FORAMS 2023

June 26th–30th, 2023 - Perugia, Italy

Abstracts with program

Edited by:

C. A. Papazzoni
& M.R. Petrizzo

International Symposium on Foraminifera

FORAMS 2023

Perugia, Italy, June 26 – June 30, 2023

Abstracts with Program

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Foreword

Dear Friends and Colleagues,

FORAMS 2023 continues the tradition of the highly successful meetings previously held in Halifax (Benthos ’75), Pau (Benthos ’81), Geneva (Benthos ’86), Sendai (Benthos ’90), Berkeley (FORAMS ’94), Monterrey (FORAMS ’98), Perth (FORAMS 2002), Natal (FORAMS 2006), Bonn (FORAMS 2010), Concepción (FORAMS 2014), and Edinburgh (FORAMS 2018).

During the last meeting in Scotland, the general assembly voted to hold the next meeting, FORAMS 2022 (now FORAMS 2023), in Perugia, Italy.

It is with great pleasure and honour that Perugia hosts this important scientific event, which certainly will contribute to spread even further the knowledge and the science among all countries represented at the meeting.

FORAMS 2023 will see **223 oral presentations** and **162 poster presentations** hosted into **25 scientific sessions**, with **more than 330 participants**. Two of the proposed field trips were activated to visit the Carso area (near Trieste, pre-congress) and the world-famous Bottaccione section (close to Gubbio, post-congress).

The presentations will cover any topics related to extant and fossil foraminifera, including biostratigraphy, taxonomy, evolution, mass extinctions, paleoclimatology, paleoceanography, paleogeography, geochemistry, biology, ecology, symbiosis, biomineralization, environmental monitoring, extreme environments, polar environments, automated recognition, molecular systematics, from all over the world.

We thank all the participants hoping this conference will be again an enjoyable place to exchange scientific knowledge, to stimulate younger researchers to build new collaborations, and to demonstrate the vitality of our scientific community.

The Organizing Committee of FORAMS 2023

Map of Perugia

with indications for the Conference venue, ice breaker party, city center, bus and train stations

Code of Conduct

This Code of Conduct applies to all FORAMS 2023 participants (students, professionals, accompanies, retired and emeritus status). FORAMS 2023 is committed to equality, diversity, inclusion and accessibility; all participants will receive equal treatment regardless of age, disability, gender reassignment, marital or civil partner status, pregnancy or maternity, race, colour, nationality, ethnic or national origin, religion or belief, gender or sexual orientation, as well as many other characteristics that can be discriminated against.

All FORAMS 2023 participants are expected to:

a) Be committed to quality, diversity and inclusion, and not act in a way that discriminates against any individual or group, for example knowingly disseminate material, which appears to encourage discrimination.

b) Help create a supportive, respectful, and inclusive environment for all. Whilst it is recognised that scientific debate should aim to challenge ideas, questions and discussions should be constructive and never demeaning, abusive or inflammatory.

c) Respect the private property and intellectual property of others, ask first permission to the corresponding author to record a presentation, or to take a picture of a poster. Requests not to disseminate content must always be respected.

d) Behave politely with all fellow participants as well as with all personnel involved in the conference organization. Alcoholic beverages will be available during lunchtime and during evening events. Alcohol misuse will be reported to the local authorities.

Allegations of behaviour that breaches the Code will be investigated by FORAMS 2023 Organizing Committee that will take appropriate action.

Field trips

Pre-Congress

(FT1) - Shallow water Cretaceous to Paleogene successions in NE Italy: the Carso Region.

2 days: June 2023, 23rd and 24th

Field leaders: Lorenzo Consorti (CNR-ISMAR, Trieste) - lorenzo.consorti@ts.ismar.cnr.it; Romana Melis (University of Trieste) - melis@units.it

This pre-congress field trip aims to unravel some key places in the surroundings of Trieste (NE Italy) including rock strata rich in larger Foraminifera as well as Recent depositional environments where benthic Foraminifera can be found as a living constituent. The Cretaceous to Eocene carbonate platform of the Classical Karst, together with the siliciclastic deposits associated to the Eocene Dinaric orogenic phase, host some of the traditional successions studied for larger Foraminifera. The Eocene deposits of Collio are moreover particularly known for releasing isolated *Alveolina* and *Nummulites* specimens. Recent intertidal rocky areas of the Trieste gulf host a wide array of niches in which benthic foraminifera, among *Ammonia*, *Trochammina* and *Elphidium*, thrive abundantly. During the morning of June 23rd, the field trip will run at Miramare Castle where Eocene olistoliths, rich in larger Foraminifera, are on stand. Then we will go for a sampling of living Foraminifera from an intertidal setting at the Villaggio del Pescatore, including a quick visit to the dinosaurs site, whereas the afternoon will be dedicated to collect fossil Larger Foraminifera nearby Cormons village. The second day (June 24th) will focus on the Cretaceous and Paleogene exposures at Aurisina (type locality of *Keramosphaerina tergestina,* Upper Cretaceous), Val Rosandra (lower to mid Eocene) and at the K-Pg bearing section of Padriciano (Maastrichtian to Thanetian). In June 25th participants should reach the conference venue at Perugia in time for the icebreaker party; train is the fastest option (Trieste->Florence->Perugia). More detailed info will be given in a next circular; for any particular request o more detailed info please contact the field leaders. The field trip mostly includes geological activity, hammers and hand lens are recommended. Follow the safe rules for excursions in the field, every participant should have a medical insurance policy or be covered by the own the national health program. The nearest international hub is Ronchi dei Legionari Airport, even the most of flight companies land at Venice airport, two hours by bus or train from Trieste. Ronchi dei Legionari Airport is connected to Trieste by train.

Post-Congress

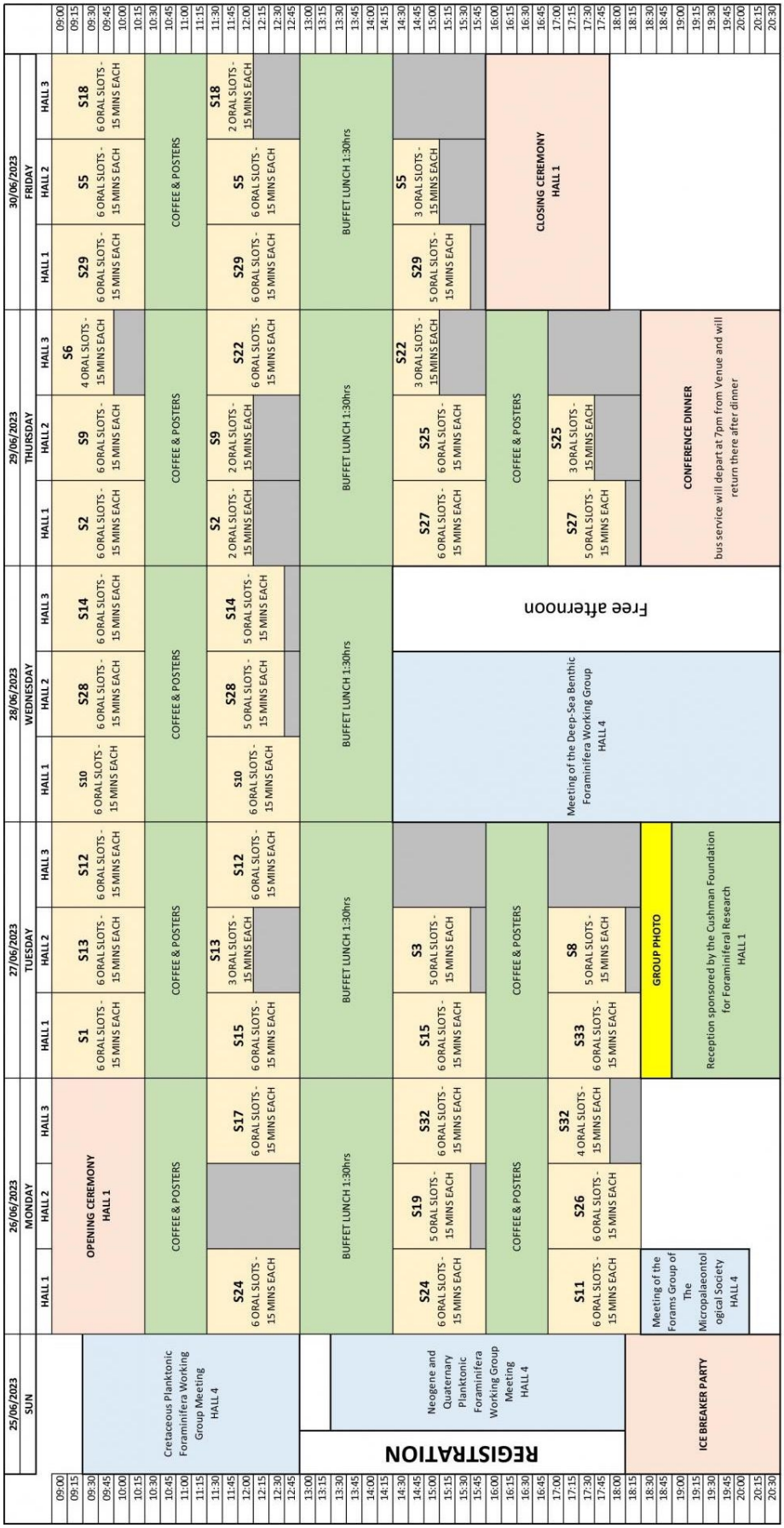
(FT3) - Mesozoic sequences and the K/Pg boundary around Perugia.

1 day: July 1st

Field leaders: Michael Kaminski (KFUPM) - kaminski@kfupm.edu.sa; Fabrizio Frontalini (UniUrbino) - fabrizio.frontalini@uniurb.it

A one-day field excursion to Gubbio and Piobbico will visit the major stage boundaries and oceanic events in Cretaceous and Paleogene. A lunchtime visit to the historical city of Gubbio is included. Departure directly from Conference Venue, visit to Bottacione Gorge to view the Campanian GSSP and the Cretaceous/Paleogene boundary. Walk on the ancient aqueduct towards the city of Gubbio. Free Lunch in Gubbio / free time for shopping. Short trip to the Contessa Road section to view the PETM and the Cenomanian/Turonian boundary. 14:30 Departure to Piobbico to view OAE1a (the Selli Event). 18:00 Arrival in Perugia, back to Conference venue.

