Foraminifera.

Funding: U.S. Science Support Program, International Ocean Discovery Program

Figure 1: Join our working group!

Modern latitudinal diversity gradients are driven by temperature modulated niche heterogeneity in marine environments

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The latitudinal diversity gradient (LDG) is the dominant ecological pattern of modern ecosystems across both terrestrial and marine ecosystems. Although this pattern has been known for well over a century, the causal mechanisms for the structure and timing of appearance of the modern LDG remain elusive. The fossil record provides the opportunity to disentangle LDG mechanisms, because the relationships among biodiversity, latitude, and possible causal factors have varied over time. We have investigated the emergence of the LDG in planktonic Foraminifera at high resolution over the last 40 million years and find that the modern-day gradient arose only 15 million years ago. Spatial and temporal models suggest this is controlled by the physical structure of the water column. Greater temperature variation within the water column at low latitudes as the planet has cooled throughout the Caenozoic has allowed species to partition by habitat, enhancing opportunities for speciation. We find higher rates of low latitude speciation steepened the diversity gradient, consistent with spatio-temporal patterns of depth partitioning by planktonic Foraminifera. Extirpation of species from high latitudes also strengthened the LDG, but this effect was weaker compared to speciation. Our results provide a major step forward in understanding the evolution of LDGs over geological time scales.

Vegetation and climate changes in the Sea of Marmara during the marine isotope stages 3, 4, and 5 (a–c)

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A giant piston core MRS-CS 27 sedimentary sequence in the Sea of Marmara (SoM) was investigated by palynological analysis to evaluate the palaeoenvironmental and climate changes, covering marine isotope stages MIS 5 (c–a), MIS 4, MIS 3, and the earliest part of the MIS 2. A warm and humid climate during the MIS 5c is documented by pollen assemblage, characterized by a broad-leaved deciduous woody taxa (mainly deciduous *Quercus*). The existence of *Fagus* and *Abies* suggests the survival of montane trees in the lowlands surrounding the SoM. This warmer phase was followed by a relatively colder and drier climate during the MIS 5b, as inferred from herbaceous assemblages. The abundant mesophyllous woody taxa within MIS 5a interval, such as deciduous *Quercus*, *Corylus*, *Betula*, *Pterocarya*, *Carpinus betulus*, *Carpinus orientalis*, *Ulmus*, and *Tilia*, indicate warm and humid climate. Thecathaya tree survived during MIS 2 on the slopes of SoM, but later disappeared from the region.

When in ontogeny do species differences emerge? A case study of a fossil planktonic Foraminifera lineage

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During their lifetime, individuals can often adjust their state in response to environmental conditions. This plasticity in developmental history is hypothesized to stimulate the expression of novel trait combinations, increasing mean population fitness and accelerating local adaptation. However, very few empirical data exist to test this hypothesis on macroevolutionary time scales, as developmental history is often impossible to reconstruct from fossilized remains.

Here, we use the exceptionally rich fossil record of planktonic Foraminifera to study ontogenetic shifts in deep time. Foraminifera retain their entire life history inside their calcium carbonate shells, allowing for detailed morphometric analyses at different ontogenetic stages. We analyse morphological changes before, during and after speciation in the *Menardella limbata–Menardella exilis–Menardella pertenuis* lineage to study changes to the timing of developmental processes. Using micro-computer tomography scans, we plot individual chamber coordinates in xyz-space and reconstruct three-dimensional growth trajectories with a new custom-made R package, 'Foram3D'. The package functions calculate distances and angles between subsequent chambers, quantify trochospirality and reconstruct 'Raupian' coiling parameters at every growth stage, and determine the number of chambers per whorl at the time each chamber was built.

The resulting developmental trajectories show that three-dimensional growth varies among species from the neanic and adult stage onwards. The

angles between subsequent chambers increase after a species-specific size threshold is crossed, resulting in an increase in chambers in the final whorl and reduced chamber growth rates. Similarly, trochospirality ('steepness' of the shell spire) decreases at different chamber numbers among species, resulting in species-specific adult shell shapes. These results suggest that ontogenetic constraints can be overcome, resulting in novel morphologies and new species.

Automatic image classification of middle Eocene tropical Atlantic radiolarian assemblages (ODP Leg 207) with the help of artificial neural networks

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The Middle Eocene siliceous chalk drilled on Demerara Rise during the ODP Leg 207 (equatorial Atlantic) yielded a well-preserved and extremely diverse radiolarian fauna, containing over 500 species, the majority of which still wait to be described. The middle Eocene sedimentary sequence is particularly expanded, as it consists of a *c.*90 m thick sedimentary pile that accumulated during *c.*4 million years. The sedimentary sequence is well dated and an orbital time framework is available for Site 1260. In an attempt to decipher the biotic response of tropical radiolarian plankton with respect to the overall climate cooling and the middle Eocene climatic optimum (MECO). Our study involves the use of artificial neural networks to automatically classify images of the entire middle Eocene radiolarian assemblages.

As a first step to achieve this objective we created a new large image

dataset of middle Eocene radiolarians from Sites 1258, 1259, and 1260, obtained with the help of a Nikon Eclipse Ni automatic microscope. Our aim is to have at least 100–1000 images/specimens per class (analysed taxa). Our biggest challenge is to find enough images for each class (taxon) as radiolarian diversity is extremely large, since it also includes many rare species. The data labelling is performed with the use of the ParticleTrieur software. At first the labelling is supervised, but once several images have been classified it is possible to use auto labelling with the help of k-nearest neighbors and trained convolutional neural network (CNN) algorithms. Our current attempts, effectuated on a dataset of *c.*9500 classified images divided into 63 different classes, obtained an accuracy of about 77 % by training on a ResNet50 CNN.

Pelagic carbonate production during Caenozoic warm periods

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Pelagic carbonate producers play a key role in the marine carbon cycle by exporting carbon from the surface to the deep ocean. The production of biogenic calcite in the surface ocean is both influenced by and influencing atmospheric carbon concentration. Because of its important role in the carbon cycle, understanding how pelagic carbonate production has changed in past warm periods is of interest.

Past changes in carbonate production can be derived from sediment-

ary records of carbonate accumulation in settings where the effect of post depositional dissolution is negligible. Here we used the high resolution and orbitally dated Ceara Rise sediment record to qualify and quantify the past changes in pelagic carbonate production, to disentangle the relative contribution of the two main pelagic carbonate calcifiers to the total carbonate flux and the reasons behind it, and finally, the orbital imprint in these processes, since the Early Miocene. We generated a new high resolution record of $CaCO_3$ accumulation rate (AR) at ODP Site 927 from Early Miocene to Late Quaternary, which is not markedly affected by dissolution prior to the Quaternary. Finally, a morphometric study (sizes and shapes) on a large number of specimens and a counting for both the coccoliths and the Foraminifera has highlighted a change of this production driven by the number of specimens rather than their sizes. Our spectral analysis shows that the pelagic carbonate production in the Equatorial Atlantic Ocean mainly varied with orbital periodicity. Furthermore, making the distinction between the two main pelagic carbonate producers, we found that both their relative contribution to the total carbonate flux and the phase relationship of this relative contribution with the orbital forcing has changed through the time.

A quantitative nitrate reconstruction on denitrifying benthic Foraminifera in the intermediate Pacific through an automated image analysis technique

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Increasing human population and the related increase in use of chemical fertilizers is altering the marine nitrogen cycle on a global scale. Nitrate (NO_3^-) is an important macronutrient that can be limiting in some marine environments. Various box modelling studies revealed elevated NO_3^- levels during the glacial period due to reduced denitrification in the water column and seafloor sediments. Here, we generate a widespread, quantitative reconstruction of bottom-water NO_3^- concentrations ($[NO_3^-]_{BW}$) in the intermediate Pacific covering the last deglaciation. We developed an automated technique to recognize pores in foraminiferal tests based on a deep-learning algorithm. Then, we utilize the pore density (number of pores) of the denitrifying benthic foraminifer *Bolivina spissa* as a proxy for deglacial $[NO_3^-]$ at the Mexican and Peruvian Margins. This denitrifying species is abundant in oxygen-depleted environments all around the Pacific and is able to use NO_3^- as an electron acceptor instead of oxygen. Our study shows higher $[NO_3^-]_{BW}$ during the last glacial maximum compared to the Holocene. Nitrate is found to be relatively low at all locations during Heinrich Stadial 1. In addition, we found a similar correlation between the $\delta^{13}C$ and $[NO_3^-]_{BW}$ records at our locations to that in the water column of the modern Pacific. Thus, we suggest that $\delta^{13}C$ of epibenthic Foraminifera might be used as a nitrate proxy in the intermediate Pacific as well.

BENFEP, a quantitative database of BENthic Foraminifera from surface sediments of the Eastern Pacific

Iván Hernández-Almeida[1], Víctor Gónzalez-Guitián[2], Rita González-Villanueva[2], Aida Ovejero[3], and Paula Diz[2]

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The Deep Ocean Observing Strategy adopted by UNESCO aims to improve the understanding of benthic ocean ecosystem for establishing adequate conservation strategies and planning for sustainable oceans. Foraminifera are important components of the ocean benthos and play a major role in ocean biogeochemistry and ecosystems functioning. Generating ecological baselines for ocean monitoring requires a reference dataset of recent census data. In this study, we provide the first quantitative **BEN**thic **F**oraminifera database from surface sediments of the **E**astern **P**acific (BENFEP). Through the collation of archival census data of living and dead assemblages, we are able to provide a database with 3093 sediment samples, corresponding to 2572 georeferenced stations of wide geographical coverage (60° N–54° S; 0–7642 m), obtained from 47 documental sources spanning the last 70 years. All faunal data were homogenized according to the most recent taxonomic standards. The resulting BENFEP database contains nearly 10 times more samples than previously publicly available databases for benthic Foraminifera of the Indian, Arctic, and North Atlantic oceans. Besides, BENFEP contains a rich collection of metadata (e.g. geographical, methodological), aiming to accommodate the database to final users' particular objectives. We also built a qualitative database (BENFEPqual) with an additional collection of georeferenced stations with reported benthic Foraminifera, published between 1929 and 2019 with inaccessible census data. BENFEP constitutes a unique georeferenced source of information for deep-sea monitoring, assessment, management, and conservation from a wide geographical perspective. We believe BENFEP will strongly contribute to a better understanding of recent benthic Foraminifera distributional patterns boosting the new increasing interest of the palaeoceanography community in using quantitative (and qualitative) benthic Foraminifera assemblages for past environmental reconstructions.

Deep learning in deep time: Exploring planktonic foraminifer evolution in response to the K–Pg mass extinction using machine learning

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Due to their calcium carbonate tests, planktonic Foraminifera form a vital component of the biological pump and the cycling of carbon between the atmosphere and the ocean. In response to the Cretaceous–Palaeogene (K–Pg) mass extinction event that occurred ~66 Myrs BP when a bolide collided with the Earth, it is estimated that ~90 % of Maastrichtian planktonic foraminifer species went extinct. Correspondingly, there was a collapse of biological pump function in the aftermath of the extinction event. Although biogeochemical evidence suggests that biological pump function recovered to pre-extinction levels by ~2 Myrs after the event, planktonic foraminifer biodiversity did not return to pre-extinction levels at that time. This raises the question of how planktonic foraminifer community structure correlates with biological pump function. Here, I describe current efforts to tackle this question using deep learning and automated high-throughput image processing. These methods allow us to build a large-scale, high-resolution morphological record of planktonic Foraminifera across the mass extinction event comprising tens of millions of specimens. This morphological record will be compared to isotopic proxy records of environmental parameters in order to understand the relationship between large-scale community evolution in Foraminifera and the collapse and recovery of the biological pump. Understanding the interplay between planktonic foraminifer diversity patterns and rapid, dramatic environmental restructuring can lead to insights that are relevant to protecting modern oceans in the face of anthropogenic climate change.

Ontogenetic morphometric basis for revision of Albian–Maastrichtian planispiral planktonic Foraminifera traditionally assigned to *Globigerinelloides*

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We present results from a comprehensive revision of Albian–Maastrichtian planispirally coiled species that have been traditionally assigned to *Globigerinelloides*. This revision was deemed necessary because of a ~3-Myr gap between the extinction of planispiral species at the end of Aptian and the next younger occurrence of planispiral species in the early Albian (Fig. 2). Because the type species of *Globigerinelloides* (*Gl. algerianus* Cushman and ten Dam) is restricted to the Aptian, continued use of that genus for Albian and younger planispirals inappropriate. Goals of the study were to (1) synonymize species showing high similarity in their ontogenetic growth trajectories, wall texture, range of total and final whorl chamber number, and apertural morphologies, (2) establish the biostratigraphic and biogeographic ranges of each species, and (3) infer ancestor-descendent relationships of all senior synonyms based on stratophenetic observations from multiple deep-sea and land-based sites.

Our stratophenetic taxonomic groupings utilize ontogenetic morphometric data, shell wall ultrastructure, and general morphological features observed from scanning electron microscope and X-radiograph images of primary type specimens and globally distributed hypotype specimens. We identify three mid- to Late Cretaceous planispiral lineages that are assigned to the new genera *Laeviella* (includes four species) and *Polycamerella* (includes one species) and the emended genus *Planohedbergella* (includes ten

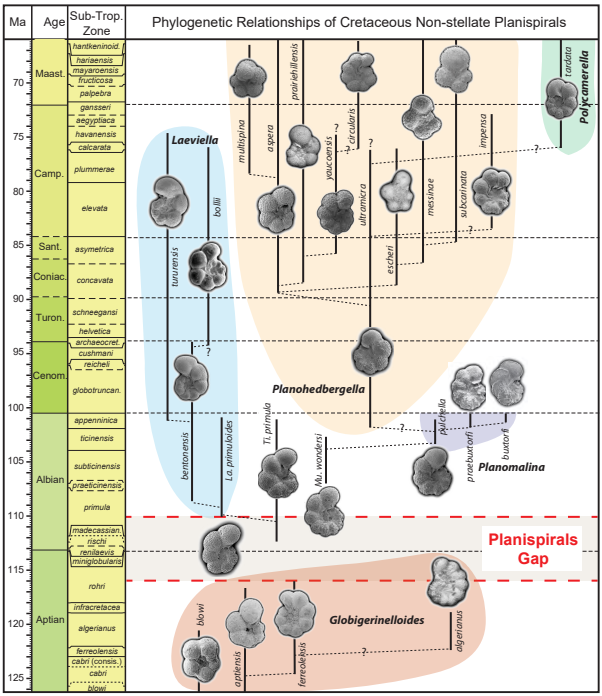

Figure 2: Stratigraphical ranges of planispiral species from the Aptian–Maastrichtian interval showing phylogenetic relationships interpreted based on stratophenetic and morphometric observations.

species). We also revise the late Albian genus *Planomalina*. Distinction of the four genera is based primarily on differences in their wall surface texture and ontogenetic morphometric growth trajectories.