Conference Schedule



OPENING CEREMONY

Monday, June 26

HALL 1

9:00 Welcome from the FORAMS 2023 Organizing Committee
Invited speakers:
Maurizio Oliviero, Rector of the University of Perugia
Diego Perugini, Head of the Department of Physic and Geology of the University of Perugia
Leonardo Varasano, Councillor for Culture of the Municipality of Perugia

10:05 **FORAMS 2023 Award** for Career Achievement

10:15 Introductory talk by ***Mike Kaminski*** (King Fahd University of Petroleum & Minerals, Saudi Arabia) - Decadal Trends in Foraminiferology

CLOSING CEREMONY

Friday, June 30

HALL 1

16:00 **Best Student Awards** for Oral and Poster presentations
Presentation of the **candidates** and selection of the **location for the next INTERNATIONAL SYMPOSIUM ON FORAMINIFERA - FORAMS 2027**
Announcements of upcoming meetings and
Closing remarks and acknowledgments by the FORAMS 2023 Organizing Committee

ORAL PRESENTATIONS

MONDAY June 26th

HALL 1

S24: Oceanographic records from K/Pg to Recent: A session dedicated to the research interests of Dick Kroon	
Conveners: Bridget Wade, Silvia Spezzaferri, Stephanie Stainbank	
11:30	Kaminski Michael A., Hikmahtiar Syouma and Cetean Claudia G. - Turnover in agglutinated foraminifera across the Cretaceous/Paleogene boundary at Contessa, Umbria-Marche Basin, Italy: assessing the Signor-Lipps Effect
11:45	Gilabert Vicente, Arenillas Ignacio, Arz José Antonio, Batenburg Sietske J., Robinson Stuart A., Krahl Guilherme, Fauth Gerson, Regelous Marcel and Ferrer Daniel - Deccan volcanism, Chicxulub impact, orbital forcing, and changes in planktic foraminiferal assemblages across the Cretaceous/Paleogene boundary
12:00	Hsiang Allison Yi - A high-resolution morphological record of planktonic foraminifera across the K-Pg boundary
12:15	Macleod Kenneth G. and Huber Brian T. - Extremely rapid evolution of earliest Danian planktonic foraminifera? Evidence from the Brazos River Cretaceous-Paleogene boundary sequence
12:30	Schmidt Daniela N., Adebowale Monsuru, Flower Amy, Thomas Ellen, Ridgwell Andy, Cotton Laura J. and Witts James - Life in a dark environment –physiological response of benthic foraminifera to the environmental changes of the Paleogene
12:45	Lowery Christopher M., Standring Patricia, Borrelli Chiara, Routledge Claire, Villa Alexandra, McIntyre Andrew and the South Atlantic transect IODP Expedition 390 & 393 Scientists - Eocene Evolution of Surface Circulation and Export Production in the Western South Atlantic
LUNCH	
14:30	Gallagher Stephen, Wade Bridget, Qianyu Li, Holdgate Guy, Bown Paul, Korasidis Vera, Scher Howie, Houben Alexander, McGowran Brian and Allan Tony - Eocene to Oligocene high paleolatitude neritic record of Oi-1 glaciation in the Otway Basin southeast Australia
14:45	Takata Hiroyuki, Sakai Saburo, Nomura Ritsuo, Tsujimoto Akira, Nishi Hiroshi, Soo Lim Hyoun and Khim Boo-Keun - Biotic response of deep-sea benthic foraminifera at ODP Site 744 (Kerguelen Plateau) in the Southern Ocean during the early Oligocene
15:00	Friedrich Oliver, Brzelinski Swaantje, Bornemann André, Wilson Paul, Liebrand Diederik and Van Peer Tim - Short-term waxing and waning of Antarctic ice sheets during the late Oligocene – evidence from benthic foraminiferal geochemistry
15:15	Cannings Torin, Kroon Dirk, Robertson Alastair, Jung Simon, Barnet James, Rae James and Mark Darren - Insights into Middle to Late Miocene conditions in the eastern Mediterranean region (Cyprus) from stable isotope and trace element analysis
15:30	Miyamoto Yusei and Takagi Haruka - Vertical distribution of planktonic foraminifera and its controlling environmental factors in the eastern South Pacific
15:45	Spezzaferri Silvia, Samankassou Elias, Basso Daniela, Pisapia Chiara, Kroon Dick, De Leau Erica, Martínez-Colón Michael and Stainbank Stephanie - Understanding coral thermal bleaching thresholds during past interglacial extremes: Insight into thermal stresses dynamics on tropical coral reef ecosystems (RESILIENCE)

POSTERS AND COFFEE BREAK	
S11: Evolution, Stratigraphy, and Geological Crises	
Conveners: Luka Gale, Rossana Martini, Katsumi Ueno	
17:00	De Nooijer Lennart, Pacho Laura, Jorissen Frans, Pawlowski Jan, Rosenthal Yair, Dissard Delphine and Reichart Gert-Jan - Does the elemental composition of foraminiferal shells reflect their evolutionary history?
17:15	McCauley Chris, Nestell Galina, Nestell Merlynd and Barrick James - Late Silurian (Ludlow, Pridoli) and Earliest Devonian (Lochkovian) Foraminifers of South-Central Oklahoma, USA
17:30	Tremblin Clément M. and Haig David W. - Early evolution of trochamminoids (trochospiral organic-cemented agglutinated foraminifera)
17:45	Nestell Galina and Nestell Merlynd - Roadian foraminifers of the Williams Ranch Member of the Cutoff Formation (Guadalupian, Middle Permian), Delaware Basin, West Texas (USA)
18:00	Haig David W., Barros Isaias Santos and McCartain Eujay - Permian–Early Jurassic Nodosarians: Punctuated diversification but no mass extinction
18:15	Boscolo-Galazzo Flavia, Jones Amy, Dunkley Jones Tom, Crichton Katherine A., Wade Bridget S. and Pearson Paul N. - Late Neogene Evolution of modern deep-dwelling plankton

HALL 2

S19: Modern and Past Tropical Belts Assessed by Foraminifera	
Conveners: Mike Kaminski, Maria Virginia Alves Martins, Silvia Helena Mello Sousa	
14:30	Alves Martins Maria Virgínia, Hohenegger Johann, Nunes Márcia, Damasceno Fabrício Leandro, Figueira Rubens, Martínez-Colón Michael, Frontalini Fabrizio, Senez-Mello Thaise M., Pregnolato Leonardo Antonio, Duleba Wania, de Mello e Sousa Silvia Helena and Geraldes Mauro César - Determining the toxicity of metals based on different extraction methods: a case study in the Guanabara Bay (SE Brazil)
14:45	Sousa Silvia Helena Mello, Damasio Bruno, Santos Felipe Rodrigues, Bonetti Carla, Siegle Eduardo, Martins Maria Virginia Alves and Bícego Marcia Caruso - Environmental compartmentation of the Santos estuary complex (SW Atlantic, Brazil): Response of biotic indices and pollutants
15:00	Vilar Amanda, Vicente Thaisa, Omachi Claudia, De Santis Wlademir, Sambugaro Julia, Nogueira Rafaela and Sousa Silvia Helena - Response of benthic foraminifera biomass on the slope and plateau of Santos Basin (South Atlantic, Brazil) to different carbon flux models
15:15	Turco Elena, Di Renzo Rosalia and Lourens Lucas - Planktonic foraminiferal quantitative record of the Burdigalian to Langhian interval at Site 1264 (Walvis Ridge, south-eastern Atlantic Ocean)
15:30	Disaró Sibelle T., Watanabe Silvia and Totah Violeta I. - A new calcareous Globothalamea (Rhizaria, Foraminifera) from the northeastern Brazilian continental margin
POSTERS AND COFFEE BREAK	
S26: Phylogeny and taxonomy of Neogene and Quaternary Planktonic Foraminifera	
Conveners: Tracy Aze, Helen Coxall	

17:00	Lamyman Grace, Fordham Barry, Pearson Paul, Wade Bridget, Woodhouse Adam, Young Jeremy, and Aze Tracy - Phylogeny of the Cenozoic planktonic foraminifera
17:15	Crundwell Martin - Phylogeny of Late Neogene and Quaternary planktic foraminifera: a temperate Southwest Pacific perspective
17:30	Fabbrini Alessio, Greco Mattia, Kucera Michal, Ezard Thomas and Wade Bridget S. - Bridging the gap: unravelling the fossil record of extant *Globigerina falconensis*
17:45	Jones Chloe Louise, Brombacher Anieke and Ezard Thomas - Classification challenges from overlapping distributions of final whorl chamber numbers
18:00	Lamyman Grace and Aze Tracy - An in-depth study of macroperforate and microperforate Neogene planktonic foraminifera speciation events
18:15	Latas Marcin, Pearson Paul N., Poole Christopher, Fabbrini Alessio and Wade Bridget - A new species of pink pigmented *Globigerinoides* (planktonic foraminifera) from the Pleistocene

HALL 3

S17: Larger Foraminifera through time and space	
Conveners: Lorenzo Consorti, Raquel Robles-Salcedo, Vicent Vicedo	
11:30	Read Michael T. and Nestell Merlynd K. - Middle Pennsylvanian-Cisuralian (Early Permian) fusulinids from the Cache Creek Complex near Meadow Lake, southern British Columbia, Canada: An exotic fauna with Paleo-Tethyan affinities
11:45	Shi Yukun - Carboniferous-earliest Permian foraminifera radiation certificated by a high-resolution biodiversity analysis
12:00	Torres-Silva Ana I. and Hohenegger Johann - Objective identification of *Lepidocyclina* (Foraminifera) species from the Eocene of Cuba based on growth-invariant morphometric characters
12:15	Pignatti Johannes, Marianelli Diego and Oliverio Dalila - Trimorphism in *Orbitolites complanata* Lamarck, 1801 from the Lutetian of the Paris Basin (France)
12:30	Arena Luca, Briguglio Antonino, Giraldo-Gómez Victor M., Gandolfi Antonella, Baucon Andrea, Papazzoni Cesare Andrea, Pignatti Johannes, Baumgartner-Mora Claudia, Luciani Valeria and Piazza Michele - Depositional and paleontological consequences of the Middle Eocene Climatic Optimum (MECO) as recorded along a shallow-water succession near Olivetta San Michele (IM), NW Italy
12:45	Fujita Kazuhiko, Webster Jody M. and Yokoyama Yusuke - Response of large benthic foraminiferal assemblages to sea-level changes over the past 40,000 years in the Great Barrier Reef: IODP Expedition 325
LUNCH	
S32: Biology, metabolisms and behavior: role of benthic foraminifera in ecosystem functioning	
Conveners: Joan Bernhard, Vincent Bouchet, Emmanuelle Geslin, Edouard Metzger	
14:30	Neumüller Katharina, Basu Subhajit, Schmidt Christiane, Stuhr Marleen, De Beer Dirk, Westphal Hildegard and Klatt Judith - *Amphistegina lobifera* as a sink for H_2O_2 in coral reef sediments from the Gulf of Aqaba
14:45	Masawa Jenipher, Winters Gidon, Kaminer Moran, Szitenberg Amir, Gruntman Michal and Ashckenazi-Polivoda Sarit - A matter of choice: The interactions between foraminifera and their seagrass host as a model ecosystem for biomonitoring environmental and anthropogenic stressors