Planktonic Foraminifera record oceanic regime shifts south of Iceland since MIS 3

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Iceland's oceanic regime and the marine ecosystem it supports are modulated by the Atlantic meridional ocean circulation and associated changes in surface water mass properties of the northern North Atlantic Nordic seas. Several rapid migrations of the subpolar front occurred during the last interglacial (Eemian, 150–130 kyrs BP) and more recently, the warming of waters south of Iceland has led to profound changes in the marine ecosystem. These changes include a northward trend in the movement of warmer water species, alongside a decline in the abundance of cold-water taxa, including commercially important species. Using planktonic fossil Foraminifera records from a transect of three new marine sediment cores from south-south-west Iceland, we investigate the characteristics, magnitude, and timing of changes in sea surface and sub-surface conditions such as temperature and salinity during past warm periods and across abrupt climate transitions. We qualitatively assess the water masses present (planktonic Foraminifera assemblage assessment) as well as quantifying the properties of these water masses (stable isotope and Mg/Ca analysis) back through time. A combination of radiocarbon dating and tephrachronology indicates that the sediment cores cover the last *c.*30–50 ka and this allows

identification of any leads or lags in the response time of Iceland's oceanic regime and marine ecosystem to regional millennial-scale variability.

Calcareous nannofossils assemblages for provenance determination: Case study of historical painting provenance

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Calcareous nannoplankton is a useful tool in provenance analyses of art rock material of marine origin (Quinn 2017). To determine the provenance, a comparison from the historical mining areas is necessary. However, material used in arts had to be processed (washed and milled), which influenced the composition of nannoplankton assemblages. Because our study is focused on the chalk grounds (Kędzierski and Kruk 2018, Fig. 3), we solved to use as reference material already processed original rocks commercially distributed, like Rügen in Germany, Belgium, Champagne in France, and Bologna in Italy chalks. From historical and archaeological sources, we expect these four materials to be used nearly fully in all art workshops in western, central, and southern Europe, from which originated studied art objects.

We compared the calcareous nannofossils assemblages from our reference materials to paintings with chalk grounds and known provenience (Champagne, Flemish from Brabant region, Italian, German, and English paintings). We compiled the known information from these paintings and verified if our provenance determination was corroborated by the other known information. We could confirm that the provenance could be assessed using the palaeobiogeographical distribution of the species, which depended on a complex set of reasons (among them the climate).

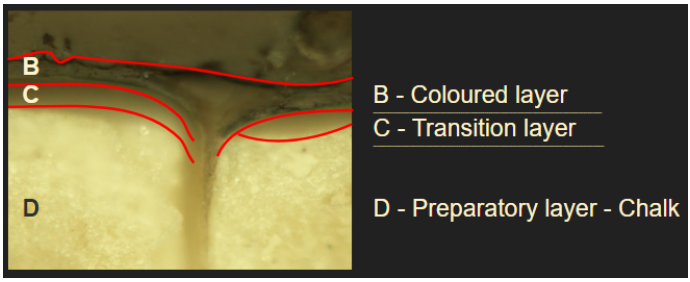

Figure 3: Cross-section detail of a historical painting with a chalk ground/preparatory layer.

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Biostratigraphic and palaeoenvironmental studies on the Eocene Albești Limestone

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The Albești Limestone is a lithostratigraphic unit restricted to the Getic

Basin and it is particularly abundant in larger benthic foraminiferal (LBF) remains. So far, nummulitids (Bombiță 1963) and rare orthophragminids (Bombiță et al. 1980) were reported from this Eocene rock record, however, its age, palaeoenvironment, and palaeogeographic affinities still need to be better constrained.

Therefore, we performed a high-resolution taxonomical and microfacies analysis based on 40 samples collected along seven exposures located in and near Albești, the type locality of the Albești Limestone.

Four main microfacies types were distinguished based on the detailed analysis of 40 large thin sections (in stratigraphic order): (1) Densely packed bioclastic grainstone-rudstone; (2) fine-grained packestone; (3) glauconitic grainstone; and (4) bioclastic packstone and floatstone. The abundant and diverse LBF assemblages are composed of 19 orthophragmina species (*Discocyclina*, *Nemkovella*, *Orbitoclypeus*, *Asterocyclina*) and 10 *Nummulites* species (*N. distans*, *N. pratti*, *N. irregularis*).

The main microfacies-types and the abundance of the LBF within the studied nummulitic limestone suggest a high-energy depositional environment located in the inner-parts of a carbonate ramp. The recovered *Nummulites* assemblages are characteristic for the SBZ 10/11 while the orthophragminids are typical for OZ 6/7 biozones and confer a late Ypresian (Cuisian) age to the studied sedimentary record.

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Middle Miocene (Serravallian) wetland development on the northwest edge of Europe

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The Miocene was identified as an interval of interest in the recent IPCC AR6 report as a geological analogue for middle-late 21st century anthropogenic climate change. The Brassington Formation, Derbyshire, is the most extensively studied of three onshore UK sites that contains a Miocene-age fossil flora. Previous palynostratigraphy has identified that the Kenslow Member is diachronous in age. Of the still-existing outcrops, the Kenslow Top Pit outcrops are dated to the Tortonian, whereas the Bees Nest outcrop is dated to the Serravallian. The Serravallian is an interesting interval to investigate terrestrial environments of northwest Europe—against a background of global temperate declines and increased aridity, the regional climate of northwest Europe remained warm and humid, likely caused by the Atlantic Meridional Oceanic Circulations. Despite this regional significance, the Serravallian Kenslow Member has only ever been studied using plant palynology from grab samples. Here we present the first continuous sequence of palynology through the Serravallian Kenslow Member at Bees Nest Pit.

Reconstruction of two identified pollen zones showed a mixed mesophytic forest with an evolving wetland palaeoenvironment. Through high-resolution sampling, it has been possible to explore the changing wetland ecology. We propose a fallen tree influenced the depositional environment and created a forest hollow, which allowed for limited lignite preserva-

tion. Co-existence Approach-based palaeoclimate reconstructions produces ranges of mean annual temperature (15.7–18.4 °C) and mean annual precipitation (1096–1372 mm) with no variations across the stratigraphy outside of uncertainty ranges, inferring a relatively short depositional period. Overall, the sequence shows the impact of a flat latitudinal temperature gradient in the North Atlantic during this time interval.

On the evolutionary changes of the middle Eocene *Podocyrtis* lineages (Radiolaria, Nassellaria) in relation to climate change

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The middle Eocene deep-sea sedimentary sequences cored at ODP Site 1260 (Leg 207; equatorial Atlantic) yielded well-preserved radiolarian faunas, which are conducive to the study of radiolarian evolutionary dynamics during this epoch of profound climate change. In addition to an expanded and almost complete sedimentary record, a well-defined framework in terms of both magnetostratigraphy and cyclostratigraphy exists at this site.

With a total of 17 species, the genus *Podocyrtis* is a prominent component of Eocene tropical radiolarian assemblages. *Podocyrtis papalis* is the oldest representative of the genus, known since the latest Palaeocene to the late Eocene; it has been considered as a long-standing species that displays a morphological stasis. However, careful examination of radiolarian assemblages in the middle Eocene climate pptimum (MECO) interval revealed the existence of a 'late morphotype' of *P. papalis*. This late morphotype is morphologically similar to the early Eocene species *P. diamesa* and co-occurs with the typical spindle shaped morphotype of

P. papalis.

Landmark-based geometric morphometric analyses of all three taxa did not reveal any statistically significant shape differences, a result that is in conflict with previous qualitative diagnoses. Additional information regarding the shell size is needed to differentiate *P. diamesa* from the late morphotype of *P. papalis*. Interestingly, disparity analyses allowed to detect a peak in *P. papalis* shell disparity during the onset of the MECO.

Finally, thanks to the unprecedented temporal resolution provided by the orbital framework of Site 1260, we studied the tempo of evolutionary changes that took place in two well-known lineages of *Podocyrtis*: the *P. sinuosa–P. mitra–P. chalara* (subgenus *Lampterium*) and the *P. diamesa–P. phyxis–P. ampla* (subgenus *Podocyrtoges*) lineages. We also document the tempo and details of the morphological changes that occurred during the origin of *P. goetheana* from a *P. chalara* stock.

Biostratigraphy and palaeoenvironment of the Krishna-Godavari Basin across the Cretaceous–Paleogene (K–Pg) boundary: Evidence from dinoflagellate cyst

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The Cretaceous–Palaeogene (K–Pg) mass extinction is evidenced as one of the prominent biotic events in the earth's history. It is a global event responsible for abrupt changes in the biosphere and geosphere. The influence of this episodic event was also found in the Indian subcontinent. In the present study, the biostratigraphic investigation of organic-walled dinoflagellate cysts has been carried out from BST Well A (3140–2630 m depth) of the Krishna-Godavari Basin, India. The recorded assemblage is dominated by marker dinoflagellate cysts, viz. *Disphaerogena carposphaeropsis*,

Disphaerogena lemniscata, *Exochosphaeridium bifidum*, *Glaphyrocysta expansa*, *Carpatella cornuta*, *Damassadinium californicum*, *Palaeocystodinium benjaminii*, and *Dinogymnium* sp. The last appearance datum of age-significant species of dinoflagellate cysts has been considered for the construction of the biostratigraphic framework. The examined sequences correspond to the late Maastrichtian–early Danian age using dinoflagellate cyst biostratigraphy. The two organic-walled dinoflagellate cyst biozone named: *Disphaerogena carposphaeropsis* assemblage zone (AZ) and *Carpatella cornuta* interval zone (IZ) have been established. The upper part of *D. carposphaeropsis* AZ and lower part of *C. cornuta* IZ represents the Late Cretaceous–early Paleogene age and the upper boundary of the *D. carposphaeropsis* zone marks the Cretaceous-Palaeogene (K–Pg) boundary in the Krishna-Godavari Basin. The established dinocyst zones are correlated with other established boundary sequences of the Tethys region and the majority of the taxa are common. The species richness suggests that organic-walled dinocysts were not affected by the K–Pg mass extinction. The turnover of dinoflagellate cyst across the K–Pg boundary supports the rapid oceanic acidification during K–Pg mass extinction and suggests, that the formation of organic-walled resting cyst is the main factor for the survival of the dinoflagellate cyst across the K–Pg boundary.

The climatic significance of the Dachangliang sedimentary sequence during the early Pleistocene, NE China

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The sedimentary sequence of the Nihewan Basin provides a record of late Pliocene–Pleistocene environmental and climate change in NE China. The sequence is also famous for embedded Palaeolithic artefacts and abundant fossils of the Pleistocene megafauna. Three stratigraphic sedimentary sections at the location Dachangliang were investigated and correlated to generate a long, continuous synthetic sedimentary section with the aim to reconstruct the climatic changes during the early Pleistocene in the Nihewan Basin and its relationship with global climatic changes. From the bottom to top, the sequence is divided into eight sedimentological zones based on visually observed variations in sedimentary structures, grain size, low frequency magnetic susceptibility, and ostracod assemblage data; and grouped into three depositional environment associations. Due to the lack of age data of the studied sediments, we correlate our sections from Dachangliang to two proximal Palaeolithic artefact-bearing sections (Majuangou and Xiantai) with published magnetostratigraphic data. The correlation shows that our investigated sedimentary sequence was probably formed between ~1.7 and 0.9 Ma. The quantification of three dominant grain size components and the ostracod assemblage changes in the sediments reflect three intervals of warmer and wetter climate and three intervals of colder and dryer climate probably representing interglacial (S_{24}, S_{20}, and $S_{9\text{-}1}$) and glacial (L_{24}, L_{20}, and L_9) periods which were previously inferred from the palaeoclimatic records of the Chinese Loess Plateau in the southwest

of the Nihewan Basin. The inferred climate cycles probably result from astronomical (Milankovitch) forcing.

Complete replacement of the planktonic Foraminifera after the K/Pg mass extinction by new benthic colonizers

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The biotic crisis following the end-Cretaceous asteroid impact resulted in a dramatic renewal of pelagic biodiversity, with extinctions of over 90 % of plankton species. Considering the severe and immediate effect of the asteroid impact on the pelagic environment, it appears remarkable that the affected pelagic groups, like planktonic Foraminifera, survived at all. Here, we challenge the classical interpretation of the fossil record by showing evidence that most if not all calcareous benthic Foraminifera of the clade Globothalamea are capable to actively disperse in the plankton and that the modern planktonic clades diverged from different benthic ancestors around or after the end-Cretaceous crisis. We conclude that the current diversity of planktonic Foraminifera is the result of constant leakage of benthic Foraminifera diversity into the plankton that continuously refuels the planktonic niche with novel lineages. The consequence of this interpretation is that the Mesozoic planktonic Foraminifera likely fell

entirely victim to the end-Cretaceous mass extinction, akin to the non-avian dinosaurs. It also implies that the interpretation of the fossil record of planktonic Foraminifera, a key testing ground for macroevolutionary models, requires a fundamentally different approach.

The Late Maastrichtian calcification crisis in planktonic and benthic Foraminifera of Bidart (France)

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The Late Maastrichtian experienced several pulses of voluminous Deccan volcanism leading into high stressed conditions. The final ~0.5 m interval of the Cretaceous–Palaeogene boundary (KPB) section at Bidart (France) records poor carbonate preservation and coincides with the geochemical 'Deccan benchmark' interval defined by a concurrence of anomalously low bulk rock magnetic susceptibility (MS) and high mercury (Hg) content. However, the faunal evidence for this critical 'acidification' interval is restricted to Foraminifera test taphonomy which is affected by environmental and post-depositional factors. This study documents new evidence of a calcification crisis in the Foraminifera assemblages of the 'Deccan benchmark' interval.

The onset of the hypothesized 'acidification' interval (~0.5 m below KPB) at Bidart is marked by a steep increase in planktonic fragmention index (FI) and a sharp decline in the absolute abundances of all larger globutruncanids, biserials, racemiguembelinids, and *Planomalina brazoensis*. Within the benchmark, high Foraminifera test fragmentation, reduced test wall thickness and intraspecific dwarfing together vouch for a biological calcification crisis linked with recurrent Deccan volcanic 'extreme

events'. The benthic Foraminifera, on the contrary, show a low FI, and even an increase in the relative abundance and average size of thick-walled genera (*Cibicidoides* spp., *Steinsioeina* spp., and *Coryphostoma* spp.) at ~0.3 m below and at the KPB. A carbonate super-saturation near KPB due to extinction of pelagic calcifiers could have given an advantage to the individuals with heavily calcified tests. These observations constrain the Deccan related acidification event to the surface ocean with minimal effects on the benthos.

Ecological and evolutionary significance of spines in Palaeogene muricate planktonic Foraminifera

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Our recently published research suggests that Palaeogene muricate-walled planktonic Foraminifera (including the diverse and abundant genera *Acarinina* (Fig. 4) and *Morozovella*) were spinose, wherein a single acicular crystalline calcite spine was embedded in and projected from each murica (surface mound). Here, we review the evidence for this interpretation, and discuss its implications for the palaeo-ecology and evolutionary history of the group. We suggest that the muricate spinose condition likely evolved in the mid-Palaeocene concurrent with an intensification of a symbiotic relationship with photosynthetic algae. This key innovation allowed planktonic Foraminifera to occupy shallow-water oligotrophic niches, sparking an adaptive radiation and enabling muricate species to dominate planktonic

foraminiferal assemblages for most of the Paleocene and Eocene. The muricate clade eventually went into decline for reasons that are currently unclear, and finally became extinct in the Oligocene. It is interesting that the spines of the muricate clade evolved independently, and later than spines in the superfamily Globigerinoidea, whose members seems not to have been initially photosymbiotic. Nevertheless, some groups of Globigerinoidea later developed a photosymbiotic habit, in which spines play an important role in harbouring and deploying symbionts, such that their possession of spines can be considered a 'preadaptation' to the mode of life initially evolved by the muricates and their symbionts. Our research suggests that the muricate planktonic Foraminifera of the Palaeogene are better analogues for modern spinose photosymbiotic groups like *Globigerinoides* and *Trilobatus* than previously thought. This helps explain their distribution and abundance patterns in the palaeo-oceans, and has implications for the interpretation of geochemical proxies based on analysis of their shells, especially those for carbon cycling and palaeo-pCO_2.

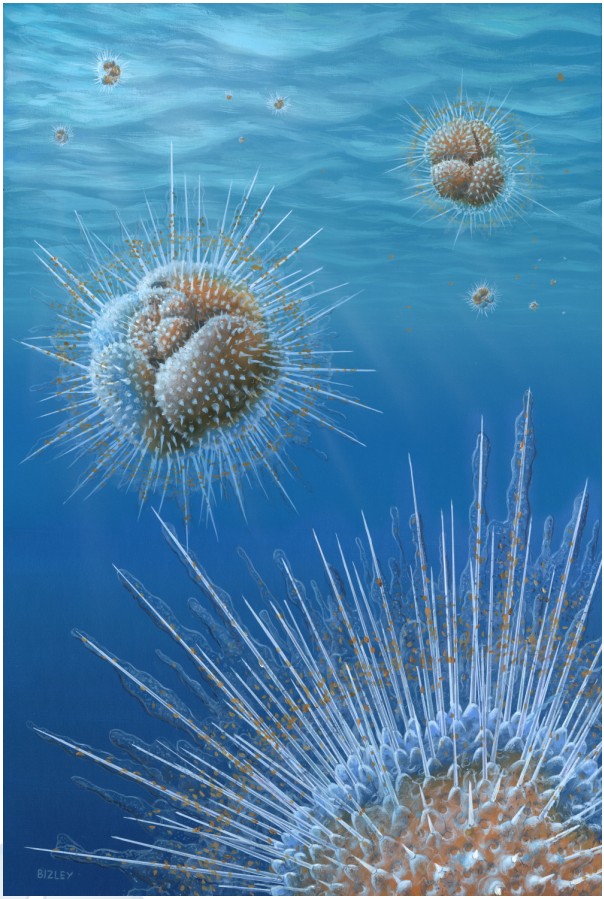

Figure 4: *Acarinina* in life with spines by Richard Bizley.

Coccolithophores: The art of Equatorial Pacific SST and productivity reconstructions during lockdown

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Here, we developed a new high-resolution reconstruction of annual sea-surface temperature (SST) and net primary productivity in the Eastern Equatorial Pacific (EEP) based on novel coccolithophore-based models. The addition of coccolithophore assemblage data from new surface sediment samples located in the EEP improved previous SST-calibrations, and resulted in higher confidence reconstruction of temperatures higher than 20 °C.

Our study sheds light on conflicting (palaeo-)temperature and productivity reconstructions for the last 20 kyrs available in the EEP. We also reconstructed processes related to export production in response to rapid climatic variability from the late last glacial to recent times at ODP Site 1240. We propose a change in the plankton ecosystem structure at the end of Termination I, from calcareous to siliceous plankton, and a concomitant reduction in the carbonate pump.

This research inspired artwork, a comic-book story, and an exhibition, with the aim of promoting science as well mental health issues during lockdown.

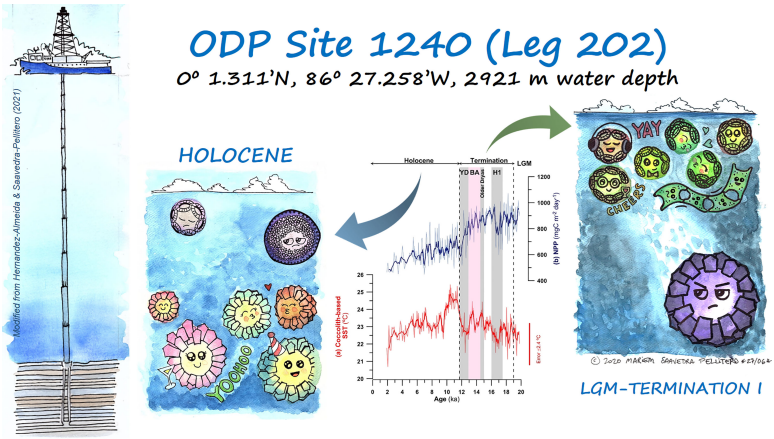

Figure 5: Estimated coccolith-derived sea surface temperature SST (°C, in red) and coccolith-derived net primary productivity (NPP, mg C m^{-2} d^{-1}, in blue) at ODP Site 1240. The vignettes depict two different scenarios (last glacial maximum and the Holocene).

Lessons from the past: Long-term response of marine plankton to global warming since the last ice age

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Future global warming is expected to have an impact on biodiversity. However, it is difficult to predict how species will respond to the continuous

climate change. Here, we use the marine microfossil records to examine how plankton biodiversity responded to climate change on a scale that is comparable to future anthropogenic warming. We compiled time series of planktonic Foraminifera assemblages that span the time from the last ice age to the current warm period. When temperatures began to rise at the end of the last ice age (about 17 000 years ago), planktonic Foraminifera assemblages changed immediately. Surprisingly, these zooplankton assemblages continued to change until about 5000 years ago, despite the fact that global temperature remained relatively stable over the last 11 000 years. The biotic response of planktonic Foraminifera was largest in the mid latitudes and dominated by range expansion, which led to the formation of novel assemblages with no analogues in the glacial ocean. Interestingly, we found a similar general pattern for phytoplankton (dinoflagellate cyst and coccolithophore) assemblage time series. Thus, zoo- and phytoplankton show a corresponding biotic response and assemblage compositional change that continued well into the current, relatively stable, warm period. Our findings show that throughout the past 24 000 years, the plankton response to climate change was spatially heterogeneous and has not tracked temperature change consistently. Climate change resulted in the formation of novel assemblages and possibly new ecological interactions. Thus, current and future anthropogenic warming may also result in new, distinct planktonic community compositions, affecting the marine ecosystem as a whole and possibly with dire consequences for marine ecosystem services.

Reading between the lines: Ecological and taphonomical signals in late Quaternary planktonic Foraminifera test size variation

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Ecologically optimal conditions are expected to drive planktonic foraminifers (PF) towards larger shell sizes, while stressor conditions can lead to a size decrease. Therefore, environmental changes can affect PF shell sizes, calcification intensity and abundance, and thus impact the marine biogenic carbonate budget. Here, we investigate the shell size response of the complex *Globigerinoides ruber–elongatus* (cGr-e) and *Neogloboquadrina incompta*, at a transitional zone in the western South Atlantic. We measured the cross-sectional area of 6653 specimens from core SAT-048A, spanning the last 43 kyrs. Further, we quantified the effect of the reconstructed sea surface temperature, productivity, species relative abundance, and dissolution on the observed shell sizes. cGr-e sizes are negatively correlated with productivity and dissolution ($p < 0.05$, $R^2 = 0.42$ both), whereas *N. incompta* showed a significant correlation with its own relative abundance ($p < 0.05$, $R^2 = 0.19$). The larger *N. incompta* sizes suggest larger shell sizes under its optimal ecological conditions. Nevertheless, although the inverse relation between cGr-e size and productivity could be explained by its preference for oligotrophic waters, using scanning electron microscopy (SEM), we could identify 'hidden-scars' of broken chambers on the cGr-e shells, suggesting a dissolution imprint. Mechanical stress added on to dissolution affects shells by destroying the thinner final cham-

ber(s), as evidenced in the record since the Jurassic (checked on SEM pictures from Mikrotax), resulting in tests hardly identified as broken and, therefore, masking possible ecological signals in the shell size analyses. The gradual loss of chamber, instead of total breakdown should encourage researchers to better understand the taphonomical imprint of dissolution on the PF shells, and to reconsider the reliability of dissolution proxies and the interpretation of size analyses.

Inferring pelagic ecosystem change during the last interglacial from ichthyoliths and phytoplankton

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Pelagic ecosystems occupy more than 50 % of the Earth's surface area and play a crucial role in regulating climate and sustaining biodiversity. However, understanding of how contemporary and future climate change may impact these biological communities is currently lacking. We use two North Atlantic sediment cores (ODP 982 and IODP U 1313) to examine how past climate change impacted pelagic ecosystems by producing high-resolution records of diatom, coccolithophore, and fish productivity over the last 150 kyrs. We selected this interval due to its potential similarity to near-future climate states, which may provide an analogue for changes expected in the coming decades (Burke et al. 2018). These fossil records will provide an objective, quantitative baseline for assessing ecosystem response to warming that is independent of anthropogenic effects and can inform future expectations for pelagic ecosystems.

Sediments are being processed for ichthyoliths (fish teeth and scales) to measure ichthyolith accumulate rates (IAR; Sibert et al. 2017) and to assess changes in fish production prior, during, and after the last interglacial. Simultaneously, we are processing the same samples for coccolithophore demographics and abundance using SYRACO (Beaufort and Dollfus 2004) and for diatom diversity. This study is the first to investigate ichthyolith and phytoplankton abundances from the same marine sediment samples and will test for concomitant responses in primary producers and fish during major environmental change.

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Photosynthesis in modern symbiont-bearing planktonic Foraminifera: Toward a better understanding of the symbiotic system and geochemical proxies

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Information on photosynthetic activities of symbiont-bearing Foraminifera

is essential for interpreting geochemical proxies such as $\delta^{13}C$ recorded in foraminiferal tests. This is because the microenvironment surrounding photosymbiotic planktonic Foraminifera is greatly affected by photosynthetic carbon assimilation (selective ^{12}C incorporation) by thousands of symbionts. Recently, active chlorophyll fluorometry has been adopted as a valuable tool for the quick estimation of photosynthesis. In order to make use of this measure to estimate actual carbon dynamics through photosynthesis, the relationship between two photosynthetic rates (electron transport rate; ETR and carbon assimilation rate; P) needs to be correlated. Here, we compared these two rates for *Trilobatus sacculifer* and *Globigerinella siphonifera*, using fast repetition rate fluorometry and ^{14}C tracer experiments. The results showed a significant positive correlation between the two measures for both species (Fig. 6), indicating that carbon assimilation can be estimated by the fluorescence method. However, the regression slopes representing the apparent electron demand for carbon assimilation (e^-/C) were significantly different between the two species, and were surprisingly high considering the theoretically and empirically realistic values of e^-/C. We hypothesized that this high e^-/C might be due to the use of unlabeled respired carbon (underestimation of P). Simple mass-balance calculations suggested that a significant amount of carbon should be derived from host respired CO_2, and that this contribution was higher in *G. siphonifera*. Our attempts to couple ETR and P could comprehensively reveal interesting perspectives on the close interactions within photosymbiotic systems. Moreover, our results suggest that when using geochemical parameters such as $\delta^{13}C$ as palaeoceanographic proxies, it is important to note that the potential magnitude of the photosynthetic effect varies among species.

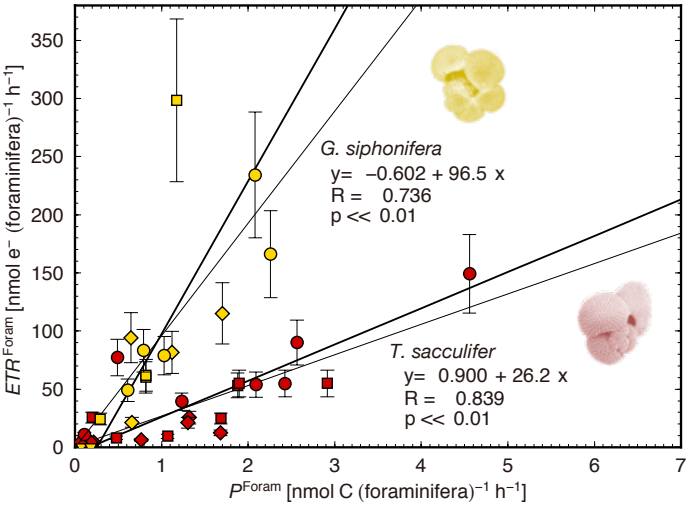

Figure 6: Comparison of individual-based electron transport rates (ETR) and carbon assimilation rates (P).

Palaeocene benthic Foraminifera from around small gas hydrates reservoirs of Western Siberia

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The West Siberian Basin is among the world's largest oil and gas producing regions, and contains several giant and supergiant oil and gas fields. The largest oil and gas reservoirs are in Jurassic and Cretaceous strata and were subject to detailed geophysical, lithological, and biostratigraphic studies. Younger Palaeocene deposits contain gas hydrates. These deposits have

received little attention in terms of biostratigraphy and depositional environment but preserve crucial clues to assess the role of the Turgay passage and its connection to the Arctic Ocean. We have studied the benthic foraminiferal assemblages from a suite of core samples obtained from the Kharasavey oilfield in Western Siberia, to provide a better understanding of the depositional environment by analysing the composition, structure, and diversity of foraminiferal biotas. Based on a modern taxonomic revision, we illustrate the entire benthic foraminiferal fauna and attempt to place the assemblages in a stratigraphic and palaeoecological context. Faunal analysis revealed different foraminiferal assemblages containing varying abundances of Cibicididae, Pulleniidae, Gavelinellidae or Elphidiidellidae, and Polymorphinidae, indicative for a shallowing upward trend and a depositional setting with different oxygen concentrations in the water column and the sediment. Based on species-level analyses and comparisons with previous studies, the foraminiferal biotas are tentatively assigned a Lower Palaeocene, possibly Danian age.

Planktonic Foraminifera from the upper Eocene of northern Saudi Arabia: Implications for stratigraphic ranges

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We examined the biostratigraphy and stratigraphic ranges of upper Eocene planktonic Foraminifera from the Rashrashiyah Formation of the

Sirhan Basin in northern Saudi Arabia. Assemblages are diverse and well-preserved, with forty species and eleven genera (Fig. 7). All samples are from the Priabonian *Globigerinatheka semiinvoluta* highest occurrence zone (E14). The good preservation coupled with high diversity allows us to re-examine the stratigraphic ranges of many taxa. Our study reveals that several species of *Globoturborotalita* including *G. barbula*, *G. cancellata*, *G. gnaucki*, *G. paracancellata*, and *G. pseudopraebulloides* evolved earlier than previously documented. Additionally, older stratigraphic occurrences are found for *Dentoglobigerina taci* and *Subbotina projecta*. Our revision to the stratigraphic ranges indicates that the tropical/subtropical diversity of planktonic Foraminifera in the late Eocene was higher than previous studies have suggested.