15:00	Courtial Julia, Metzger Edouard, Lothier Jeremy, Choquel Constance, Limami M. Anis and Geslin Emmanuelle - Seasonal dynamics of respiration and photosynthesis of benthic kleptoplast foraminifera inhabiting an intertidal mudflat: what ecological roles?
15:15	Lintner Michael, Wildner Manfred, Lintner Bianca, Wanek Wolfgang and Heinz Petra - The use of VIS spectroscopy to detect kleptoplasts and food particles in foraminifera
15:30	Daviray Maxime, Geslin Emmanuelle, Risgaard-Petersen Nils, Scholz Vincent Valentin, Jorissen Frans, Fouet Marie and Metzger Edouard - Foraminiferal shell preservation under mudflats colonised by electrical cable bacteria
15:45	Langlet Dewi, Mermillod-Blondin Florian, Deldicq Noemie, Bauville Arthur, Duong Gwendoline, Konecny Lara, Hugoni Mylene, Denis Lionel and Bouchet M.P. Vincent - Benthic foraminifera mediate oxygen penetration and prokaryotic diversity in intertidal sediment
POSTERS AND COFFEE BREAK	
17:00	Richirt Julien, Okada Satoshi, Glock Nicolaas, Ishitani Yoshiyuki and Nomaki Hidetaka - Correlative analyses of cellular structures and elemental distribution of soluble compounds: Cryo-SEM imaging coupled to EDS elemental mapping in the denitrifying species *Bolivina spissa*
17:15	Nomaki Hidetaka, Chen Chong, Oda Kaya, Tsuchiya Masashi, Tame Akihiro, Uematsu Katusyuki, Salonen Iines S. and Isobe Noriyuki - Abundant chitinous structures in cytoplasm of *Chilostomella* and their potential functions
17:30	Glock Nicolaas, Nomaki Hidetaka, Woehle Christian, Algar Christopher, Govindankutty Menon Anjaly, Ishitani Yoshiyuki, Kienast Markus, Mutzberg André, Okada Satoshi, Rakshit Subhadeep, Richirt Julien, Schmiedl Gerhard, Steiner Zvi and Zhang Zhouling - Ubiquitous occurrence of phosphate storage in foraminifera – Another adaptation to anaerobic environments?
17:45	Nielsen Kurt Søren Svenson - Bio-erosional traces on the foraminiferal test

TUESDAY June 27th

HALL 1

S1: A Latin American and Caribbean cluster: gathering foraminiferal researchers	
Conveners: Jaime Y. Suárez-Ibarra, Lizette León-Rodríguez, German D. Patarroyo	
09:00	Reyes-Macaya Dharma, Hoogakker Babette, Martínez Fontaine Consuelo, Glock Nicolaas, Tapia Raul, De Pol Holz Ricardo, Martínez − Méndez Gema, Erdem Zeynep, Garrido Sebastian, Michel Elisabeth, McCorkle Daniel, Yokoyama Yusuke, Mohtadi Mahyar, Tavera Laura, Marchant Margarita, Cardich Jorge, Flores Edgart, Ingle James, Cordova Kathy, Kuhnert Henning, Krause Stefan, Gayo Eugenia, Castillo Alexis, Hromić Tatiana, Lückge Andreas, Santamaria Pablo, Troncoso-Ojeda Rodrigo, Aguilera Victor, Davis Catherine, Vargas Cristian and Hebbeln Dierk - Stable isotopes of oxygen and carbon in benthic foraminifera: Proxy validation in the Southeast Pacific, an international collaborative endeavour
09:15	Suárez-Ibarra Jaime Y., Freire Tiago M., Battaglin Beatriz B.F., Dias Bruna B., Ballalai João, Chalk Thomas, Chaabane Sonia, Costa Karen, Toledo Felipe, Scheiner Filip, Holcová Katarina, de Garidel-Thoron Thibault and Pivel Maria A.G. - Decoupling of productivity and carbonate dissolution in the western South Atlantic during MIS 5-4
09:30	Garrido Sebastián, Hoogakker Babette, Reyes-Macaya Dharma, Richirt Julien, Fouet Marie, Hebbeln Dierk, Gayo Eugenia M., Cardich Jorge, Muñoz Praxedes, Castillo Bruna Alexis, Michel Elisabeth and Jorissen Frans - Pore patterns of epifaunal benthic Foraminifera as a palaeoxygenation proxy in the South-East Pacific
09:45	Trejos-Tamayo Raúl, Garzón Darwin, Flores José-Abel, Pardo Andrés, Vallejo-Hincapié Felipe and Duque-Castaño Mónica - Paleoenvironmental changes during the late Paleogene – Early Neogene in the SW Caribbean Region (ANH-San Jacinto-1 well): inferences from benthic foraminifera
10:00	Kropiwiec Isabela S. and Disaró Sibelle T. - When rose Bengal fails to detect living foraminifers by simple observation through the tests – methodological approaches in the Santos Basin, Brazil (Southwestern Atlantic)
10:15	Samsoondar Sadie and Knappertsbusch Michael - Revitalizing historic and iconic Trinidad type sections through archival research within Hans G. Kugler´s Legacy in Basel, Switzerland
POSTERS AND COFFEE BREAK	
S15: Foraminiferal records of climatic and oceanographic change across critical intervals during the Cretaceous	
Conveners: Maria Rose Petrizzo, Brian T. Huber	
11:30	Görög Ágnes and Zsiborás Gábor - A glimpse into the past of planktonic foraminifera: Aalenian (Middle Jurassic) forms and their phylogenetic relationships
11:45	Colpaert Clémentine, Reboulet Stéphane and Li Gang - The response of benthic foraminifera to disaerobic event – example of the Valanginian Weissert event based on the reference Vergol and La Charce sections, Vocontian Basin, Southeast France
12:00	Giraldo-Gómez Victor M., Petrizzo Maria Rose, Bottini Cinzia and Erba Elisabetta - Bottom water conditions during the Ocean Anoxic Event 1a in the southern Tethys and central Pacific Ocean: the benthic foraminiferal response
12:15	Wolfgring Erik, Petrizzo Maria Rose and Watkins David - Integrated biostratigraphy of the Albian of the Southern High Latitudes

12:30	Gutiérrez-Puente Nicté, Barragán Ricardo, Núñez-Useche Fernando, Enciso-Cárdenas Juan, Camacho-Ortegón Luis and Mesa-Rojas Julián - Microfossil events and planktic foraminifera response to Cretaceous Oceanic Anoxic Events in the Sabinas Basin, Northern Mexico
12:45	Petrizzo Maria Rose and Gale Andy S. - Planktonic foraminifera and paleoceanographic changes across the middle Cenomanian carbon-isotope excursion (MCE 1) in south-east England, UK
LUNCH	
14:30	Kender Sev, Walker-Trivett Chloe, Edvardsen Trine, Bogus Kara, Littler Kate, Lacey Jack and Leng Melanie - Elevated productivity during Oceanic Anoxic Event 2 in the Mentelle Basin, Western Australia (IODP Expedition 369), indicated by benthic foraminifera and geochemical proxies
14:45	Amaglio Giulia, Petrizzo Maria Rose, Holbourn Ann, Kuhnt Wolfgang and Wolfgring Erik - Late Cretaceous benthic foraminifera responses across Oceanic Anoxic Event 2 at southern high latitudes (Mentelle Basin, SW Australia)
15:00	Falzoni Francesca, Petrizzo Maria Rose, Amaglio Giulia and MacLeod Kenneth G. - A causal link between re-organization of ocean circulation patterns during Oceanic Anoxic Event 2 and extinction of Rotaliporids
15:15	CP Sooraj and Punekar Jahnavi - Late Cretaceous foraminifera from Eastern Lower Narmada Valley as part of the marine seaway through Central India
15:30	Dameron Serena, Leckie R. Mark and MacLeod Kenneth G. - Re-evaluating Water Mass Influence on Late Cretaceous Deep-Sea Benthic Foraminifera
15:45	Kesen Kebenle and Punekar Jahnavi - The effect of the end-Cretaceous ocean acidification on the community structure of planktic foraminifera
POSTERS AND COFFEE BREAK	
S33: Honoring Martin Buzas: Innovative approaches to analyzing distributions of benthic foraminifera	
Conveners: Pamela A. Buzas-Stephens, Laurel S. Collins, Stephen J. Culver, Lee-Ann C. Hayek, Maria Rose Petrizzo	
17:00	Buzas-Stephens Pamela, Culver Stephen J., Marchitto, Thomas M. Jr. and Buzas, Martin A. - Attributes allowing for long species duration in benthic foraminifera
17:15	Schmiedl Gerhard, Milker Yvonne and Mackensen Andreas - Benthic foraminiferal record of deep-sea biodiversity changes during the late Quaternary
17:30	Fentimen Robin, Depuydt Pauline, De Deckker Patrick and Mojtahid Meryem - Deep-sea response to interglacial-glacial variability on the South Australian margin over the last 94 ka
17:45	Hayward Bruce W., Sabaa Ashwaq T., Howarth Jamie D., Orpin Alan R. and Strachan Lorna J. - Foraminiferal evidence for the provenance and flow history of turbidity currents triggered by the 2016 Kaikōura Earthquake, New Zealand
18:00	Jorissen Frans, Fouet, Marie, Singer, David and Howa Hélène - Foraminiferal communities of intertidal estuarine mudflats – The MII and EFDI indices, a first step towards solving the estuarine quality paradox
18:15	Burkett M. Ashley - Using seafloor substrate experiments to acquire, assess, and describe populations of *Cibicidoides wuellerstorfi* recruiting to plastics over the course of months to years

HALL 2

S13: Foraminifera in polar environments: problems of preservation, presence in different palaeoenvironments and related problem solving	
Conveners: Lucilla Capotondi, Romana Melis, Caterina Morigi	
09:00	Bombard Samantha, Leckie R. Mark and IODP Exp. 374 Science Party - Middle Miocene Foraminifera of the Ross Sea Continental Shelf, IODP Exp. 374
09:15	Melis Romana, Colizza Ester, Del Carlo Paola, Di Roberto Alessio, Torricella Fiorenza and Capotondi Lucilla - The significance of foraminifera in Southern Ocean: examples from the west-central Ross Sea
09:30	Wilkin Jack, Kender Sev, Dejardin Rowan, Allen Claire, Peck Victoria, Swann George, McClymont Erin, Scourse James, Littler Kate and Leng Melanie - South Georgia palaeo-productivity and glacial evolution over the past 15 ka
09:45	Majewski Wojciech, Szczuciński Witold and Gooday J. Andrew - Benthic foraminiferal communities (stained) in sub-Antarctic fjords of South Georgia
10:00	Bartolini Annachiara, Sabbatini Anna, Andreo Antoine, Aleon Jérôme, Mostefaoui Smail, Morigi Caterina, Rollion-Bard Claire and Monti-Birkenmeier Marina - Looking for a geochemical imprinting of sea-ice environment in the planktic foraminiferal *Neogloboquadrina pachyderma*
10:15	Coxall Helen K., Vermassen Flor, Cronin Thomas M., Regnier Alexa, Darling Kate, West Gabriel, Husum Katrine, Huber Brian T., Voelker Antje H. L. and Matt O'Regan - The genus *Turborotalita* in the Arctic Ocean: *quinqueloba*, *egelida* and *exumbilicata*
POSTERS AND COFFEE BREAK	
11:30	Szymanska Natalia, Lacka Magdalena and Zajaczkowski Marek - Climate change induced decrease in foraminifera abundance in an Arctic fjord (Hornsund, Svalbard). Implications for carbon burial
11:45	Ricardo de Freitas Thaise, Hess Silvia, Renaud Paul E. and Alve Elisabeth - Spatio-temporal distribution patterns of benthic foraminifera in the northern Barents Sea
12:00	Wollenburg Jutta E., Matthiessen Jens, Vogt Christoph, Grotheer Hendrik, Wilhelms-Dick Dorothee, Geibert Walter and Mollenhauer Gesine - The influence of post-mortem alterations in calcareous microfossils on their proxy values - exemplified by *Neogloboquadrina pachyderma* in sediment cores of the Arctic Ocean
LUNCH	
S3: Advances in larger foraminiferal biostratigraphy: a framework for reconstructing shallow-water events	
Conveners: Cesare A. Papazzoni, Antonino Briguglio, Laura J. Cotton	
14:30	Simmons Mike and Bidgood Mike - A critical review of Larger Benthic Foraminifera of the Cenomanian; planispiral (or near-planispiral) forms
14:45	Papazzoni Cesare Andrea, Fornaciari Beatrice, Giusberti Luca, Simonato Michela and Fornaciari Eliana - A new proposal for biozonation of the Paleocene: Shallow Benthic Zones (SBP) calibrated with calcareous nannofossils
15:00	Kövecsi Szabolcs-Attila, Less György, Pleş George, Bindiu-Haitonic Raluca and Silye Lóránd - The Albeşti nummulitic limestones: biostratigraphic, paleoenvironmental and paleogeographic remarks
15:15	Less György, Kövecsi Szabolcs Attila and Silye Lóránd - The distribution of some numerical parameters of *Nummulites perforatus* (Montfort) A-forms from the Bartonian of Transylvania (W Romania): evidence for trimorphic life cycle in fossil foraminifera?

15:30	Dimou Grigoria Vasiliki, Koukousioura Olga, Less György, Triantaphyllou Maria, Dimiza Margarita and Syrides George - Exceptionally abundant Larger Benthic Foraminiferal fauna from the uppermost Eocene of Fanari (Thrace Basin, Greece)
POSTERS AND COFFEE BREAK	
S8: Evolutionary and environmental control on coiling direction and loss of algal photosymbiosis (bleaching) in the foraminiferal fossil and recent record	
Conveners: Valeria Luciani, Bridget Wade, Roberta D'Onofrio	
17:00	Filippi Giulia, Luciani Valeria, Sigismondi Silvia, D'Onofrio Roberta, Dickens Gerald R., Wade Bridget S. and Westerhold Thomas - Disentangling implications of changes in morozovellids coiling direction at the Eocene Climatic Optimum (EECO, ca 53-49 Ma) (Pacific, Atlantic and Indian Oceans)
17:15	Gheiasvand Masoumeh, Bartolini Annachiara, Huber Brian T. and Fiorillo Denis - Response of morozovellid and acaraninid planktic foraminifera to early Eocene global warmth in a southern high-latitude site in the Indian Ocean
17:30	King David J., Wade Bridget S. and Miller C. Giles - Coiling direction and biostratigraphic utility of mid Miocene paragloborotaliids and globorotaliids (planktonic foraminifera)
17:45	Kenigsberg Chen, Pinko Doron Levin Sivan, Abdu Uri and Abramovich Sigal - An indoor thermal acclimation of symbiodinium endosymbionts within a foraminiferal host
18:00	Takagi Haruka and Saito Hiroaki - Responses to DCMU, high light, and high temperature in *Trilobatus sacculifer* photosymbiosis

HALL 3

S12: Foraminifera as seawater oxygen proxies	
Conveners: Sebastian Garrido, Babette Hoogakker, Nicolaas Glock, Helena Filipsson, Madelyn Cook, Jeroen Groeneveld, Constance Choquel	
09:00	Kranner Matthias, Harzhauser Mathias, Beer Christoph, Auer Gerald and Piller Werner E. - New approach to calculating dissolved marine oxygen values with the Enhanced Benthic Foraminifera Oxygen Index
09:15	Brinkmann Inda, Barras Christine, Jilbert Tom, Paul K. Mareike, Somogyi Andrea, Ni Sha, Schweizer Magali, Bernhard Joan M. and Filipsson Helena L. - Mn/Ca as a potential recorder for bottom-water oxygenation
09:30	Doherty Shannon, Davis Catherine and Fehrenbacher Jennifer - Anaerobic microbial metabolisms in particle microenvironments recorded by *Globorotaloides hexagonus*
09:45	Alcorn Rachel, Davis Catherine and Ontiveros-cuadras Jorge Feliciano - Reconstructing Pacific oxygen minimum zone structure through deglacial warming using planktic foraminifera
10:00	Davis Catherine, Doherty Shannon, Fehrenbacher Jennifer and Wishner Karen - Potential for conventional trace elements in *Globorotaloides hexagonus* as proxies for the pelagic Oxygen Minimum Zone
10:15	Van Dijk Inge, Barras Christine, Oron Shai, Mouret Aurelia and Geslin Emmanuelle - Biological adaptation of Foraminifera to low oxygen conditions
POSTERS AND COFFEE BREAK	
11:30	Subba Rohan and Ghosh Anupam - Exploring the link between Pore Morphology in Benthic Foraminifera (Ammonia) and Dissolved Oxygen: Insights from Chilika Lagoon (INDIA)

11:45	Ford Trenity and Burkett Ashley - Test volume response to bottom water oxygen changes in *Cibicidoides wuellerstorfi*
12:00	Eichner Daniela, Schmiedl Gerhard, Titschack Jürgen, Triantaphyllou Maria, Ferreira Malu and Milker Yvonne - Dysoxia in shallow bathyal marine deposits of the island of Rhodes (Greece) during the Plio-Pleistocene
12:15	Pilade Francesco, Mancini Alan, Pellegrino Luca, Lozar Francesca, Schmiedl Gerhard and Gennari Rocco - Insights into the benthic foraminiferal response to precessional forcing and environmental changes across the Messinian Salinity Crisis onset in the Sorbas Basin (SE Spain)
12:30	Sutton Seth Reid and Kelly Daniel Clay - Neritic Benthic Foraminifers as Indicators of Ocean Deoxygenation in the Salisbury Embayment (U.S. Atlantic Coastal Plain) during the Mid-Miocene Climatic Optimum
12:45	Rosenthal Yair, HESS Anya V., Auderset Alexandra, Miller Kenneth G., Zhou Xiaoli, Sigman Daniel M. and Martínez-García Alfredo - A well oxygenated eastern tropical Pacific during the warm Miocene
LUNCH	

WEDNESDAY June 28th

HALL 1

S10: Environmental monitoring with benthic foraminifera: assessing the Ecological Quality Status of coastal and marine systems	
Conveners: Michael Martínez-Colón, Irina Polovodova Asteman, Silvia Spezzaferri	
09:00	Barras Christine, Labrune Céline, Hubert-Huard Raphaël, Lescure Lyvia, Madre Mathilde, Orts Ameline, Pruski Audrey, Quinchard Sophie, Vétion Gilles and Astruch Patrick - Impact of sediment discharges on benthic faunas in coastal Mediterranean Sea
09:15	Gardoki Jon, García-artola Ane, Cearreta Alejandro, Irabien María Jesús, Gómez-arozamena José, Villasante-marcos Víctor, Galaz-Samaniego Carlos and Bessa Filipa - Modern environmental conditions on an agriculture-impacted estuary (Mondego, N Portugal): a foraminiferal approach
09:30	Golikova Elena, Korsun Sergei, Varfolomeeva Marina, Kursheva Anna and Morgunova Inna - Assessment of ecological quality status of Arctic salt marshes and adjacent tidal flats using foraminifera
09:45	Joshi Neha, Saulnier Talbot Émilie and Montero-Serrano Jean-Carlos - Foraminifera as indicators of late Holocene sediment contamination in the Bay of Sept-Iles
10:00	Hoober Lin, Titelboim Danna, Abramovich Sigal, Herut Barak, Teutsch Nadya, Benaltabet Tal and Torfstein Adi - Establishing the baseline assessment levels for monitoring coastal heavy metals in seawater using benthic foraminiferal shells
10:15	Krekova Vasilisa, Abramovich Sigal, Herut Barak and Torfstein Adi - Assessing Heavy Metal Contamination Along the Mediterranean Coast of Israel Using Foraminiferal Shell Geochemistry
POSTERS AND COFFEE BREAK	
11:30	Hess Silvia, Alve Elisabeth and Helland Aud - Retrospective benthic foraminiferal community studies: a sensitive method to determine early environmental changes
11:45	O'Brien Phoebe A.J., Barrenchea Angeles Inès, Pawlowski Jan, Nordberg Kjell, Alve Elisabeth and Polovodova Asteman Irina - Assessing the environmental quality of a historically-polluted fjord: a comparison of benthic foraminiferal eDNA and morphospecies proxy approaches
12:00	Rosa Marín Angelique and Martínez-Colón Michael - Benthic foraminifera as bioindicators of reef health in Jobos Bay, Puerto Rico
12:15	Trubin Yaroslav S. and Langer Martin R. - Benthic foraminifera from shallow-water of Line Islands
12:30	Schwing Patrick, Garrett Matthew, Hubbard Katherine, Lam Tristan, Mopps Gabe, Dauzvardis Geo, Inga Bailey, Cory Ariana, O'Malley Bryan, Larson Rebekka and Brooks Gregg - Harmful Algal Bloom (Red Tide) Monitoring Utilizing Benthic Foraminifera on the West Florida Shelf (USA)
12:45	O'Malley Bryan, Schwing Patrick, Lam Tristan, Larson Rebekka, Brooks Gregg and Gooday Andrew - Patterns of foraminiferal diversity and species composition from a three-year time series in the Southeastern Clarion-Clipperton Zone, an area designated for deep sea mining
LUNCH	