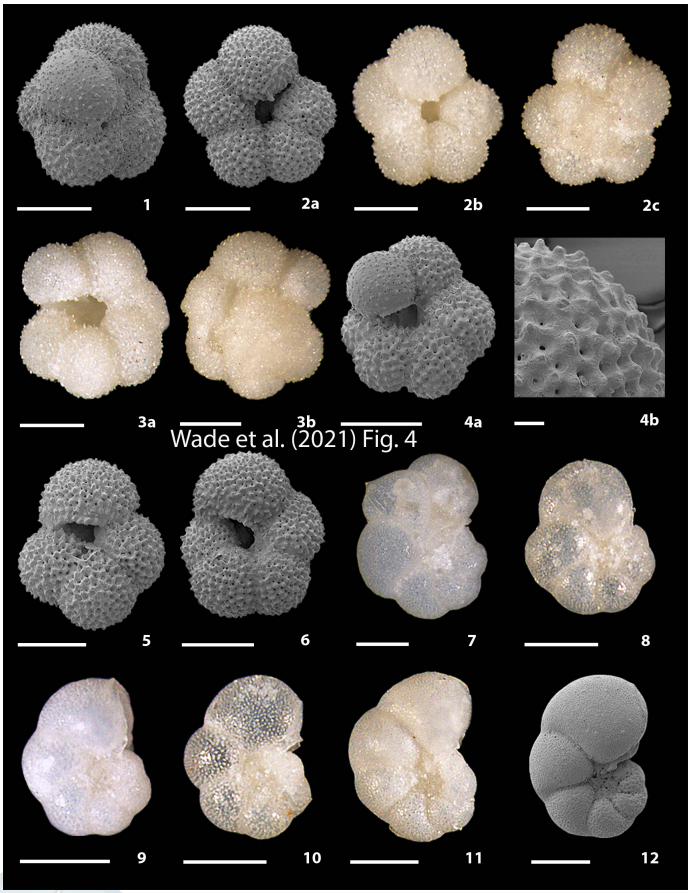

Figure 7: Light microscope and scanning electron microscope images of *Acarinina* and *Pseudohastigerina* from the Rashrashiyah Formation. Scale bars: (1)–(4a), (5)–(12) = 100 µm; (4b) = 10 µm.

Part III

Annual Conference 2022—Posters

The last glacial maximum Amazon revealed by the palynological record of marine sediments

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The Amazon Basin is the world's largest drainage basin covering an area of over 7 million km^2. The Amazon drainage system transports a highly diverse pollen load gathered from a wide range of ecosystems throughout the basin. Pollen assemblages from modern riverbed sediments indicate that the main sources are located at the Amazonian lowlands, whereas the marginal montane and savanna vegetations are represented in lower amounts. This pollen load is delivered by the Amazon River to the western equatorial Atlantic, where the North Brazil Current transports most of the material northwestwards along the South American continental margin. Here we report on the pollen analysis of marine sediment core GeoB 16224-1 (6° 39.38′ N, 52° 4.99′ W, 2510 m water depth) collected under the influence of the Amazon River plume. It reveals that the Amazon vegetation has undergone striking changes during the late Pleistocene. During the last glacial maximun (LGM), the combination of a significantly colder and relatively drier climate, lower atmospheric CO_2 concentrations and *c.*120 m lower sea-level transformed the Amazon landscape. The basin remained predominantly covered by forests with a distinct composition. Warm-lowland tropical forest taxa decreased at the expense of currently montane forest taxa that migrated to the lowlands. These glacial forests likely sustained a less dense but yet closed canopy. The savanna contribu-

tion was slightly larger than today, probably reflecting its encroachment over eastern Amazon ecotones. The intensified fluvial incision associated with the low LGM sea-level stand reduced the availability of floodplains and increased the competitive stress of species adapted to these habitats. This is supported by a decrease in the contribution of seasonally flooded vegetation taxa during the LGM. Despite the decline of seasonally flooded areas, Cyperaceae and Poaceae, likely from proximal sources such as salt marshes, were abundant during the LGM.

Seasonal, interannual, and pre-industrial planktonic Foraminifera calcification patterns in the Gulf of Lions (NW Mediterranean)

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Planktic Foraminifera and other marine calcifying organisms response to recent climate and Ocean Acidification (OA) in the Mediterranean Sea remains understudied. This part of global ocean is considered a key and sensitive zone to understand the impact of recent climate evolution. Here we present planktonic Foraminifera calcification data coming from sediment traps, but also from sediment cores, in order to compare calcification of different timescales in the Gulf of Lions (NW Mediterranean).

More than 4500 Foraminifera individuals were picked (13 to 27 specimens per sample), cleaned with light ultrasonication, weighted using a high precision balance (0.001 mg) and had their morphometric parameters measured with a Nikon SMZ 18 microscope and a DS-Fi3 camera. The picking focused on three different species according to their different ecologies: *Globigerina bulloides*, *Neogloquadrina incompta*, and *Globorotalia*

truncatulinoides. Finally, environmental data comes from the DYFAMED site.

Comparison between sieve based weights (SBW) and measurement based weights (MBW) showed that the later are a better and reliable calcification indicator. Calcification varied across the different timescales studied. Seasonal patterns showed that calcification maximums were reached at different moments of the year for each species, and were linked with optimum growth conditions, sea-surface temperatures, and carbonate system parameters. Interannual patterns also differed according to the species, and carbonate system parameters were the main factor affecting these trends. However, the comparison between core-top and sediment trap data allowed a pre-industrial Holocene comparison, displaying a constant calcification reduction for all three species.

The hidden agglutinated Foraminifera of the mid-Cretaceous hemipelagic carbonate deposits: A method-derived bias?

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Five different micropalaeontological methods (H_2O_2, Glauber's salt, liquid nitrogen, acetic acid + copper(II)-sulfate, and formic acid) were applied to study the differences of obtained agglutinated foraminiferal faunas of typical hemipelagic carbonate deposits of the mid-Cretaceous of Europe, and to prove whether there is a method-derived bias of knowledge about agglutinated foraminiferal faunas in these sedimentological settings. Split samples of the same weight were treated with each method to compare overall (calcareous + agglutinated) numbers of foraminifers per gram,

numbers of agglutinated foraminifers per gram, and numbers of agglutinated foraminiferal genera per sample.

The results show that the number of agglutinated foraminifers per gram strongly vary between 0.1 and 7.8 with use of standard micropalaeontological methods. With application of formic acid, more agglutinated foraminifers per gram are obtained than with any other tested method. The number of agglutinated foraminifers per gram is 1.5 to 211.0 times higher in formic acid treated residues. Furthermore, with use of standard micropalaeontological methods at least $\frac{2}{3}$ of agglutinated foraminiferal genera and species are completely missing in these sedimentological settings. Consequently, standard micropalaeontological methods are not applicable to study the whole agglutinated foraminiferal fauna, and a bias of knowledge and utility of agglutinated foraminifers in these sedimentological settings is obvious. A separate application of both acetic acid + copper(II)-sulfate and formic acid on samples is suggested for studies on the whole foraminiferal fauna, and a precise description of the applied method in studies is suggested.

MICRO2MACRO: Microfossils and data science, a new approach to infer the impact of global climate on plankton macroecology

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One of the most pressing scientific challenges today is understanding the fate of our oceans and marine ecosystems under on-going climate change. Unfortunately, anthropogenic stressors act at a rate and magnitude that exceed recent natural variability, making the use of decadal ecological data and time-series insufficient for predictions of future behaviour of marine

ecosystems. I will here introduce the recently started Marie-Skłodowska Curie Action project MICRO2MACRO, which will reconstruct snapshots of marine pelagic ecosystems between 54 and 32 million years ago (Eocene and early Oligocene), when climate and environmental conditions approximated what we will start to experience in the next century and beyond. Using the microfossil record of planktonic Foraminifera (PF), the most complete of any Caenozoic eukaryote, the project will generate the first methodologically controlled (hence reproducible) early Caenozoic global dataset of ecology, abundance, species composition, diversity, and biogeography (macroecology) of these prolific pelagic calcifiers. Benefiting from the mole of data generated over the last 15 years, the project will apply novel tools in data-science technology to compile ocean temperature and chemistry datasets for the studied time intervals and statistically compare them against the new PF dataset generated with this project. Specifically, this study will test for links between time-specific climate (e.g. sea surface temperatures) and ecosystem (e.g. species composition, dominant ecology) configurations, and understand how plankton biogeography was shaped in a warmer world. Hence, MICRO2MACRO will highlight future ecological and evolutionary analogues if the current climate trajectory remains interrupted and we are to hit climate conditions similar to those in the Eocene and Oligocene.

Late Miocene–Pliocene palaeoceanographic and sea level changes off northern-central Chile based on Foraminifera from the Bahía Inglesa Formation

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The oceanographic setting at the continental margin off northern-central

Chile is characterized by high biological productivity and an oxygen minimum zone (OMZ), triggered by coastal upwelling centres related to the Humboldt Current system. However, little is known about palaeoceanographical conditions during the Miocene and Pliocene, an interval characterized by significant global climate changes. We carry out micropalaeontological and sedimentological analyses of upper Miocene to Pliocene marine sediments from the Bahía Inglesa Formation, outcropping 70 km SW of Copiapó at Quebrada Tiburón (27° 42′ S; 70° 59′ W).

Quantitative analysis of benthic and planktonic foraminiferal assemblages are applied as proxies for palaeobathymetry, bottom-water oxygenation, and productivity. Grain-size data are used to further characterize the depositional environment. Our preliminary results reveal a depositional succession of fine sands and diatomaceous silty sediments marked by transgressive–regressive patterns in a neritic to bathyal palaeoenvironment. The basal sand facies is rich in epifaunal taxa, indicative of an oxygenated inner-middle shelf palaeoenvironment. The overlying diatomaceous fine sediments contain a stress-tolerant infauna dominated by species of *Bolivina*, indicating poorly oxygenated, eutrophic conditions on the upper slope to outer shelf. Planktonic assemblages are dominated by *Globigerina bulloides*, suggesting increased productivity and the establishment of an OMZ due to enhanced upwelling activity as the result of a marine transgression. Subsequent sands are still rich in benthic foraminiferal infauna, while the abundance of epifaunal types adapted to higher water energy could indicate a relaxed OMZ during sea-level regression.

Sea surface temperature variation in the South China Sea during last glacial maximum and Holocene: Evidence from diatoms and foraminifers

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During the Holocene warm inter glacial periods (~4642 ± 20 yrs BP), the presence of diatoms was low in numbers along with some other siliceous microfossils like radiolarians, sponge spicules, and silicoflagellates. In contrast to this, the abundance of diatoms increased during the glacial period of the last glacial maximum (LGM), with good preservation. In this study from a sediment core in the northern South China Sea (SCS), we observe less diatom diversity and abundance during the warm interglacial period. The abundance of upwelling-responder subtropical–tropical foraminiferal species *Neogloboquadrina dutertrei* and diatom species *Thalassionema nitzschioides* and *Thalassiothrix longissima* in the SCS during the LGM suggests, that there was intense upwelling during the glacial period. These variances in diatom abundances are probably due to changes in regional environmental conditions, that are also seen within the marginal SCS basin. This finding was supported by the clumped isotope (Δ_{47}) values of two near sea surface dwelling planktonic foraminifer species recovered from the same core. This study deepens our knowledge of ocean dynamics during LGMs and the warmer Holocene era.

Contrasting assemblage and ecological structure of radiolarians within and above the Sapropel S5 of the Eastern Mediterranean (ODP Site 969)

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The Sapropel S5 was deposited in the Eastern Mediterranean Sea during the Eemian interglacial period about 125 000 years ago as a result of high eutrophication after excessive discharge of nutrients from the Nile river. Polycystine radiolarian assemblages were examined from within the Sapropel S5 drilled at ODP Site 969 (south of Crete). Counting was based on over 500 specimens from each sample.

The radiolarian assemblage from within the Sapropel is very diverse, with over 100 species identified so far, belonging mainly to the families Lophophaenidae (23 %), Theoperidae (17 %), Spongodiscidae (14 %), and large Actinommidae (10 %). Amongst the dominant species, the surface-dwelling and symbiont-bearing *Hexacontium enthacanathum* accounts for 7 %, while other surface-dwelling and herbivorous species, such as *Peridium spinipes* and *Dimelissa thoracites* account for 5 and 8 %, respectively. *Spongodiscus resurgens* (4 %) and *Spongodiscus osculosa* (4 %), which appear to prefer living at the base of the euphotic zone, close to the chlorophyll *a* maxima, account for 4 % each. Deep-water niches are represented by detritivore radiolarians, such as *Encycrephalus gengebauri*, which accounts for 3 %.

A post-sapropel sample, a few cm above, contains a very different assemblage, including mainly representatives of the families Pyloniidae (28 %), small Actinommidae (23 %), and Trissocyclydae (18 %). Two symbiont-bearing species are particularly dominant: *Acanthodesmia vinculata* (17 %) and *Hexacontium pachydermum* (16 %).

In conclusion, the sharp decrease of nutrients and productivity at the

end of the Sapropel S5 appears to have greatly affected the deep-dwelling detritivore radiolarian niches, as these are only well-represented within the Sapropel S5, but they are practically absent from the sample above it, while surface-dwelling and symbiont-bearing species are dominant in the post-sapropel assemblage.

Do Foraminifera-based proxies reveal the Greenland Sea mystery?: Insight into palaeoenvironmental and Return Atlantic Current evolution since 35 ka

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The variability of the Return Atlantic Current (RAC) during the last 35 kyrs has been studied. This current may have a substantial impact on the stability of the Northeast Greenland ice sheet (NE GIS) as well as local deep-water development. Here, we present evidence for Atlantic water (AW) inflow and associated changes in the NW Greenland Sea from sediment core GR02-GC retrieved from the NE Greenland continental slope (1170 m water depth) based on foraminiferal faunas, ice rafted debris, and stable isotopes. Our results show that AW has been present in the NW Greenland Sea for the past 35 kyrs almost continuously. Two distinct meltwater events associated with the AW-induced melting of the adjacent NE GIS were indicated by low planktonic $\delta^{18}O$ at around 34.5 and 33 kyrs BP. The NE GIS advanced between 32 and 29 kyrs BP, lowering meltwater input to the NW Greenland Sea. After 29 kyrs BP, increased iceberg calving and

melting augmented sediment input, most likely due to surface warming and glacier advance towards the shelf-break, which lasted until 26 kyrs BP. The unstable oceanographic conditions that prevailed during the Bølling–Allerød interstadials may be influenced by glaciers and sea ice melting, as a combined effect of the associated warming and AW-induced melting. We propose that a permanent major inflow of warm AW via RAC from the western Fram Strait to the NW Greenland Sea began at ~13 ka. However, during the Younger Dryas, the advection of AW to the NW Greenland Sea was reduced due to the RAC being weakened. After 11.7 kyrs BP, the RAC has reached its modern strength, whereas, during the Holocene thermal maximum, it reached its maximum strength during studied period.

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The Island of Rhodes in the Early Pleistocene—palaeoecological evolution and dysoxic events

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Marine fossiliferous sediments of Late Pliocene to Middle Pleistocene age

are outcropping in scattered locations along the eastern coast of the Island of Rhodes. These sediments represent individual depocentres, each reflecting the sedimentary and neotectonic history and distinctive environmental conditions, even with small-scale differences.

Here we present new insights into the Early Pleistocene palaeoenvironmental evolution and dysoxic events of depocentres in Plimiri, Lardos, and Agathi, located in the southern and middle east coast of the Island of Rhodes. For all sections, detailed benthic foraminiferal faunal data and palaeo-waterdepth reconstructions were generated.