HALL 2

S28: Recent benthic foraminifera in extreme environments	
Conveners: Luisa Bergamin, Letizia Di Bella, Elena Romano	
09:00	Bernhard Joan M, Rogers Daniel, Huang I-Ting, Powers Christopher, Zhang Ying, Utter Daniel R., Cavanaugh Colleen, Edgcomb Virginia P, Gomaa Fatma - Gene expression of in situ preserved kleptoplastidic *Nonionella stella* from an aphotic sulfidic anoxic setting
09:15	Ćosović Vlasta, Šanjek Rahela, Hadžić Eric, Rakarić Mihovil, Ištuk Željko, Šušmelj Kaja, Čermelj Branko And Žvab Rožič Petra - Submarine sulphur springs in Northern Adriatic (Koper Bay) and benthic foraminiferal assemblages: extreme conditions or not?
09:30	Di Bella Letizia, Casalbore Daniele, Conte Aida Maria, Conti Alessia, Cornacchia Irene, D'Ambrosi Andrea, Gaglianone Giovanni, Ingrassia Michela, Spatola Daniele, Pierdomenico Martina, Provenzani Claudio, Ruspandini Tania and Chiocci Francesco Latino - The foraminiferal response to methane emissions in shallow water environments from the Scoglio d'Africa (Tuscan Archipelago, Northern Tyrrhenian Sea)
09:45	Hyams-Kaphzan Orit, Almogi-Labin Ahuva, Zolotarvesky Sophia, Kitin Michael, Katz Oded, Torfstein Adi and Langer R. Martin - Under the south-eastern deep Mediterranean Sea: Benthic foraminifera serve as sentinels for various microhabitats definition
10:00	Dissenha Joicce and Disaro Sibelle T - Attached and encrusting Foraminifera on mobile unconsolidated substrates in the Santos Basin (SE - S, Brazil): unexpected records
10:15	Giovenzana Francesca, Mateus-Vicens Guillem, Westphal Hildegard, Petrovic Alexander and Vahrenkamp Volker - Mesophotic benthic foraminifera assemblages record the drowning of a carbonate platform in the northern Red Sea, Saudi Arabia
POSTERS AND COFFEE BREAK	
11:30	Guilhermic Corentin, Nardelli Maria Pia, Mouret Aurélia, Pusceddu Antonio, Baltzer Agnès and Howa Hélène - Difficult life under a tidal glacier terminus: Interseasonal responses of benthic foraminifera close to the Kronebreen glacier front (Kongsfjorden, Svalbard)
11:45	Koukousioura Olga, Georgiou Sofia, Dimiza D. Margarita, Triantaphyllou V. Maria and Langer R. Martin - When stress creates high diversity: the case of Thermaikos Gulf (NW Aegean Sea)
12:00	Rohret Shari, Borda Elizabeth and Bernhard Joan M. - Assessing biodiversity of benthic foraminifera in an anoxic-hypoxic karst subterranean estuary of the Yucatan Peninsula, Mexico
12:15	Romano Elena, Bergamin Luisa, Di Bella Letizia, D'Ambrosi Andrea, Di Fazio Melania, Medeghini Laura, Pierdomenico Martina, Provenzani Claudio, Rampazzo Romano, Rinaldi Sheila and Spagnoli Federico - Agglutinated foraminifera as early indicators of microplastic pollution in two Mediterranean marine caves
12:30	deCuba Jeanette M., and Collins Laurel S. - Benthic Foraminiferal Response to the BP Deepwater Horizon Oil Spill in the Northeastern Gulf of Mexico
LUNCH	

HALL 3

S14: Foraminiferal geochemical proxies: novel approaches, unique applications and facing poorly-understood problems
Conveners: Lennart de Nooijer, Gert-Jan Reichart, Howard Spero

09:00	Branson Oscar, Holland Katherine and Eggins Stephen - Controls on B/Ca in Planktic Foraminifera
09:15	Fang Wei-Ning, Branson Oscar, Yang Er-Wen, Spero Howard J., Fehrenbacher Jennifer S. and Ren Haojia - Diet controls foraminiferal nitrogen isotopes: a feeding experiment on *T. sacculifer*
09:30	Hauzer Hagar, Evans David , Müller Wolfgang, Rosenthal Yair, Erez Jonathan - The effect of carbonate chemistry on the incorporation of trace elements into shells of benthic foraminifera: Paleoceanographic and biomineralization implications
09:45	Mojtahid Meryem, Depuydt Pauline, Mouret Aurélia, Le Houedec Sandrine, Fiorini Sarah, Chollet Simon, Massol Florent, Dohou Francis, Filipsson Helena L., Boer Wim, Reichart Gert-Jan and Barras Christine - Assessing the impact of different carbonate system parameters on benthic foraminifera from controlled growth experiments
10:00	Pacho Laura, de Nooijer Lennart, Nagai Yukiko, Toyofuku Takashi and Reichart Gert-Jan - The effect of $[Mg^{2+}]sw$, $[SO_4^{2-}]sw$, and temperature on Mg incorporation in cultured benthic foraminifera
10:15	Sigismondi Silvia, Filippi Giulia, D'Onofrio Roberta, Tiepolo Massimo, Cannaò Enrico, Dickens Gerald R., Wade Bridget S., Westerhold Thomas and Luciani Valeria - Mg/Ca surface-water paleotemperatures at the Early Eocene Climatic Optimum from the Pacific Ocean: repercussions on planktic foraminiferal assemblages
POSTERS AND COFFEE BREAK	
11:30	Singh Brijesh, Sriwastava Piyush and Punekar Jahnavi - Geochemical and Mineralogical investigation of "foraminifera barren layer" in Maastrichtian carbonate ooze of Walvis ridge
11:45	Spero Howard - Reconstructing past changes in cloud cover from foraminifera population geochemistry – A testable hypothesis
12:00	Bieler Aaron L., Schiebel Ralf, Martínez-García Alfredo, Smart Sandi M., Eßmann Tobias, Heins Lena, Gaye Birgit, Waniek Joanna J., and Haug Gerald H. - Nitrogen isotopic signals in tissue of planktic foraminifers in the northern South China Sea from the shelf to the open ocean and implications for the foraminifer-bound nitrogen isotope paleo-proxy
12:15	Fehrenbacher Jennifer, Lane Mary Kelsey, Fritz-Endres Theresa, Hupp Brittany, Davis Catherine, Branson Oscar, Ren Abby, Vetter Lael and Spero Howard - The geochemistry of non-spinose foraminifera: What is it good for?
12:30	Searle-Barnes Alex, Milton J. Andy, Standish Christopher, Foster Gavin and Ezard Thomas - Trace elements through life and time of planktic foraminifera
LUNCH	

THURSDAY June 29th

HALL 1

S2: Advances and challenges in modern and fossil benthic foraminifera research: a session dedicated to Prof. John Murray	
Conveners: Elisabeth Alve, Andrew Gooday, Babette Hoogakker, Malcolm Hart, Irina Polovodova Asteman	
09:00	Stuhr Marleen, Gea Neuhaus Aitana, Fuchs Lea T.A., Perry Chris T. and Lange Ines D. - Foraminifera of the remote Chagos Archipelago – Community responses to local and global drivers and their effects on coral reef sediment production
09:15	Prayudi Sinatrya D., Amao Abduljamiu O., Korin Asmaa and Kaminski Michael A. - Exploring the Larger Benthic Foraminifera Diversity and Deformities in the Hypersaline Arabian Gulf: An Update on the Ecological Aspects
09:30	Pavard Jean-Charles, Richirt Julien, Bouchet Vincent M.P., Holzmann Maria, McGann Mary, Armynot du Chatelet Eric, Pezy Jean-Philippe, Dauvin Jean-Claude and Seuront Laurent - Unexpected high records of non-indigenous foraminiferal species in the eastern English Channel
09:45	Polovodova Asteman Irina, Alve Elisabeth, Dolven Jane K., Eliassen Nicole, Ferraro Mattia, Hess Silvia, Morin Filip, Panova Marina, Rumpfhuber Nina, Schweizer Magali, Wiechmann Marlene R., Maciute Adele, Choquel Constance, Filipsson Helena L., Sundberg Per, Bergström Per, Risebrobakken Bjørg and Aasgaard Sigrid - Spreading of an alien benthic foraminifer in the North Sea: a reason to be worried?
10:00	Schweizer Magali, Geslin Emmanuelle, Bird Clare, Filipsson Helena L., Jauffrais Thierry, LeKieffre Charlotte, Manero Florence, Metzger Edouard, Mouret Aurélia and Quinchard Sophie - Foraminifera and Other Organisms: Determination of Interactions and Ecology (project FOODIE) in two contrasting environments
10:15	Bowser Samuel, Bernhard Joan, Landing Ed, Andreas Amanda, Patrucco Reyes Sandra and Walker Sally - Rhizarian stercomata: Experimental notes on their potential for fossilization
POSTERS AND COFFEE BREAK	
11:30	Barragán-Montilla Sofía, Johnstone Heather J.H., Mulitza, Stefan and Pälike, Heiko - Benthic foraminiferal palaeothermometry in deglacial sediments off NW Africa: how accurately is Mg/Ca recording bottom water temperature changes in the past?
11:45	Ghosh Anupam, Dasgupta Utsha, Tsujimoto Akira, Nomura Ritsuo and Saraswati Pratul Kumar - Applying faunal indices to understand paleoenvironmental changes with benthic foraminifera: a case study from Chilika Lagoon, East coast of India
LUNCH	
S27: Quaternary planktonic foraminifera: tool for paleoclimatic and paleoceanographic studies	
Conveners: Giulia Margaritelli, Fabrizio Lirer, Francisco Javier Sierro, Lucilla Capotondi, Isabel Cacho Lascorz	
14:30	Asioli Alessandra, Piva Andrea, Andersen Nils and Trincardi Fabio - Deep water production in Adriatic Sea during MIS3-MIS2 from foraminiferal and geochemical proxies
14:45	Havard Emily, Cherry Katherine, Davis Catherin, Tappa Eric and Benitez-Nelson Claudia - A changing response of planktic foraminifera to seasonality in the California Current Ecosystem: Updates from 2018-2021