The elevated proportion of eutrophic indicator species with average percentages of 35 % for Plimiri, 40 % for Agathi, and 57 % for Lardos indicate rather mesotrophic conditions during the Early Pleistocene, unlike the modern oligotrophic conditions in the eastern Mediterranean Sea. The benthic foraminiferal assemblages further exhibit periodic changes in the abundance of eutrophic and oligotrophic indicator species. This suggests variations in oxygen and food levels at the sea floor and likely represent the impact of orbital-scale changes in the regional hydrology. Likewise, relative abundance of eutrophic taxa increases up to 97 % in Plimiri and up to 93 % in Lardos for short periods of time, indicating dysoxic and sapropel-like conditions at estimated water depths between approximate 100 and 300 m. The different depocentres along the east coast of the Island of Rhodes underwent specific vertical motions of tectonic coastal uplift and subsidence, which are displayed in all three sediment records. While Agathi shows a deepening trend down to 340 m, marine sediments of Plimiri and Lardos rather suggest a shallowing trend in water depth up to 125 and shallower than 100 m, respectively.

Benthic Foraminifera across a late Eocene carbon cycle perturbation on Blake Nose (NW Atlantic)

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The Eocene was an epoch of high climatic variability in Earth's History. Our planet transitioned from a hothouse to a coolhouse state, with several brief (10s–100s of kyrs) perturbations of the global carbon cycle superimposed. Most of these episodes are associated with paired negative oxygen and carbon isotope excursions in marine carbonates, and they are known as hyperthermals.

Here, we present a preliminary study across a late Eocene (planktonic foraminiferal biozone P16; calcareous nannofossil subzone CP15b) carbon cycle perturbation recorded in bathyal sediments at Ocean Drilling Program Site 1053 (Sections 1053B-8H5 and 1053A-8H2) on Blake Nose, NW Atlantic. Stable isotope analyses ($\delta^{13}C$ and $\delta^{18}O$) in bulk sediment show a ~0.25 ‰ and 1.1 ‰ negative excursion, respectively, across the event.

We aimed to perform a quantitative analysis of benthic foraminiferal assemblages across this interval and to carry out isotopic analyses on their shells, but attaining these objectives proved challenging. Taxonomic identification at the species level is not straightforward due to the small size of the specimens, and the species commonly used in geochemical analyses (e.g. *N. truempyi*, *O. umbonatus*) are very scarce. Assemblages are strongly dominated by calcareous Foraminifera, with abundant *Pseudoparrella* sp]. and *Nuttallides* spp., and common *Globocassidulina subglobosa*, *Uvigerina proboscidea*, *Brizalina tectiformis*, and *Brizalina* spp. We selected

Pseudoparella sp., a small to medium sized biconvex species with a low trochospire, as the target species for isotopic analyses. Its taxonomic identification and differentiation from *Nuttallides* and *Epistominella*, however, is challenging. Further studies of selected samples will aim to calibrate the isotopic signal of *Pseudoparella* sp. to the commonly used species *Oridorsalis umbonatus*.

Unravelling the *Globigerina falconensis* plexus: A journey from the Miocene to the present

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Globigerina falconensis and *Globigerina bulloides* are two widely used taxa in palaeoceanographical and palaeoclimatological studies. Morphologically, these two species are similar, with the main difference being the distinctive apertural lip in *G. falconensis*. This taxon was originally described from Miocene sediments in Venezuela and it still remains a largely unexplored and mysterious taxon. We traced the *G. falconensis* plexus through its entire stratigraphic record, compiling a biometric study of its morphology and wall texture.

Ocean floor drilled cores from numerous DSDP, ODP, and IODP expeditions (DSDP 590, ODP 662, ODP 747, ODP 871, ODP 925, ODP 982, ODP 984, IODP U 1482, IODP U 1489, IODP U 1490, and M 32/2) have been used in this study. We selected cores to cover the entire

fossil range of *G. falconensis*, spanning from two sites at high latitudes in the North Atlantic Ocean and in the Southern Indian Ocean to sites in equatorial regions.

These global data reveal morphological differences between modern and Miocene specimens. We report a consistently more lobate morphology in populations that evolved in the latest Miocene. Moreover, we observed an irregular wall texture along the entire fossil record of the *G. falconensis* plexus. Such wall texture inconsistency might ultimately question the retention of the *G. falconensis* plexus in the genus *Globigerina*, and open new research opportunities.

Planktonic Foraminifera updated biostratigraphy and quantitative abundances from Hole 762C at the Early Eocene climaticoptimum (EECO, c.53–49 Ma)

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The Early Eocene climatic optimum (EECO; ~53–49 Ma) is the interval when Earth surface temperatures and atmospheric pCO_2 reached the peak of the Caenozoic. This past Earth global warming scenario offers possible model systems for the coming warming trend. In this respect, planktonic Foraminifera, a major group of open-marine calcifiers, play an essential role in palaeoclimatology reconstructions as they are extremely sensitive to palaeoenvironmental changes. Previous studies on Atlantic and Pacific Oceans recorded a dramatic decline in abundance and diversity

of the symbiont-bearing genus *Morozovella* close to the carbon isotope excursion (CIE) J event (EECO beginning), in opposition to a permanent increase in abundance of genus *Acarinina*. In addition, the *Morozovella*-species switched their coiling direction (the ability to add chambers in clockwise or counter-clockwise) from dextral to dominantly sinistral within 200–400 kyrs after the CIE K/X event. The record from Atlantic and Pacific Oceans also underlines diachroneities among planktonic foraminiferal biohorizons. Here we present planktonic foraminiferal biostratigraphy, quantitative abundance, and coiling direction from Hole 762C (Exmouth Plateau). This site records several CIEs below and within the EECO, though affected by some core breaks. The southern high latitude location in the northwest margin of Australia makes this site appropriate for outlining a global perspective of plank-tic foraminiferal resilience to the EECO. The new biostratigraphic data here suggested the importance of an Eocene zonal scheme revision that can solve the diachronicity problems. Our results also record the *Morozovella* change in coiling direction from the K/X event as previously documented. This study improves the knowledge on global planktonic foraminiferal resilience to the EECO and provides new insights for a thoroughgoing investigation of past global warmings that is essential to improve the understanding of the current climate changes.

Does particle selectivity explain the differential biogeography of *Sigmoilopsis species*?

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Sigmoilopsis ottnangensis is a short-lived (~500 kyrs) benthic foraminiferal species endemic to the mid-Burdigalian (*c.*18 Ma) Central Paratethys. Its

biogeographic range was limited to the North Alpine Foreland Basin (NAFB), where it is recorded in outer neritic to upper bathyal deposits. Like other species of *Sigmoilopsis*, *S. ottnangensis* covers its miliolid shell with agglutinated particles. Here, we determine the size and mineralogy of the agglutinated particles based on scanning electron microscopy coupled with energy dispersive X-ray diffraction. We compare the results to those of the cosmopolitan *S. schlumbergeri*, collected from various locations in the North Atlantic. To determine particle selectivity, X-ray diffraction was performed on sediments from the sampling locations.

The results reveal that both species select particles of a similar size range and of variable shape. We observe distinct differences in particle mineralogy between species. *S. ottnangensis* exclusively agglutinates calcite and dolomite although particles of other mineralogy are available in the sediment. Considerable differences in particle mineralogy are found between specimens of *S. schlumbergeri*. The inter-individual variability reflects that of the respective sediment.

Our observations may offer insights into the contrasting biogeographic ranges and evolutionary success of the two species. The expansion of *S. ottnangensis* seems prohibited by dolomite availability: Outer neritic/upper bathyal deposits of the NAFB contain considerable amounts of dolomite while sediments from comparable water depths in adjacent basins do not; it does not tolerate inner to middle neritic conditions where dolomite does occur (e.g. Vienna Basin). Consequently, the species became extinct when the sea retreated from the NAFB by 17.5 Ma. In contrast, *S. schlumbergeri* appears more adaptive with respect to particle mineralogy, possibly contributing to its cosmopolitan success story since the early Miocene.

Novel approaches to high resolution coccolith geochemistry through the late Pliocene *Discoaster* extinctions

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The climatic transition from the warmer Pliocene to the high-amplitude glacial–interglacial cyclicity of the Pleistocene was clearly associated with a series of species extinctions from the *Discoasters*. Although these were once a major component of tropical to sub-tropical calcareous nannofossil assemblages, they suffered throughout the late Pliocene, culminating in a series of five species extinctions over a period of ~1 Myr, with the final occurrence of *Discoaster brouweri* at 1.9 Ma. The immediate proximal causes of the extinction are currently unknown, although throughout this period there is a clear trend in declining total coccolithophore species diversity, size, and an overall transition into a more intensely glaciated climate state.

To investigate these events, a novel size separation technique was employed to generate high-resolution coccolith size specific isotopic and Sr/Ca records throughout the Pliocene–Pleistocene transition from IODP Site U 1482 (Exp. 363), on the north-west Australian continental margin. By utilizing this novel technique, we have been able to increase the speed of sample processing to rapidly generate geochemical records from the large (~7–10 µm) versus small (<4 µm) coccolith size fractions. Within the isotope records, there is a consistent offset of ~1 ‰ in the carbon isotopes. These results are consistent with previous low-resolution but long-term size fraction isotopic records, and demonstrate that these carbon isotopic offsets are retained through orbital scale variations in the climate system.

Catalog of recent North Sea Foraminifera

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An online catalogue of recent North Sea Foraminifera is being built. To date it contains 280 entries representing 104 species (23 'sp.'). The catalogue is a mutual and ongoing effort of avocational and professional scientists. It is coordinated by the Foraminifera.eu Lab, hosted on the Foraminifera.eu webpage, and is open for contributions.

The North Sea has a rich foraminiferal fauna. It reflects the diverse habitats ranging from brackish to fully marine, from areas getting temporarily dry to deeper trenches, and from estuaries to areas connected to the open North Atlantic. The foraminiferal fauna of the North Sea was last portrayed more than 50 years ago with drawings by Gabel (1971). The online catalogue is based on single specimens, represented by optical and/or scanning electron microscope images and accompanying data. The user interface is that of Foraminifera.eu and offers a data-base query. The query results are presented as plates (Hesemann 2015). The nomenclature is in accordance with the World Register of Marine Species and is updated regularly.

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Palaeoenvironmental analysis and correlation of Triassic sediments, North Sea

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Triassic sediments in the central and northern North Sea are a significant resource for hydrocarbon potential. The Triassic of the North Sea represents a sequence of continental sediments that were deposited in a climate-driven distributive fluvial system. It is made up by the Skagerrak Formation and the Hegre Group, the nomenclature varies widely across the North Sea. Connecting regional scale lithologies with localized studies in North Sea fields and basins has been problematic due to a number of issues. This includes a lack of reliable biostratigraphic information, heterogeneous lithostratigraphy, the varying influence of salt tectonics, unconformities and erosion, and partial Triassic well penetrations. The Triassic sediments of the central and northern North Sea are dominated by the continental red-bed facies. The sandstones within these red-beds form important hydrocarbon reservoirs, however, they are most often barren of palynomorphs or contain limited diagnostic biostratigraphic material. By conducting an in-depth palynological investigation of Triassic strata within the North Sea, this study aims to reconstruct the palaeoenvironmental conditions. This project involves extending an existing palynomorph biozonation scheme developed for the early and middle Triassic (Skagerrak) of the central North Sea (UK and Norwegian sectors) into the northern sectors of the Norwegian Sea and UK North Sea. Triassic core and cuttings amples have been collected from both UK and Norwegian quadrants (focusing on darker, fine-grained sediments) and these, combined with digitized historical microscope slides from the Norwegian Geobank, form the basis for this project. Results from this study will not only help to bridge correlation across the North Sea but

also to help gain insight into floral recovery in a continental setting post Permian–Triassic extinction.

Changes in overturning circulation of the Red Sea during marine isotope stage 3

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The oceanography of the landlocked basin of the Red Sea is controlled by a restricted exchange of water masses with the Indian Ocean through the narrow and shallow strait of Bab al-Mandab and by high evaporation rates due to the arid to the semiarid climate of the surrounding land areas. At intermediate water depths, the overturning circulation in the northern Red Sea associated with the replenishment of oxygen-rich deep waters and the local oxygen consumption due to the re-mineralization of organic matter, drive the strength of the oxygen minimum zone. Here, we present benthic foraminiferal faunal data from a sediment core of the central Red Sea allowing for the quantification of orbital and millennial-scale changes in the bottom water oxygen during marine isotope stage 3. The benthic foraminiferal fauna is relatively high-diverse (~80 species), and is dominated by the infaunal species *Bolivina subreticulata*, *Cassidulina laevigata*, *Bulimina marginata*, and *Siphouvigerina porrecta*, which represent suboxic to dysoxic environments. Our preliminary results indicate millennial-scale changes in the overturning circulation of the Red Sea reflecting the influence of short-term hydrological changes in the regions of deep-water

formation sites. The oxygen minimum zone was weaker during stadials, with maximum ventilation during hyperarid conditions associated with Heinrich events in the North Atlantic Ocean.

Benthic Foraminifera as proxies of the Holocene palaeoenvironmental changes in the Krka River estuary (Adriatic Sea, Croatia)

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Estuaries are complex coastal environments with unique organisms that evolved adjusting themselves to a specific set of conditions. Along with some rare biota, estuaries are rich with benthic Foraminifera, the most common biological proxies used in palaeoenvironmental reconstructions. The Adriatic Sea has complex late Quaternary evolution and since the last glacial maximum, the sea level rise led to the flooding of the coastal areas which led to the formation of drowned karst river valleys along the coast. Our study will focus on the Holocene palaeoenvironmental record of the Krka River salt-wedge estuary. The investigated environment is a karst estuarine setting with submerged tufa barriers that influenced its Quaternary development. The sediment core PROK-3 from Prokljan Lake was analysed in detail. The Foraminifera assemblages were used for palaeoenvironmental assessment and the obtained data were further supplemented with radiocarbon dating, organic C/N analysis and grain-size. The results showed that sediments deposited during the last ~8300 years were under the significant influence of sea level variability. The intervals in the basal part of the core were absent of Foraminifera and imply the existence of

a terrestrial environment. The first evidence of marine influence is the presence of *Ammonia tepida* populations. As marine influence gradually increased due to the further sea level rise, assemblages were dominated by *Haynesina* sp. and *Elphidium* sp. and had more biodiversity. Our findings enabled a better understanding of the response of benthic Foraminifera to sea level changes in the karst estuarine setting. The results are also important for the reconstruction of the Quaternary palaeoenvironments along the eastern Adriatic coast, which is still insufficiently explored.

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Contribution of planktonic Foraminifera in global ocean carbon flux

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Planktonic Foraminifera contribute 32–80 % of the total deep-marine calcite budget and also has a substantial impact on the organic carbon export to the ocean bottom. However, their exact contribution to organic carbon export to the deep ocean has not been quantified. This is because the organic carbon depends on the internal volume of the shell where the cytoplasm is located and is species specific. To fill this knowledge gap, we conducted a survey and produced computer-tomography scans of all major species of planktonic Foraminifera. We measured the calcite and internal volume of

each species to determine their relative contribution to calcite and organic carbon export. Such basic information can be applied to the existing data of planktonic foraminiferal shell flux from sediment trap samples, and provide the quantitative contribution of planktonic Foraminifera to carbonate and organic carbon exportation in the global ocean.

Can we use morphological traits to estimate genome size in fossil plants?