15:00	Jackson Rebecca, Andreasen Nanna, Ribeiro Sofia, Knutz Paul, Guðmundsdóttir Esther Ruth, Kjær Kurt and Richardson Katherine - Quantifying oceanic regime shifts south of Iceland across glacial/interglacial transitions and millennial scale oscillations using the planktonic foraminifera record
15:15	Jonkers Lukas, Laepple Thomas, Rillo Marina C., Shi Xiaoxu, Dolman Andrew M., Lohmann Gerrit, Paul André, Mix Alan and Kucera Michal - Using spatial patterns in planktonic foraminifera biodiversity to assess climate models
15:30	Li Baohua, Yu Zhoufei, Wang Xiaoyan, Chen Jianfang and Jian Zhimin - Seasonal variation of Planktonic Foraminifera in the South China Sea and its paleoceanographic implication
15:45	Singh Vikram Pratap, Pathak Shivani and Dwivedi Rahul - Migration of the Subtropical Front over the Indian Ocean and its Impact on the Agulhas Current during Quaternary: Planktonic Foraminiferal Evidences
POSTERS AND COFFEE BREAK	
17:00	Tang Hung Yung, Minhat Fatin Izzati, Mohammad Muhammad Hanif Haziq, Abdullah Amira Afrina and Rosman Nur Iman Iwana - The distribution of planktonic foraminifera from Central Locunia province, southern South China Sea
17:15	Telesiński Maciej and Zajączkowski Marek - A mid-Holocene cold spell in the Nordic Seas and its links to a global cooling event
17:30	Chaabane Sonia, de Garidel-Thoron Thibault, Schiebel Ralf and FORCIS Working Group - Exploring the distribution and diversity of modern planktonic foraminifers under multiple climatic stressors: FORCIS database
17:45	Woodhouse Adam, Swain Anshuman, Fagan William F.. Fraass Andrew J. and Lowery Christopher M. - Late Cenozoic cooling restructured global marine planktonic foraminiferal communities
18:00	Ying Rui, Monteiro Fanny M. and Schmidt Daniela N. - Adaptive thermal niche of planktic foraminifera and the emergence of mechanistic model

HALL 2

S9: Determining the processes involved in biomineralisation – how do foraminifera build their shells?

Conveners: David Evans, Jennifer Fehrenbacher	
09:00	Erez Jonathan, Hauzer Hagar, Mor-Khalifa Gal, Bentov Shmuel and Evans David - Biomineralization and proxies in foraminifera
09:15	Meilland Julie, Nadar Pushpak, Morard Raphaël, Siccha Michael and Kucera Michal - Mass reproduction and multi-generation culture of planktonic foraminifera in laboratory
09:30	Procter Frances, Piazolo Sandra, John Eleanor, Walshaw Richard and Aze Tracy - Using electron backscatter diffraction to investigate shell microstructure and preservation impacts on planktonic foraminiferal calcite
09:45	Arns Anthea, Evans David , Schiebel Ralf, Fink Lothar, Mezger Markus, Alig Edith, Linckens Jolien, Jochum Klaus Peter, Schmidt Martin, Jantschke Anne and Haug Gerald - Non-classical crystallisation mechanisms as a part of hyaline foraminifer biomineralisation
10:00	Jaques Victory A.J., Vaňatková Kateřina, Kerkhoff Marta, Holcová Katarína, Šalplachta Jakub, Zikmund Tomáš and Kaiser Jozef - Submicron Computed Tomography to analyse and quantify microstructures in *Uvigerina* spp.
10:15	Paoloni Tommaso, Hoogakker Babette, Navarro Rodriguez Alba, Pereira Ryan, McClymont Erin, Jovane Luigi and Magill Clayton - Composition of Foraminifera test

	bound organic matter and proxy potential
POSTERS AND COFFEE BREAK	
11:30	Costanzi Elisa, Caridi Francesca, Bartolini Annachiara, Amici Adolfo, Zito Francesca and Sabbatini Anna - Preliminary study of proteins involved in the biocalcification of Rotaliid Foraminifera
11:45	Ujiié Yurika, Ishitani Yoshiyuki, Ulanova Dana, Inagaki Yuuka, Ikuma Issui, Yoshimura Toshihiro and Endo Hirotoshi - Transcriptome analyses unveil the molecular flamework of calcification in Rotaliida, benthic and planktic foraminifers: What are the differences among species?
LUNCH	
S25: Palaeo- and biogeographical dynamics of benthic foraminifera	
Conveners: Davide Bassi, Meena Förderer, Jere H. Lipps, Johannes Pignatti, Willem Renema	
14:30	Saupe Anna, Petersen Jassin, Schmidt Johanna, Bahr André and Grunert Patrick - Biogeography of benthic foraminifera in contourite drift systems
14:45	Langer R. Martin, Förderer E. Meena and Rödder Dennis - Biogeography of modern larger symbiont-bearing foraminifera: A fully revised update
15:00	Manda Sneha, Ashckenazi-Polivoda Sarit, Herut Barak, Rilov Gil, Kucera Michal and Abramovich Sigal - Hotspot pattern of benthic foraminifera in highly productive environments of the Levant
15:15	Zsiborás Gábor and Görög Ágnes - Pliensbachian–Aalenian (Jurassic) palaeobiogeographical patterns of the Neotethyan benthic foraminifera
15:30	Leckie R. Mark, Parker Amanda, Dameron Serena N. and Bryant Raquel - A Neritic Record of Oceanic Anoxic Event 2 from Coastal Utah: New Insights into U.S. Western Interior Seaway Paleoceanography and Foraminiferal Paleoecology
15:45	Doubrawa Monika, Stassen Peter, Robinson Marci M. and Speijer Robert P. - Paleoecological and biogeographical dynamics of the U.S. Atlantic Coastal Plain prior and during the Paleocene-Eocene Thermal Maximum
POSTERS AND COFFEE BREAK	
17:00	Gandolfi Antonella, Giraldo-Gómez Victor Manuel, Luciani Valeria, Piazza Michele, Arena Luca, Fornaciari Eliana, Kocsis Laszlo and Briguglio Antonino - Resilience of microbenthic and planktic foraminiferal across the Middle Eocene Climatic Optimum (MECO) along the shallow-water Sealza succession (Liguria, NW Italy)
17:15	Baumgartner Peter O., Baumgartner-Mora Claudia, Ferràndez-Cañadell Carles, Goeting Sulia, Epard Jean-Luc and Andjic Goran - Did Upper Eocene short-lived corallinacean-foraminiferal carbonates form in mesotrophic paleoenvironments along the Alpine convergent margin?
17:30	Faulkner Katherine, Lowery Christopher, Martindale Rowan, Simpson Carl and Fraass Andy - Long-Term Evolutionary Trends within Benthic Foraminifera

HALL 3

S6: Automated image recognition in microscopic analysis for foraminifera studies	
Conveners: Emmanuelle Geslin, Morten Hald, Thibault de Garidel-Thoron, Steffen Aagaard Soerense, Christine Barras	
09:00	de Garidel-Thoron Thibault, Adebayo Michael, Bolton Clara, Chaabane Sonia, Godbillot Camille, Licari Laetitia, Lichterfeld Yohan, Mazur Jean-Charles, Suarez-Ibarra Jaime Yesid, Le Thang, Chevalier Cristele, Pérez-Asensio Jose Noel, Thiam Malick,

	Walla Tobias, Barras Christine, Geslin Emmanuell and Marchant Ross - Principles and applications of automated recognition and picking of microfossils using the Microfossil Sorter (MiSo) automaton
09:15	Sørensen Steffen Aagaard, Myrvoll-Nilsen Eirik, Galata Stamatia, Johansen Thomas Haugland, Martinsen Iver, Hald Morten and Godtliebsen Fred - Automated image/video classification and object detection of foraminifera
09:30	Choquel Constance, Pirzamanbien Behnaz and Filippson Helena L. - Addressing the segmentation challenge posed by 3D pore patterns and thickness of foraminiferal tests
09:45	Govindankutty Menon Anjaly, V. Davis Catherine, Nürnberg Dirk, Nomaki Hidetaka, Salonen Iines and Glock Nicolaas - Pore detection of the denitrifying benthic foraminifer *Bolivina spissa* through automated image analysis technique
POSTERS AND COFFEE BREAK	
S22: New threats on foraminifera from climate change to emerging environmental contaminants: innovative methodological approaches and opportunities	
Conveners: Vincent M.P. Bouchet, Fabrizio Frontalini, Hidetaka Nomaki	
11:30	Sabbatini Anna, Caridi Francesca, Costanzi Elisa, Birarda Giovanni, Medas Daniela, Buosi Carla, Amici Adolfo and Mobbili Giovanna - Toxicological effects of CBs and nicotine as emerging pollutant for benthic foraminifera
11:45	Frontalini Fabrizio, Greco Mattia, Al-Enezi Eqbal, Amao Abduljamiu, Francescangeli Fabio, Cavaliere Marco, Bucci Carla, Toscanesi Maria, Trifuoggi Marco and Pawlowski Jan - Evaluation of the effects of decabromodiphenyl ether BDE-209, a persistent organic pollutant, on benthic foraminiferal community using morphological and eDNA metabarcoding approaches
12:00	Lintner Michael, Schagerl Michael, Lintner Bianca, Nagy Matthias and Heinz Petra - Symbiont-bearing foraminifera *Heterostegina depressa* affected by sunscreens
12:15	Bouchet Vincent M.P., Bertile Fabrice, Muller Leslie, Deldicq Noémie, Deiss Alice, Tailliez Loic and Seuront Laurent - Virgin or Aged does not matter: Microplastic leachates alter the behavior and the proteome of the kleptoplastidic foraminifera *Haynesina germanica*
12:30	Joppien Marlena, Westphal Hildegard, Chandra Viswasanthi, Doo Steve S. and Stuhr Marleen - Plastic particles can be mistaken as a food source and incorporated into benthic foraminifera tests
12:45	Ishitani Yoshiyuki, Ciacci Caterina, Ujiié Yurika, Nomaki Hidetaka and Frontalini Fabrizio - Time-course analyses on foraminiferal strain *Ammonia veneta* reveal unique adverse physiological effects and metabolic changes when exposed to nanoplastics
LUNCH	
14:30	Rebecchi Federica, Lattanzi Davide, Abramovich Sigal, Ambrogini Patrizia, Ciacci Caterina, Betti Michele, Schmidt Christiane and Frontalini Fabrizio - Evaluation of the effects and emerging perspectives of electric current stimulation on larger benthic foraminifera: a case study on the genus *Amphistegina*
14:45	Martínez-Colón Michael, Ross Benjamin, Martins María V.A., Owens Jeremy, Fajemila Olugbenga T. and Bouchet Vincent M.P. - Comparative analysis of potential toxic element extractions in environmental micropaleontology: “Bioavailability” anyone?
15:00	Schmidt Christiane, Puerto Rueda Diana, Stuhr Marleen, Raposo Debora, Pochon Xavier and Davy Simon - Menthol-induced bleaching as an effective method to rear foraminifera aposymbiotic

FRIDAY June 30th

HALL 1

S29: Molecular advances in foraminiferal research: from phylogenomics and molecular systematics to environmental monitoring and paleogenomics	
Conveners: Maria Holzmann, Inès Barrenechea-Angeles, Raphael Morard, Jan Pawlowski	
09:00	Morard Raphaël, Darling Kate F., Cordier Tristan, Henry Nicolas, Hassenrück Christiane, Vanni Chiara, Greco Mattia, Weiner Agnes K.M., Vollmar Nele M., Milivojevic Tamara, Rahman Shirin N., Siccha Michael, Meilland Julie, Jonkers Lukas, Quillévéré Frédéric, Escarguel Gilles, Douady Christophe J., De Garidel-Thoron Thibault, De Vargas Colomban and Kucera Michal - The global genetic diversity of planktonic foraminifera
09:15	Pawłowska Joanna, Nguyen Ngoc-Loi and Pawlowski Jan - Foraminiferal diversity uncovered by sedaDNA metabarcoding
09:30	Nguyen Ngoc-Loi, Pawłowska Joanna and Pawłowski Jan - Foraminifera diversity from the ocean surface to the surface layer of sediments in Nordic Sea
09:45	Barrenechea Angeles Ines, Holm Villads, Holzmann Maria, Pawlowski Jan and Panieri Giuliana - Foraminifera eDNA assemblages from arctic methane cold seeps
10:00	Frontalini Fabrizio, Greco Mattia, Cavaliere Marco, Buresta Andrea, Barrenechea Angeles Ines, Montresor Marina, Martins Alves Maria Virginia and Pawlowski Jan - Benthic foraminiferal changes in hydrothermal areas around Ischia Island: the evaluation of the effects of ocean acidification through morphological and molecular ecology
10:15	Girard Elsa B., Didaskalou Emilie A., Rattner Carolina, Pratama Andi M. A., Morard Raphaël and Renema Willem - Towards estimating community composition from metabarcoding output in large benthic Foraminifera
POSTERS AND COFFEE BREAK	
11:30	Pawlowski Jan, Barrenechea Angeles Inès, Nguyen Ngoc-Loi, Holzmann Maria and Gooday Andrew - Monothalamous foraminifera: mapping the unknown diversity revealed by environmental genomics
11:45	Holzmann Maria, Siemensma Ferry, Pawlowski Jan and Gooday Andrew - Freshwater and soil foraminifera: an overview
12:00	Grow Adri K. and Katz Laura A. - Assessing freshwater foraminifera diversity in New England (USA)
12:15	Timmons Caitlin, Le Kristine, Rappaport Hannah, Sterner Elinor G. , Maurer-Alcalá Xyrus X. and Katz Laura A. - The life cycle of *Allogromia laticollaris* has brief haploid and diploid phases followed by a 12,000 fold amplification of genome content and then Zerfall
12:30	Weinmann Anna E., Hassenrück Christiane, Raposo Débora, Goldstein Susan T., Langer Martin R., Li Qingxia, Triantaphyllou Maria V. and Morard Raphaël - Tracking community turnover through time: A combined approach of propagule culture experiments and eDNA metabarcoding
12:45	Langlet Dewi, Ruppli Rahel, Suzuki H. Nicole, Phua Yong-Heng, Fujita Kazuhiko and Husnik Filip - Eukaryotic symbioses of large benthic foraminifera
LUNCH	
14:30	Pinko Doron, Abramovich Sigal, Rahav Eyal, Belkin Natasha, Rubin Blum Maxim, Kucera Michal, Morard Raphaël, Holzmann Maria and Abdu Uri - Shared ancestry of

	algal symbiosis and chloroplast sequestration in foraminifera
14:45	Salonen Iines, Husnik Filip, Naumova Mariia, Ishitani Yoshiyuki, Richirt Julien and Nomaki Hidetaka - The ecology and evolution of the deep-sea foraminifer *Chilostomella ovoidea* and its enigmatic plastid
15:00	Takagi Haruka, Nakamura Yasuhide, Schmidt Christiane, Kucera Michal, Moriya Kazuyoshi and Saito Hiroaki - Photosymbiotic partnerships and evolution in planktonic foraminifera revealed by single-cell metabarcoding
15:15	Lane M. Kelsey, Fehrenbacher Jennifer, Hönisch Bärbel, Haynes Laura, Izaguirre Ingrid and Crump Byron - Genotypic & geochemical variability of a planktonic spinose foraminifera species, *G. bulloides*, across the Northeast Pacific
15:30	Fordham Barry G. and Ogg James G. - Tappan & Loeblich's phylogeny of Foraminifera families: dusting it off for a closer look
CLOSING CEREMONY	

HALL 2

S5: Applying integrated foraminifera, sedimentology and stratigraphy to refine paleoenvironmental and paleoceanographic reconstructions

Conveners: Renata Moura de Mello, Lizette Leon Rodriguez, Serena Dameron	
09:00	Bergh Eugene - Strontium isotope and biostratigraphy of the Namibian continental shelf and associated palaeoenvironmental changes during the Neogene to Quaternary
09:15	Blake Gregg H. - Benthic Foraminiferal Faunal Response to The Middle Miocene Climatic Transition From Greenhouse to Icehouse Conditions Along Central California, USA
09:30	Bouhdayad Fatima, Freire Tiago, Auer Gerald, Carballeira Rafael, Herwartz Daniel, Scheidt Stephanie, Leicher Niklas, Wennrich Volker, Albert Richard, Gerdes Axel, Petersen Jassin, Nielsen Sven, Rivadeneira Marcelo and Grunert Patrick - Unlocking the paleoceanographic archives of the Humboldt Current System through the foraminiferal record: A case study from the Bahía Inglesa Formation, northern-central Chile
09:45	Charoentitirat Thasinee, Jitmahantrakul Sukonmeth, Tokiwa Tetsuya and Hara Hidetoshi - Age constraints of Fusulinid Foraminifers and U-Pb Detrital Zircon from Conglomerates in the western margin of Indochina Block, Thailand: Evidence of Paleogeography and Indosinian Orogenies
10:00	Cotton Laura J., Evans David and Schmidt Daniela N. - Shelf ecosystem response to the Eocene-Oligocene Transition
10:15	Devendra Dhanushka, Łącka Magdalena, Szymańska Natalia, Szymczak-Żyła Małgorzata, Krajewska Magdalena, Weiner Agnes K.M., De Schepper Stijn, Hildegard Simon Margit and Zajączkowski Marek - Holocene sea ice dynamics and paleoenvironments on the southwest Svalbard shelf reconstructed using a multiproxy approach
POSTERS AND COFFEE BREAK	
11:30	Gastaldello Maria Elena, Agnini Claudia, Westerhold Thomas, Drury Anna Joy, Sutherland Rupert, Drake Michelle K., Lam Adriane R., Dickens Gerald R., Dallanave Edoardo, Burns Stephen and Alegret Laia - Regional imprint and global signature of the Late Miocene-Early Pliocene Biogenic Bloom in the Tasman Sea (IODP Site U1506)
11:45	Hupp Brittany and Kelly D. Clay - 'Unmixing' Deep-Sea Sedimentary Records of Planktic Foraminifer Community Turnover during the PETM through Isotopic Filtering
12:00	Kearns Lorna E., Sánchez-Montes Maria Luisa, Jones Heather, Sepúlveda Julio and Lowery Christopher M. - Recovery of planktic ecosystems following the end-

	Cretaceous mass extinction at El Kef, Tunisia
12:15	Leon-Rodriguez Lizette, Jonk Rene, Knabe Keith, Kevin Bohacs Kevin and Davis J. Steve - The application of biostratigraphic studies in the energy and subsurface-storage industries. An example from the Ainsa Basin, Spain
12:30	Sayed Mostafa M., Heinz Petra, Abd El-Gaied Ibrahim M. and Wagreich Michael - Paleoclimate and paleoenvironment reconstructions from middle Eocene successions at Beni-Suef, Egypt: foraminiferal assemblages and geochemical approaches
12:45	Peñalver-Clavel Irene, Agnini Claudia, Bhattacharya Joyeeta, Dallanave Edoardo, Westerhold Thomas, Dickens Gerald, Sutherland Rupert and Alegret Laia - First record of deep-sea benthic foraminiferal response to the Late Lutetian Thermal Maximum in the Tasman Sea (IODP Site U1508, Southwest Pacific)
LUNCH	
14:30	Roslim Amajida, Alfian Amirah, Briguglio Antonino, Goeting Sulia and Kocsis László - Species distribution and biostratigraphic evaluation of fossil foraminifera from Miocene to late Pleistocene sediments obtained from deep wells offshore Brunei Darussalam
14:45	Strohschoen Oscar Jr, Luft-Souza Fernanda, Krahl Guilherme, Bruno Mauro Daniel Rodrigues, Baecker-Fauth Simone and Fauth Gerson - Early Cretaceous marine incursions in the Proto-South Atlantic Ocean: foraminiferal record from Brazilian basins
15:00	Lu Zhengbo and Fan Junxuan - Pattern of foraminiferal diversity change across the Eocene-Oligocene transition
CLOSING CEREMONY	