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Genome size (GS) varies by several orders of magnitude in land plants. It has been linked to both extinction selectivity and diversification following adaptive radiations, with whole genome duplication (WGD) events thought to be a driver of both taxonomic diversification and morphological evolution. The only empirical evidence for GS changes in the past comes from the fossil record, with cell size, and in particular stomatal guard cell length (GCL), showing a positive correlation with GS. The most common and abundant plant fossils however are sporomorphs (pollen and spores), which if leveraged as a palaeo-genome size proxy would allow for a more complete picture of GS variation through time than is available from leaf and cuticle fossils alone. To date there is mixed evidence for a relationship between GS and sporomorph size, however, within species comparisons across ploidy series suggest a positive correlation, while broader scale, among-taxon comparisons indicate at best only a weak control of GS on sporomorph size. Here, we investigate this problem using (1) direct measurements of angiosperm pollen size and GCL, and (2) a literature

compilation of pollen and spore size across a range of plant groups. While GCL and GS are positively and linearly related to each other, pollen size is weakly correlated with GS and is strongly phylogenetically structured. A predictable relationship between genome size and sporomorph size is not supported by this study, and future research should focus instead on developing GCL as a palaeo-genome size proxy.

Who knows *Globorotalia mentum*?—Making micropalaeontological data FAIR

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Microfossil assemblage data are invaluable for palaeoclimatology, palaeoecology, and biomonitoring. Meta-analysis of such data allows answering different questions than can be addressed using individual studies and can hence yield marked progress in these fields. However, such analyses are difficult because microfossil assemblage data rarely comply with the FAIR (findable, accessible, interoperable, and reusable) data principles.

Raw assemblage data is often not publicly available or only findable by searching for derived data. This not only hinders findability, but lack of access to raw data renders quantitative ecological research irreproducible. Interoperability is often hindered by insufficient metadata. However, reusability issues arguably present the largest challenge to meeting FAIR standards. They primarily stem from the complexity of taxonomic data.

Standardization of this type of data is challenging because of evolving taxonomic insights that are difficult to apply to legacy data sets. Many taxonomic issues arise from the use of synonyms. In many cases, standardiza-

tion can be achieved by one-to-one or many-to-one mapping of ontologies. However, lack of taxonomic consensus leads to ambiguity when the same name is used for more than one species or when lumped species are given the same name as the parent species, or even given a new name. Together with the tendency to report relative, rather than absolute, abundances and the habit to include individual and lumped species in the same data set, this has led to an embarrassingly high proportion of archived data sets to contain obvious errors.

Clearly, these issues need to be addressed in order to increase the value of assemblage data. Here we propose a method to harmonize legacy data and a recommendation for reporting standards. These proposals are meant as a starting point for a discussion and we explicitly solicit feedback from the entire community on how to increase the FAIRness of micropalaeontological data.

Assessing the community composition of UK benthic Foraminifera: Little Neston Saltmarsh & Dulas Bay Estuary

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The community composition of benthic Foraminifera was documented at two contrasting estuaries: Little Neston Saltmarsh, England, UK, and Dulas Bay Estuary, northern Wales, UK. This study aimed to assess whether the spatial variability of the foraminiferal fauna exhibits a similar zonation pattern to temperate coastal saltmarshes, relative to the tidal frame. The modern distribution of benthic Foraminifera from surface sediment samples, across 22 sample stations, was described at the above estuaries. The results

suggest that the distribution of benthic foraminiferal species corresponds to the reports from other studies and appears to be controlled by elevation. The fauna was dominated by calcareous species at the sand and mud-dominated Dulas Bay Estuary. Stations across the high and mid marshes show a higher proportion of agglutinated Foraminifera at Little Neston, whereas the low marsh and mudflats are dominated by calcareous species.

The faunal composition, species richness, and diversity were found comparable to the other saltmarshes of the same latitude. It appears to be an unpolluted environment with an exceptionally low proportion of morphological test abnormalities. The study areas have never previously been the subject of micropalaeontological analysis and there is a lack of modern datasets that would facilitate sea level studies. This study generated new occurrence data to add to pre-existing categorical records of Foraminifera at Little Neston Saltmarsh site and will contribute to global databases: PANGAEA® Data Publisher.

Dynamic palaeoenvironmental changes in the late Eocene (Priabonian) of the Transylvanian Basin

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The Eocene–Oligocene transition is mostly known as a cooling event on a global scale. This had an impact on the global ocean and consequently on the marine biota, although it can be assumed that its effect was dependent on regional palaeoceanography, which is poorly constrained in

the Transylvanian Basin. Therefore, we investigated a core recovered from the late Eocene Brebi Formation, Transylvanian Basin, in order to reconstruct the shallow-marine palaeoenvironment before it was impacted by the Eocene–Oligocene global changes. Multi-proxy analysis based on the recovered benthic foraminiferal and bryozoan assemblages were used to constrain the environmental parameters, i.e. water depth, energy, temperature etc. The diversity indices and multivariate data analysis (principal component analysis and cluster analysis) performed on the benthic Foraminifera assemblages were further corroborated with palaeoenvironmental interpretation of the bryozoa assemblages. Our results show that just before the onset of global cooling, the late Eocene shallow-water environment of the Transylvanian Basin was relatively stable with some perturbations of the palaeoceanographic parameters. These perturbations were mainly linked to local or regional environmental factors, as the influence of the sedimentary processes, i.e. substrate or sediment grain size, can be excluded.

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Coiling directions in the mid Miocene paragloborotallids (planktonic Foraminifera): A potential bioevent for the base of the Langhian

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Trochospiral planktonic Foraminifera will coil either sinistral (left) or dextral (right). The prevalence of sinistral or dextral coiling can change through the stratigraphic range of morphospecies, with several coiling flips used

as bioevents in recent to late Miocene (~0–7 Ma) biochronology. However, no such events have been applied beyond this age despite a number of species being known to adopt preferential coiling. One such example is the *Paragloborotalia mayeri–Paragloborotalia siakensis* group, which undergoes a change from random to sinistrally dominated coiling in the mid Miocene (~15 Ma) in the tropical–subtropical realm. We investigated low (IODP Sites U 1337 and U 1338, ODP Sites 871 and 925), mid (JOIDES-3 hole), and high latitude (ODP Site 747) sites to assess the global synchronicity of the coiling change. We also extended the study to other Miocene paragloborotaliids to determine if the coiling change is unique to the *P. mayeri–P. siakensis* group. Our results show that in the low-mid latitudes, the random to sinistral coiling shift is at ~15.37 Ma within planktonic foraminiferal Zone M5 and is observed in both *Paragloborotalia siakensis* and *Paragloborotalia continuosa*. In the high latitudes (ODP Site 747), the absence of paragloborotaliids through a portion of the mid Miocene prevents accurate dating, although random coiling trends are found in the older paragloborotaliids (~17.3–19.8 Ma) compared to the sinistral dominance adopted within the younger forms (~13.5–9.0 Ma). We propose the recognition of a coiling change in *Paragloborotalia* as a secondary bioevent in the mid Miocene at 15.37 Ma, and a useful means for the recognition of the base of the Langhian in the mid to low latitudes. This bioevent will be particularly useful in regions where the currently used bioevents, namely the *Praeorbulina–Orbulina* lineage, are rare or poorly represented.

Change in biodiversity and abundance of benthic Foraminifera with distance from an active hydrothermal vent field

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Hydrothermal vent fields can provide a habitat for many organisms in the mostly oligotrophic deep sea. In these environments, chemoautotrophic microbes often represent the beginning of the food chain and, thus, a possible food source for heterotrophic benthic Foraminifera. The distribution of benthic Foraminifera is controlled by food availability and other environmental factors such as oxygen or temperature. This study investigates the influence of hydrothermal activity on the biodiversity and abundance of benthic Foraminifera by comparing the distribution of living and dead Foraminifera assemblages along a proximal-to-distal transect in close vicinity to the Rainbow hydrothermal vent field. The vent field is located at the Mid-Atlantic Ridge near the Azores and consists of ten active black smokers with fluids of high temperature and low pH forming a stable vent plume. The transect follows the plume of the black smokers for ~41 km. Biodiversity and abundance of living benthic Foraminifera increase with distance to the black smokers until a distance of 2 km. The Shannon–Wiener diversity increases from 2.3 (living) and 2.8 (dead) close to the vents to 3.3 (living) and 3.6 (dead) at 2 km distance. The population density of living benthic Foraminifera (>125 µm-fraction) in the uppermost centimetre of the sediment increases from 0.65 ind. cm^{-3} at 0.2 km distance to 2.33 ind. cm^{-3} at a distance of 23 km. The species distribution shows remarkable differences along the transect. Miliolids dominate near the vent field while hyaline and agglutinating benthic Foraminifera become more abundant with increasing

distance. Thus, miliolids might be better adapted to tolerate the extreme hydrothermal conditions than the hyaline and agglutinating species.

The *Entzia macrescens* (Brady) population of a continental salt marsh (Sic, Transylvanian Basin, Romania)

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Entzia macrescens (Brady) is a species of agglutinated Foraminifera with a fine grained, flat trochospiral test. First described by Jenő Daday (1883) as *E. tetrastomella* based on specimens collected from a salt marsh near Deva (Romania), it is the only modern Foraminifera species occurring in the Transylvanian Basin (TB). Unfortunately, the type locality and former habitat of this taxon can no longer be found, but in 2011 specimens of *E. macrescen* were retrieved from a salt marsh near Turda (Romania). So far, this locality was considered to be the only one habitat of this species in the TB (Filipescu and Kaminski 2011). However, most recently, living and subfossil speciemens of *E. macrescens* were found in the salt marsh from Sic too (Jakab et al. 2018).

The aim of the present study is to investigate the distribution and dynamics of *E. macrescens* populations from the salt marshes of Sic. Therefore, we perform regular sampling, detailed biometric analyses, and survey their habitats by water chemistry parameters.

Our results show so far that the average protoconch diameter of the *E. macrescens* population (300 specimens, for three locations) is 14.42–16.60 µm, while the average diameter of the shell is 114.49–214.01 µm. The average number of chambers is between 12.61 and 13.34. Data on

water chemistry point out that the studied *E. macrescens* populations have a high tolerance toward water temperature, total dissolved salt, and Eh.

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Determinants of benthic foraminiferal zonation at Cape Blanc, Atlantic Ocean

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Offshore Cape Blanc is considered one of the most productive areas on the Earth, due to the upwelling currents and major dust input from NW Africa.

Previously, a link between the vertical migration and distribution of the benthic foraminiferal taxa and the oxygen penetration depth, nitrate, and sulfate levels was suggested in the studied zone (Jorissen et al. 1998). These

observations however are based only on the >150 µm size-fraction, thus neglecting important smaller taxa. Furthermore, previous diversity and abundance surveys (Lutze and Coulbourn 1984) focused only on the >250 µm size-fraction. Thus, a need was created to conduct a high-resolution investigation of the benthic foraminiferal assemblages of the >63 µm fraction.

The aim of this study is to investigate the horizontal and vertical distribution of the benthic species in the top 10 cm of the bottom sediment. Therefore, we used six Multi-Corer samples (GeoB 20317, -18, -21, -22, -23, and -24), recovered from ~100 to 3000 m water depths during the MSM 48 ADOMIS cruise (Zonneveld et al. 2017).

Our results show a vertical and horizontal zonation of the foraminiferal assemblages: The deepest consist of *A. weddellensis*, *C. wuellerstorfi*, and *E. exigua*, meanwhile the shallower-water are dominated by *P. ariminensis*, *H. boueana*, *B. aculeata*, and *Cassidulina* spp. Vertically, a down-deep increase of low-oxygen tolerant taxa (i.e. *B. aculeata* and *U. peregrina*) could be observed. Our findings indicate a clear zonation of the benthic foraminiferal species, and their abundance and distribution are related and mainly influenced by the availability of organic matter and dissolved oxygen. Thus, the benthic species are controlled by the depth and upwelling-related environmental parameters.

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Foraminifera indicate turbidite activity intensified during the last 500–1000 years in the upper slope of the Eastern Mediterranean

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The longshore current system responsible for the transport of Nile-derived sediments to the Levant Basin has been studied in detail. In contrast, the cross-shelf component of sediment transport (turbidites), responsible for conveying sediments toward the upper slope, is much less documented. Reconstructing sediment transport down the continental slope is critical for understanding its natural dynamic and for estimating the timing, rate and risk of geohazard events. We studied two sediment cores from the upper (HRZ 500; ~6.5 m at 500 m water depth) and lower (SAM 058; ~2 m at 1111 m) continental slope of the Apollonia landslide scar offshore central Israel. The cores were analysed in high resolution using foraminiferal assemblages, radiocarbon dating, and sedimentological and geochemical methods. Core SAM 058 contains at its base glacial deposits with allochthonous (shallow) benthic Foraminifera overlain by ~1 m of Sapropel S1 interval dated at its topmost part to 6 ka. Core HRZ 500 shows at its base a discontinuity interpreted as the Apollonia landslide basal plain dated using Foraminifera to early Holocene. It is overlain by ~4.5 m of homogeneous hemipelagic sediments characterized by a high planktonic/benthic ($\frac{P}{B}$) ratio and low abundance of autochthonous (local) benthic Foraminifera. The top ~1 m is characterized by laminated intervals with a lower $\frac{P}{B}$ ratio and

an increase in poorly preserved benthic Foraminifera, some of shallow habitat. These findings suggest a high sedimentation rate since the late Holocene in the upper slope governed by contourites, and a shift to intense turbidite activity in the last 500–1000 years. Comparison to a previously studied core at 280 m offshore northern Israel corroborates an increase in turbidites in the last hundreds of years, but shows a higher contribution of shallow benthic Foraminifera in shallower depths. Thus, Foraminifera act as an important tool for reconstructing sediment transport, used also for geohazard assessment.

Coccolith clumped isotopes reveal a colder Miocene North Atlantic and deep tropical coccolithophore habitat depths

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While widely-used temperature proxies like Foraminifera Mg/Ca and $\delta^{18}O$ require assumptions of past seawater chemistry, and the mechanism linking organic indicators like TEX86 and $U^{k\prime}_{37}$ to temperature remains unknown, clumped isotope (Δ_{47}) thermometry depends only on thermodynamics. Therefore, its application to well-preserved coccolith calcite has the potential to improve absolute temperature reconstructions of euphotic oceans.

We measured Δ_{47} in world-wide distributed Holocene core top coccoliths,

in North Atlantic well-preserved and pure coccolith size fractions during the last 16 Myrs, in a monospecific *Coccolithus pelagicus* sediment trap in the Iceland Sea, and in coccoliths of the tropical Equatorial Pacific throughout the Caenozoic.

We observed similar temperatures between satellite data during the monospecific *C. pelagicus* bloom and those reconstructed using Δ_{47}, piling up to the evidence of no vital effects in coccolith Δ_{47}. We find that Δ_{47} applied to core top coccoliths in tropical regions are colder than surface temperatures, suggesting that tropical coccolithophores are likely living deeper than at the surface, and calling for re-evaluation of calibrations for the application of other traditional temperature proxies.

The extreme polar amplification during warm intervals is a conundrum yet to be resolved by climate models. Coccolith Δ_{47} suggest a ~10 °C colder North Atlantic compared to $U^{k\prime}_{37}$ from the same samples, agreeing much better with simulations of climate models. Neither assemblage variation, preservation issues, potential vital effects, or Δ_{47} calibration, could explain such a large temperature difference.

Preliminary coccolith Δ_{47} results from the Equatorial Pacific show the expected cooling trend throughout the Caenozoic, but too cold absolute temperatures show the importance of careful separations to eliminate potential recrystallized particles from coccolith separations to achieve accurate absolute temperature reconstructions.

HMS Challenger surface plankton samples at The Natural History Museum benchmark the state of the ocean 150 years ago

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The Challenger Collection of Ocean Sediments is the nucleus of a larger collection of ocean bottom deposits at the Natural History Museum that consists of samples from over 30 000 sites from collections made over the last 150 years. Two recent publications have highlighted pilot studies that encourage further use of these sediments as a baseline for oceanic conditions almost 150 years ago. A publication in *Scientific Reports* (Fox et al. 2020) compared 1875 Challenger plankton tow collected planktonic Foraminifera with material from the recent Tara Oceans expedition that visited the same region of the equatorial Pacific Ocean in 2011. Using nano-computer (CT) tomography scans, comparison of two species present in both collections showed that all modern examples have thinner shells. Although there are many drivers for production of calcium carbonate shells from sea water, the conclusion was that the Foraminifera are finding it increasingly difficult to secrete their shells because of the increased acidity of our oceans. Another research article (Rillo et al. 2019) assessed the planktonic foraminiferal content of the bottom sediments, comparing other datasets from core top samples and the last glacial maximum about 21 kyrs BP, to conclude that some of these sediments from an early age of seafloor exploration can provide a late 19th century baseline of the marine environment. Here we show some early results from a CT scanning method that provides a further assessment of these sediments so that specific samples can be identified as best representing the oceanic conditions at the time of the Challenger Expedition. However, we highlight a collection of recently discovered

slides of surface plankton samples from the HMS Challenger and suggest that these show the importance of the historical data available from these collections and their potential for answering big questions like the effects of anthropogenic climate change.

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Benthic Foraminifera assemblages at IODP Site U 1387 reveal environmental changes on the seafloor—first results from marine isotope stages 20–19

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Analysis of benthic Foraminifera assemblages from the Gulf of Cadiz reveal a considerable change in the abiotic factors such as oxygen levels and trophic conditions during the Early–Middle Pleistocene transition (EMPT, 700–1250 ka). The EMPT was a global climate event and characterized by a drastic change in the deep thermohaline circulation that resulted in more intense and longer lasting interglacial periods. However, in the North

Atlantic, high-resolution records documenting variations in the ocean associated with the EMPT are still limited. The Gulf of Cadiz is a transition zone between the Mediterranean Sea and the Atlantic Ocean, which is affected at intermediate depths by changes in the Mediterranean outflow water (MOW). Variations in the MOW might influence the thermohaline circulation and affect the oxygen level and bottom current activity along the western Iberian margin. The benthic Foraminifera fauna in the Gulf of Cadiz (IODP Site U 1387; 559 m water depth) during marine isotope stages (MIS) 20–19 (814–761 ka) was evaluated to reconstruct changes in bottom current velocity, food flux to the sea floor, and oxygen fluctuations. Throughout the glacial MIS 20, high relative abundances of cassidulinid and miliolid species appear to reveal changes in the quality of food availability. MIS 20 and the later phase of MIS 19 are marked by high abundances of the elevated epifauna species indicating a prevailing vigorous MOW. Moreover, at the onset of interglacial MIS 19 and later within MIS 19, short periods with low oxygen conditions are revealed by high relative abundances of sub- and anoxic groups and a decrease of the elevated epifauna, suggesting a poorly oxygenated, low velocity MOW current. The study will be expanded to other interglacial-glacial cycles during the EMPT to shed light on the links between ocean hydrography and climate.

Morphology variations of benthic Foraminifera in the Baltic Sea during the last interglacial

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Presently, marine environments globally face multiple threats: Warming, deoxygenation, and ocean acidification. These anthropogenically induced marine environmental changes have created a need for a context to understand the severity and potential outcomes of such changes. This context can be provided from the geological record covering a comparable time period in the past with such rapid climate changes and associated marine environmental changes. We use records of benthic Foraminifera from the Danish Straits at the Baltic Sea entrance covering the last interglacial period (LIG, marine isotope stage 5e) for reconstructing environmental changes. A combination of synchrotron radiation X-ray microcomputed tomography (μCT) and foraminiferal assemblage and geochemistry data has been employed to generate time series of environmental records during the LIG. We analysed the foraminiferal species *Elphidium clavatum* with respect to shell thickness, surface/volume ratio, size, and pore density. Our hypothesis is based on that Foraminifera respond to environmental variations and stresses by having their test morphology changed. The μCT results show the surface area/volume ratios were decreasing, while the mass was increasing throughout the LIG (from 126 to 119 kyrs BP), indicating the Foraminifera were becoming more smooth and heavier. It coincides with a

decreasing salinity and dissolved O_2 concentrations of the bottom water revealed from foraminiferal trace elements and stable isotope results. Our study evaluates the use of benthic Foraminifera morphological features as a proxy for reconstructing past bottom water conditions in a brackish and potentially hypoxic environment.

The onset of the Santonian cooling registered by planktonic Foraminifera and stable isotopes at southern high latitudes

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The latest Cenomanian to Santonian sedimentary record recovered at IODP Expedition 369 Site U 1513 in the Mentelle Basin (eastern flank of the Naturaliste Plateau, SE Indian Ocean, palaeolatitude 60° S at 85 Ma) is studied to interpret the palaeoceanographical evolution in the Southern Hemisphere. The changes in planktonic foraminiferal assemblage considering depth ecology preferences of different species and surface and seafloor temperatures inferred from the stable isotopic values measured on foraminiferal tests provide a valuable perspective on Late Cretaceous climate. The hothouse climate during the Turonian–Santonian, characterized by weak latitudinal temperature gradients and high atmospheric CO_2 concentrations, is followed by a progressive cooling during the Campanian. At Site U 1513, the beginning of this climatic transition is nicely recorded within the Santonian, as indicated by an ~1 ‰ increase in $\delta^{18}O$ values of planktonic Foraminifera

suggesting a significant decline in surface water palaeotemperatures of 4 °C. The onset of cooling also recorded changes in the planktonic foraminiferal assemblages including extinctions among surface (*Marginotruncana*) and deep (*Planoheterohelix papula*) dwellers, appearances (*Archaeoglobigerina cretacea*) and diversification of newly evolving taxa (*Globotruncana*), and changes from predominantly epifaunal oxic to infaunal dysoxic/suboxic taxa among co-occurring benthic Foraminifera.

Overall, the data presented here document an interval in the Santonian during which the rate of southern high latitude cooling increased. Both surface and bottom waters were affected, although the cooling signal is more evident in the data for surface waters. This pattern of cooling is in agreement with model simulations and palaeotemperature reconstructions and ascribes the deterioration of the Late Cretaceous climate to decreased CO_2 in the atmosphere and changes in the oceanic circulation correlated with enhanced meridional circulation.

3 D geometric morphometrics on ostracod shells

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The detailed description of valve traits is a fundamental aspect of ostracod taxonomy, especially in fossil systematics where soft parts are missing. Quantitative 2 D geometric morphometric methods have been successfully used to determine morphospecies, distinguish ecophenotypes, and to compare valve shape with molecular data. 3 D approaches are still under development in the field of ostracodology, but may provide an even more

precise idea of morphological diversity and morphological response to environmental changes. Establishing 3 D workflows requires an efficient way to digitize a high amount of specimens, as well as quantitative methods for capturing variations of morphological 3 D-traits. This case study focused on the morpho-variable non-marine ostracod species *Eucypris virens*. We used an epoxy µ-computer tomography (CT) carrier and high-resolution µ-CT scans to generate 3 D surface models of the shells. Software and statistics applied in (palaeo-)anthropology were transferred to ostracod shells for an objective geometric morphometric approach using 3 D curve and surface-sliding semi-landmarks. We show that 3 D curve and surface-sliding semi-landmarks are useful to quantify small-scale 3 D changes on feature-poor ostracod shells. These methods need to be tested on more sculpted and fossil species. In addition to quantitative analysis of µ-CT generated 3 D-Models, they can be easily shared digitally and included in databases.

Seasonal variances in the athalassic palaeolake of Tayma (Saudi Arabia) seen in Ostracoda and Foraminifera during the Early Holocene humid period

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Tayma in Saudi Arabia is an important archaeological and historical oasis city, with Neolithic finds and an almost permanent settlement history since the early Bronze Age. During the Early Holocene humid period (EHHP), a perennial lake was located in the endorheic depression north of the modern settlement. While the climate in this area is arid to hyperarid today, it was

arid to semiarid during the EHHP. A deep lake phase occurred around the 8.2-ka climate deterioration that led to general cooling and drying on the Arabian Peninsula. Foraminifers and ostracods in the sediments of the sabkha basin represent a brackish to hypersaline inland water fauna, which provides valuable information on the past precipitation/evaporation balance. In the lower part of an analysed core section from the deepest part of the basin, they reflect the beginning of the EHHP with a transition to a more humid phase and the development from oligohaline wetlands to a shallow brackish lake, shown by increasing microfossil abundances, a decreasing adult/juvenile-ratio in ostracods, and an increase of δ^{13}C. This culminated in a deep lake phase at *c.*8.3 ka_{cal}. In the varved sediments in this section, ostracods (*Cyprideis torosa*) and foraminifers (*Ammonia tepida* and *Quinqueloculina seminula*) are more abundant in the dark layers, indicating more favourable living conditions during deposition of these layers. This is also indicated by higher frequencies of juvenile carapaces in the light layers, suggesting possibly higher juvenile mortality rates. A sieve pore analysis in *C. torosa* valves proposes distinctly higher salinities during deposition of the light layers. The seasonal variances in the microfossil assemblages indicate generally dry summers and more humid winters.

In the uppermost part of the section, a decrease in both microfossil and macrofossil frequency, and stable isotopes in the ostracod shells indicate the transition to drier conditions in the mid-Holocene, at *c.*8.1–7.9 $kyrs_{cal}$ BP.

Effects of electrical stimulation on viability of marine benthic *Amphistegina lessonii*

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The impacts of human activities have reached a critical level that is destined to worsen due to climate change. Environmental disturbances resulting from anthropogenic energy pollution (e.g. construction of infrastructure, wind turbines, submarine power cables) are intensely growing and represent a concern for the marine environment. The Marine Strategy Framework Directive (MSFD) foresees the evaluation of the impact of introducing anthropogenic forms of energy as a descriptor in the assessment of the marine quality status. Although marine invertebrates are the significant fauna exposed to this kind of pollution, they have received little attention. Among benthic organisms, Foraminifera are largely used as pollution bioindicators in marine environments but studies on the effects induced by electrical stimulation are not documented. This study aims at assessing the effects of different electric current densities on the viability of *Amphistegina lessonii*, a larger symbiont-bearing foraminiferal species, sensitive to environmental stress. The viability was evaluated after exposure to both constant and pulsed direct currents stimulation by checking the pseudopodial activity. After three days of treatment, the viability of *A. lessonii* exposed to pulsed current was higher at low electric current density (0.6, 1.7, 2.9 $\mu A\,cm^{-2}$) than at high electric current density (11.4, 14.3, 17.1 $\mu A\,cm^{-2}$), whereas *A. lessonii* stimulated with constant current showed pseudopodial activity

at lower electric current density (0.3, 0.9, 1.4 µA cm^{-2}) up to 24 h, while at high electric current density (2.9, 5.7, 8.6 µA/cm^2) the pseudopodial activity was absent. Based on these preliminary results, the selected benthic foraminiferal species seem to better stand pulsed currents than constant ones and even at higher density. These first experiments might provide useful information for the definition of the appropriate electrical density threshold to avoid side effects on a part of the benthic community.

Benthic foraminiferal biodiversity in the northern Barents Sea: Preliminary results

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In the Arctic region, foraminiferal diversity and distribution have been associated with water depth gradients and changes in temperature and food availability. However, there are still a lot of uncertainties about how spatial and temporal variability of sea ice patterns that influence the temperature and food conditions affect the Arctic foraminiferal community structure. In this work, we described preliminary results of spatial and seasonal variations in benthic Foraminifera from the northern Barents Sea region. Living benthic foraminiferal (rose Bengal stained) material was analysed from surface sediment samples (0–1 and 1–2 cm) collected at ten stations in the Barents Sea shelf and slope in October 2018, August and December 2019, and March and May 2021. The size fractions 63, 125, and 500 µm were analysed separately. We observed that agglutinated species dominated most

of the fauna (>50 %), comprising almost all the assemblages at shallow, southern sites with high sand content. Allogromiids were highly abundant. High proportions of calcareous species were observed at slope stations, where the presence of cold deep-water species such as *Melonis affinis* and *Pullenia bulloides* is characteristic. Moreover, a substantial proportion (>25 %) of calcareous species were decalcified, mostly at shallower shelf sites and in the subsurface samples. There is considerable variability in total abundance between the sampled locations and periods, with the highest values at slope sites during October 2018, December 2019, and March 2021. The agglutinant species *Portatrochammina bipolaris*, *Lagenammina difflugiformis*, and *Reophax scorpiurus* dominate the assemblages, whereas the most abundant calcareous species are *Epistominella arctica*, *Elphidium excavatum* var. *clavatum* and *M. affinis*. Continued biodiversity assessments within the Barents Sea will improve our understanding of the seasonality in the benthic realm providing insights into the past and future of the Arctic ecosystem functioning.

Response of the coccolithophore species *Calcidiscus leptoporus* to environmental change during the industrial era in the subantarctic Southern Ocean

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The Southern Ocean is a critical component of the global overturning circulation and a major sink for anthropogenic CO_2. However, the physical and chemical properties of its surface waters are experiencing rapid and

relentless change. The rate of warming of the Southern Ocean waters exceed that of the global ocean while the enhanced uptake of CO_2 is leading to a reduction in pH and decrease in the concentration of carbonate ions, a process known as ocean acidification. This pronounced change in ocean water properties poses a serious risk for marine ecosystems in general and for marine calcifying organisms in particular.

Coccolithophores are the most prolific group of marine calcifying phytoplankton and important contributors to the pelagic production of both particulate organic and inorganic carbon. Satellite reflectance observations suggest the development of extensive blooms of coccolithophores in the circumpolar Subantarctic Zone during the austral summer. Therefore, changes in coccolithophore composition, composition and calcification of coccolithophores may have important consequences on Southern Ocean marine ecosystems and ocean chemistry, ultimately affecting the climate. Available evidence suggests that ongoing environmental change in the Southern Ocean is influencing the distribution and composition of pelagic plankton communities. However, these studies are scattered in space and time, and large regions of the Southern Ocean, remain undocumented.

Here, we compare the variations in morphometric parameters of the coccoliths of the keystone species *Calcidiscus leptoporus* across different time scales. In particular, we compare the coccoliths collected during an annual cycle by a sediment trap, with those from the underlying sediments and in a sediment core covering the Holocene epoch. Our results allow us to reconstruct the response of *C. leptoporus* to environmental variations in the Southern Ocean.

Space-for-time substitution only partially predicts temperature-change effects on marine plankton biodiversity

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Space-for-time substitution is the use of contemporary, spatial ecological patterns to predict temporal ecological patterns into the future or reconstruct them into the past. Many fields have developed methods relying on space-for-time substitution, such as palaeoecological transfer functions, vegetation chronosequences, and, increasingly, conservation biology. However, the fundamental assumption that the processes driving ecological change across space are also those driving change through time, remains largely untested. Here, we empirically test this assumption by compiling assemblage data of planktonic Foraminifera spatially across the global ocean and temporally through the past 250 000 years, as well as corresponding data on sea-surface temperature (SST). We then modelled temperature-driven compositional turnover across space and time, as SST has been shown to be the best predictor of planktonic Foraminifera spatial turnover. We find that predictions of temporal turnover based on the spatial model are 43 % as accurate as the temporal model ($R^2_{\text{temporal}} = 0.44$; $R^2_{\text{spatial}} = 0.19$). When SST differences are minimal, there is a significant amount of unexplained turnover (i.e. baseline turnover) that is better predicted by the

temporal than the spatial model. Based on the assumption that SST is the major control on planktonic Foraminifera assemblage composition, our results imply weaker empirical support for the space-for-time substitution than previous studies based on Quaternary north-American pollen data.

Palaeoproductivity of the Eastern Equatorial Pacific Ocean during the Eocene–Oligocene climate transition: Records from benthic Foraminifera (ODP Hole 1218 A)

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The Pacific Ocean, being world's largest reservoir of heat and water, has played a major role in climate evolution throughout the Caenozoic. This study aims to comprehend the palaeoproductivity and ecological shifts that happened ~34 Myrs BP, which brought about dynamical changes globally and marked the first appearance of ice sheets on Antarctica. Benthic foraminiferal census records and total organic carbon (TOC) measurements from a continuous succession of sediment core of ODP Hole 1218 A (water depth 4828 m and core depth 273 mbsf) from the Eastern Equatorial Pacific (EEP) were analysed. The cluster analysis depicts the three main groups of species, with *Cibicides* spp. serving as the main shared habitat. Along with this, *Globocassidulina* spp., *Gyroidinoides* spp., *Oridorsalis umbonatus*, *Nuttallides umbonifera*, *Pleurostomella* spp., *Pullenia subcarinata*, *Siphonodosaria abyssorum*, *Spiropectammina spectabilis*, *Stilostomella subspinosa*, and various forms of dentalinids/nodosarids consistently present in this interval (~42–31 Ma). The prevalence of *Cibicidoides*, as well as other epifaunal species including *Gyroidinoides*, *Epistomella*, and *Oridorsalis*, suggests a well-oxygenated, oligotrophic habitat during the Eocene–

Oligocene transition. The presence of the infaunal genus *Stilostomella* implies a medium to high flux of organic food, as well as intermediate seasonality, implying lower oxygenation. *Cibicides havanensis*, *C. grimsdalei*, and *C. praemundulus* were indicators of lower bathyal and abyssal palaeoenvironments but are also commonly reported from abyssal palaeo-depths. A low organic carbon flux is also shown by the TOC records, which from this interval indicate a high value of 3.21 % and a minimum value of 0.05 %. This works hence broadens the understanding of the palaeo-productivity of EEP which ultimately give significance to the Eocene–Oligocene climate transition.

High-resolution micropalaeontological and sedimentological investigation of an Eocene thanatocoenosis (Transylvanian Basin, Romania)

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Nummulitic accumulations are peculiar sedimentary records because they have no modern counterparts. As a result, the reconstruction of their genesis and evolution is a difficult task, and generated may controversies. In order to offer a new perspective on this long-debated subject, we collected detailed micropalaeontological, sedimentological, and stratigraphic data to better constrain the geological history of the largest Eocene nummulitic accumulation of the northern Neotethyan realm. The studied sedimentary

record preserves *Nummulites* assemblages, which consist of *Nummulites perforatus* (granulate, large) and/or small *Nummulites beaumonti* (radiate, small) and are correlated to the SBZ 17 (Bartonian). Based on the relative abundance of the taxa and/or relative abundance of A- vs B-forms, three assemblages could be distinguished: (1) Assemblage 1, characterized by abundant *N. beaumonti* (A-forms), and rare *N. perforatus* (A-forms), while B-forms of both taxa are rare or missing; (2) Assemblage 2, defined by only *N. perforatus* (A and B-forms); and (3) Assemblage 3, composed of *N. perforatus* (A- and B-forms) with only rare *N. beaumonti* (A and B-forms). The accumulation of these assemblages formed a large-scale thick (up to 10 m) thanatocoenosis on a low-angle inner shelf. The horizontal and vertical distribution of the three assemblages reflects the interaction between the biological and physical environment, and the ability of *Nummulites* taxa to colonize new habitats. Thus, the studied thanatocoenosis offers a detailed view on how the ecological preferences of the two *Nummulites* species, relative sea-level, sediment supply and possibly climate history contributed to the development of nummulitic accumulations.

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Palaeoenvironmental changes of the Curonian Lagoon (SE Baltic Sea) inferred from the diatom data

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Diatoms are sensitive to environmental conditions and pretty quickly react to changes in their habitat, so diatom analysis is one of the basic methods used to correlate the patterns of ecosystem development and climate change.

A 4-m deposit core at a depth of 2.4 m was recovered from the south part of the Curonian Lagoon. For the micropalaeontological study, samples were performed from each 10 cm interval according to the standard techniques. The ecological groups were determined using published papers.

Based on the diatom analysis results, preliminary data about environmental and climatic changes were received. A visual inspection and stratigraphically constrained cluster analysis were applied for the subdivision of the three palaeobotanical zones. Along the entire length of the core, the most abundant taxa were benthic alkaliphiles diatoms. Most of the species are freshwater–brackish, which indicates the low salinity of the water.

The first zone is characterized by the mass diversity and development of benthic diatoms, thus, reflecting the period of the low water level. Planktonic taxa are, thus, more abundant in the middle section of the core, indicating that the water level was higher at that time. However, the sediment sequence contained several intervals in which the diatoms population was very small or absent. It suggests the existence of short-term arid conditions. In the upper part of the core previously undetected taxa, *Actinocyclus normanii*, was recorded. *Actinocyclus normanii* might be an invasive species that originated from the north of the lagoon and migrated south to

the freshest site with a high concentration of nutrients. It is considered a warm stenothermic species and could be an indicator of an increased eutrophication process.

Our study revealed that diatoms developed in the shallow coastal zone of a freshwater basin with periodic changes in water level.

Study on pore patterns of *Ammonia*; proxy for a palaeo-oxygen indicator of Chilika Lagoon, Odisha, India

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The oxygen-depleted environment in the marine ecosystem has been increasing daily, which will have profound consequences such as reduced diversity, the decline in fisheries, the redistribution of communities, and altered biogeochemical cycles. A highlight on using benthic Foraminifera as a proxy for palaeo-oxygenation detection has been addressed.

Ammonia is one of the benthic Foraminifera's dominant and abundant taxa in shallow marine and lagoonal settings. For the study, a core sample of 52 cm was retrieved from the outer sector of Chilika Lagoon, Odisha, India. The study's primary aim is to investigate the pore pattern of *Ammonia* spp. and correlate them with the palaeo-oxygenic condition of the environment. Pore characters have a morpho-functional adaptation to the microhabitat and are also species-specific. So, detailed computation of the pore morphology of *Ammonia* can be used as a biological proxy to elucidate the trends in oxygen changes of the past. *Ammonia* spp. with their characteristic pore patterns have been observed using scanning electron microscope (SEM) imaging. Pore parameters at the spiral and umbilical sides were measured

and calculated. The software measured pore characteristics such as pore diameter, density, and porosity. The dissolved oxygen of the lagoon has also been considered for correlation. In addition, energy-dispersive X-ray spectroscopy (EDS) has been used to assess the relative composition and quantity of the target elements.

Drivers of planktonic Foraminifera calcite flux in the Nordic Seas

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Planktonic Foraminifera are major pelagic carbonate producers in the Arctic. Ongoing rapid climate change influences the Arctic as a habitat and might lead to changes in the Foraminifera calcite production and flux to the sea floor. The current contribution of Foraminifera to the pelagic carbonate flux is not yet fully resolved, preventing quantitative assessment of potential future scenarios of changes in Arctic carbonate budget.

To resolve the relevance of the variability of shell flux and shell mass for planktonic Foraminifera $CaCO_3$ mass fluxes, and to understand which factors are driving their variability in the Arctic, we analysed a time series of shell flux from a sediment trap deployed in the HAUSGARTEN observatory in the eastern Fram Strait from June 2014 to July 2015, complemented by three published time series from the Nordic Seas covering different periods between 1991 to 1995. The data from the HAUSGARTEN observatory show the tendency of Foraminifera shells being heavier during

summer and decreasing in weight towards the end of the productive period. Nevertheless, the magnitude of the variation throughout the sampling period is small in contrast to the change in shell flux, which varies by more than three orders of magnitude. In order to understand the mass flux of planktonic Foraminifera $CaCO_3$, we therefore need to know what is causing the variability in shell flux.

Our analysis shows that the timing of fluxes of planktonic Foraminifera shells is influenced by sea surface temperatures, and by sea ice in regions where sea ice is present during winter in high concentration. However, as the variability of climatic conditions and nutrient availability in terms of particulate organic carbon and chlorophyll α concentration cannot explain differences in planktonic Foraminifera mass fluxes between different years at the same location, other environmental or biotic factors must contribute to the variability in planktonic Foraminifera mass fluxes in the Arctic.

The effect of temperature on growth, photosynthesis and calcification of *Emiliania huxleyi*

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Emiliania huxleyi is a dominant member of the coccolithophores functional group with an exceptionally wide geographical distribution. As observed in other cosmopolitan phytoplankton, it is usually expected that populations from different latitudes might have experienced distinct local adaptations and evolved with related thermal tolerance. As such, these adaptations could have altered the biological contribution of *E. huxleyi* to the organic

pump vs the carbonate counter pump on oceanic pCO_2. In this study, we exposed nine strains of *E. huxleyi* to temperatures between 15 and 28 °C and evaluated the change in their growth, photosynthesis, and calcification to quantify their optimal range and threshold temperatures.

Our results suggest that the biogeographical origin of *E. huxleyi* does not directly affect thermal tolerance, as no clear patterns are created by local adaptation of 'cold-adapted' strains and 'warm-adapted' strains. In fact, while all strains exhibit optimal growth at 23–25 °C, the greatest difference in thermal response is observed between two of the Mediterranean strains with one (RCC 1830) exhibiting an optimum at 23 °C and no growth at 25 °C, and another (RCC 1853) displaying an optimum at 25 °C and being the only examined strain growing at 28 °C. This suggests that other factors might play larger roles in local thermal adaptation than a latitudinal niche partitioning.

Moreover, inhibition of either net photosynthesis or calcification by temperature only occurred in two strains: The resilient Mediterranean (RCC 1853) continued to calcify but reduced net photosynthesis to zero at 28 °C. The sub-polar strain ARC 28-3, decreased net photosynthesis to zero from 23 °C and stopped calcification at 25 °C. The observed relative sensitivities of photosynthesis and calcification to temperature implies that as sea water temperatures continue to increase *E. huxleyi* population might become less effective as a sink of atmospheric CO_2.

Do biotic controls buffer against climate-driven extinction threats?

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Both biotic and abiotic factors control diversification and extinction. Climate change is widely suggested as the main abiotic control on macroecology and macroevolution. Identifying biotic regulators of biodiversity change in deep time is more complex as we typically cannot directly observe biotic interactions. In taphonomic settings that preserve multiple individuals, we can begin to reconstruct community dynamics. The spatially, biogeographically, and taxonomically comprehensive fossil record of Plio–Pleistocene planktonic Foraminifera (PF) allows high-resolution studies of long-term eco–evolutionary response.

Here, we characterize assemblage diversity through the integration of richness, evenness, and dominance of taxa using Hill numbers to represent the effective number of species. We calculate Hill numbers for multiple individual species' extinction events using abundance counts of PF assemblages from tropical Atlantic ODP Site 925. We document changes in biodiversity structures across three intervals of pre-, imminent-, and post-extinction.

Using an analysis of covariance, we show differential relationships between climate states and extinction intervals. There is a correlation at the reference Hill numbers for Shannon's and Simpson's diversity indices (evenness and dominance, respectively) with climate state during the pre-extinction and imminent-extinction phases, but not post-extinction. There is no correlation at any state for species richness. Results suggest a decoupling from climate and thus a shift to less abiotic regulation on PF assemblages post-extinction. While species richness is consistently lower

post-extinction, the difference in dynamics between richness, evenness, and dominance calls into question the reliance on taxon counts for inferring the regulators of biodiversity in deep time. With increased resolution, there is potential to gain an understanding of how biotic forces shaped past extinctions to predict future extinctions under climate-driven threats.

High stress palaeoenvironmental conditions during Maastrichtian, Eastern Tethys: Inferred from diversification of planktonic Foraminifera

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Planktonic foraminiferal diversification from the late Cretaceous sediments of the Eastern Tethys (Pakistan) indicates high-stress depositional environment in response to local intense tectonic activities coupled with eustatic changes. The biostratigraphic studies reported abundant planktonic foraminiferal species of *Globotruncana*, *Heterohelix*, and *Globotruncanita*. A single biozone of age range 75 to 69 Ma is erected. The rapid sedimentation that occurred in the studied basin as a result of rapid tectonic activity generated a dilution effect that led to a general lack of species diversity. Such high rate sedimentation is further supported by the increase in turbidite sequences implying that a sediment shed area was closer to the basin. Moreover, the richness of planktonic Foraminifera in the rock unit shows a declining tendency from the base to the top of the section which infers a transitional shift from a colder to warmer climate, i.e. the change in nutrient structure as a result of the early Maastrichtian (75–73 Ma) more stratified ocean giving way to the late Maastrichtian mixed ocean (73–69 Ma).

It's getting hot around here—new insights from propagule experiments into foraminiferal assemblage reactions to heat exposure

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With ongoing ocean warming, exposure of shallow-water communities to periods of high temperatures (>30 °C) is to be expected more frequently. In some tropical areas (e.g. eastern Africa, Persian Gulf), field observations revealed diverse and species-rich thermotolerant assemblages of benthic Foraminifera. However, examples from anthropogenically heat-polluted warm-temperate areas in the Mediterranean (e.g. near power plants), showed significant effects on assemblages.

Here we provide data on propagule cultivation experiments from shallow-water material of Corfu in the Central Mediterranean Sea. Experiments were performed over a duration of 65 days and were set up in two steps: First, bulk sediment (<53 µm) was set up at two temperatures over 25 days (22 °C and a 12-hour-cycle of 29–36 °C). After termination, the material was re-sieved and set up in microcosms at 22 °C and 26 °C.

Preliminary results show that specimens grew in both treatments during the first experiment and assemblage composition was not significantly different. However, both the abundances of grown taxa and the survivability of individuals decreased in the hot treatment. In the second experiment, the microcosm assemblages differed significantly between the previous exposition at 22 °C and 29–36 °C. It is worth noting, that the associated algae that grew in the respective treatments were also different, which might have influenced the communities beyond the temperature variable.

Our experiments suggest that heat stress might pose longer-lasting effects on foraminiferal assemblages—either directly or indirectly by affecting their food sources. In the microcosm experiment, the propagule assemblages were still influenced by their initial thermal treatment. Recovery to pre-experimental states could still be possible, but might take longer than the time frame of the present experiment. Future studies with longer recovery phases and the use of tropical propagule material could give further insights into these mechanisms.

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