HALL 3

S18: Linking Morphogenesis and Biomineralization	
Conveners: Yukiko Nagai, Lennart de Nooijer, Takashi Toyofuku, Jarosław Tyszka	
09:00	Toyofuku Takashi and Nagai Yukiko - Chamber of Secrets: Decoding the Formation Process of Foraminiferal tests
09:15	Goleń Jan, Tyszka Jarosław, Bickmeyer Ulf, Bijma Jelle, Godos Karolina, Nagai Yukiko and Toyofuku Takashi - Ectoplasmic control of calcium ion transport during chamber biomineralization in rotaliid Foraminifera: novel results from live fluorescent labelling of frothy pseudopodia
09:30	François Daniel, De Goeyse Siham, Reichart Gert-Jan, King Helen E. and De Nooijer Lennart J. - Proton pumping influences element incorporation in hyaline foraminifera
09:45	Charrieau Laurie M., Rollion-Bard Claire, Terbrueggen Anja, Wilson David J., Pogge von Strandmann Philip A.E., Misra Sambuddha and Bijma Jelle - Lithium incorporation and isotopic fractionation in large benthic foraminifera under decoupled pH/DIC conditions
10:00	Brombacher Anieke, Searle-Barnes Alex, Mulqueeney James, Standish Chris, Watson Richard, Wilson Paul, Foster Gavin and Ezard Thomas - Environmental drivers of developmental plasticity distinguished from genetic change in the fossil record
10:15	Nagai Yukiko, Tsubaki Remi, Fujita Kazuhiko and Toyofuku Takashi - Ultrafine structure observation and pH imaging of site of calcification in *Sorites orbiculus*
POSTERS AND COFFEE BREAK	
11:30	Hohenegger Johann - Perspectives of growth in Foraminifera
11:45	Tyszka Jarosław, Godos Karolina, Goleń Jan and Radmacher Wiesława - Phylogenetic patterns of Foraminiferal Organic Linings
LUNCH	

POSTER PRESENTATIONS

CODE	REFERENCE
S1: A Latin American and Caribbean cluster: gathering foraminiferal researchers	
S1-1	Baumgartner-Mora Claudia , Baumgartner Peter O., Ferràndez-Cañadell Carles and Buchs David M. - Larger benthic foraminifera from the Azuero Peninsula (SW-Panama) define Eocene accretionary events and an arc gap along the trailing edge of the Caribbean Plate
S1-2	Disaro Sibelle T., Totah Violeta I., Watanabe Silvia, Ribas Elis R. and Pupo, Daniel V. - "Biodiversidade Marinha da Bacia Potiguar – Foraminifera", an atlas of benthic Foraminifera from Rio Grande do Norte (NE, Brazil)
S1-3	King David J., Wade Bridget S. and Miller C. Giles - The influence of the Caribbean in Oligo-Miocene planktonic foraminifera taxonomy and biostratigraphy
S1-4	Zardin Tamires N., Kochhann Karlos, Krahl Guilherme, Martins Alisson, Roloff Greice, Fauth Gerson and Chiessi Cristiano - Integrated stratigraphy of the last glacial-interglacial transition in the Sergipe-Alagoas basin, South Atlantic Ocean
S1-5	Mendes Rafaela, Yamashita Cintia, Vicente Thaisa, Santa Rosa Ana, Fonseca Gustavo, Vieira Danilo, Martins Maria Virginia and Sousa Silvia Helena - Predicting deep-sea living (stained) benthic foraminifera from the continental slope and São Paulo Plateau, Santos Basin (SW Atlantic): Differences between genus and species data using machine learning
S2: Advances and challenges in modern and fossil benthic foraminifera research: a session dedicated to Prof. John Murray	
S2-1	Barras Christine, Le Moigne Damien, Mojtahid Meryem, Labrune Céline, Mouret Aurélia, Metzger Edouard, Maillet Grégoire, Morisseau Célestine, Pruski Audrey, Vétion Gilles, Lescure Lyvia and Vaz Sandrine - Distribution of benthic foraminifera in the Gulf of Lions, Mediterranean Sea: Response to trawling activity or natural variability?
S2-2	Faizieva Kamila, Wollenburg Jutta, Heinz Petra and Wukovits Julia - Phytodetritus-colonising living (Rose Bengal stained) benthic foraminifera during a spring phytoplankton bloom in the Arctic Ocean
S2-3	Francescangeli Fabio, Bouchet Vincent M.P., Milker Yvonne, Frontalini Fabrizio, Richard Xavier, Trentesaux Alain and Armynot du Chatelet Eric - Temporal changes in intertidal benthic foraminifera: a seasonal survey from the English Channel (France)
S2-4	Tremblin Clément M., Holzmann Maria, Parker Justin H. , Sadekov Aleksey and Haig David W. - Invasive *Trochammina* in a south-west Australian estuary
S2-5	Markoglou Eleni Anastasia, Tsourou Theodora, Parinos Constantine, Gogou Aleka, Dimiza Margarita, Danelian Taniel and Triantaphyllou Maria - Modern agglutinated foraminifera in the surface sediments of NE Mediterranean environments
S2-6	Bardis Dimitrios, Triantaphyllou Maria, Dimiza Margarita, Tsourou Theodora, Koukousioura Olga, Weinmann Anna, Langer Martin and Hallock Pamela - *Amphistegina lobifera* Larsen life cycle mode in a stressed coastal environment: The Vravron site, Aegean Sea Greece, revisited
S2-7	Gfatter Christian, Martínez-Colón Michael and Owens Jeremy - Comparing flow-through culturing systems to investigate elemental uptake in the calcite tests of

	benthic foraminifera
S2-8	Wukovits Julia, Wollenburg Jutta, Glock Nicolaas, Heinz Petra and Roy Alexandra-Sophie - A review and new observations on *Tholosina vesicularis* Brady (1879), an extraordinary monothalamous foraminifera
S2-9	Fentimen Robin, Rime Valentin, Francescangeli Fabio, Negga Haile, Atnafu Balemwal and Foubert Anneleen - Fossil benthic foraminifera from the Danakil Depression (northern Ethiopia): avian transport within an active rift valley
S2-10	Bryant Raquel, Belanger Christina and Meehan Kim - Multivariate analyses on benthic foraminiferal assemblages: Two case studies from the Late Cretaceous Western Interior Seaway
S2-11	Nagy Matthias, Enge Annekatrin J., Heinz Petra and Albano Paolo G. - Documentation of the native shallow water benthic foraminiferal assemblage in a sediment core from the coastal region of Northern Israel
S2-12	Disaro Sibelle T, Dissenha Gonçalves Joicce, Kropiwiec Isabela S., Mendes Rafaela, Ribas Elis R., Pupo Daniel V. and Moreira Daniel L. - Benthic foraminifera from the continental shelf of the Santos Basin (SE-S, Brazil) - traditional and Machine Learning, integrated approach
S2-13	Brombacher Anieke, Butts Susan, Cheng Evan and Hull Pincelli - Studying morphological variation across space and through time using existing museum collections
S3: Advances in larger foraminiferal biostratigraphy: a framework for reconstructing shallow-water events	
S3-1	Crobu Simone, Briguglio Antonino, Arena Luca, Giraldo-Gómez Victor M., Gandolfi Antonella, Baucon Andrea, Papazzoni Cesare Andrea, Pignatti Johannes and Piazza Michele - Biodiversity of Larger Benthic Foraminifera (LBF) from the Bartonian succession of Capo Mortola promontory (Liguria, NW Italy)
S3-2	Gheiasvand Masoumeh and Bartolini Annachiara- New morphotypes of *Balkhania balkhanica* Mamontova, 1966 from the upper Valanginian - lower Aptian of the northern Tethyan margin
S3-3	Papazzoni Cesare Andrea and Benedetti Andrea - Larger foraminiferal biodiversity from Paleocene to Miocene: possible relationships with climate changes
S5: Applying integrated foraminifera, sedimentology and stratigraphy to refine paleoenvironmental and paleoceanographic reconstructions	
S5-1	De Almeida Fabiana K., de Mello Renata M., Rodrigues André R. and Bastos Alex C. - Factors controlling the benthic foraminiferal distribution on the Espírito Santo Basin slope, SW Atlantic
S5-2	De Almeida Fabiana K., de Mello Renata M. and Bastos Alex C. - The influence of submarine canyons processes in the benthic foraminifera distribution on the Espírito Santo Basin, SW Atlantic
S5-3	Diz Paula, Sierro Francisco J., Groba Ricardo and Hernández-Almeida Iván - Surface drivers of deep-sea benthic foraminifera variability during the Mid-Pleistocene Transition in the subpolar North Atlantic
S5-4	Filippi Giulia, Schmidt Daniela, Barret Ruby, D'Onofrio Roberta, Westerhold Thomas, Brombin Valentina and Luciani Valeria - Planktic foraminiferal abundance and test-size record across the Early Eocene Climatic Optimum (EECO, ~53-49 Ma) at Shatsky Rise (Pacific Ocean)
S5-5	Gale Luka, Kresnik Tjaša, Brajkovič Rok and Košir Adrijan - Foraminiferal view on Toarcian environmental perturbations on the northern part of the Adriatic Carbonate Platform, Slovenia

S5-6	Gandolfi Antonella, Giraldo-Gómez Victor Manuel, Luciani Valeria, Piazza Michele, Papazzoni Cesare A., Pignatti Johannes and Briguglio Antonino - Planktic and benthic foraminifera across the Middle Eocene Climatic Optimum (MECO): the case study of the shallow-water Capo Mortola succession (Liguria, NW Italy)
S5-7	Goeting Sulia, Lee Huan Chiao, Kocsis László, Baumgartner Claudia and Marshall David J - Diversity and distribution of the benthic foraminifera on the Brunei shelf (Palawan/North Borneo ecoregion): effect of seawater depth
S5-8	Székely Adrienn and Görög Ágnes - Reconstruction of the Oligocene paleoenvironment in the Central Paratethys, North Hungarian Paleogene Basin
S5-9	Hernitz Kučenjak Morana, Pezelj Đurđica, Marković Frane, Kovačić Marijan and Matošević Mario - Middle Badenian foraminiferal assemblages from Papuk Mt, North Croatian Basin
S5-10	Bu Khamsin Ali and Kaminski Michael - New Bajocian shallow-water agglutinated foraminifera from the basal D1 member of the Dhruma Formation west of Riyadh, Saudi Arabia
S5-11	Standring Patricia, Lowery Christopher, Kearns Lorna and Martindale Rowan - Palaeoceanographic Changes and Ecological Impacts on Foraminifera during Eocene-Oligocene Transition in the Gulf of Mexico
S5-12	Koukousioura Olga, Puentes-Jorge Xabier, Panagiotopoulos Konstantinos, Diz Paula and Grunert Patrick - Paleoenvironmental changes in the Gulf of Corinth (eastern Mediterranean) during MIS 5 from benthic foraminifera and geochemical proxies
S5-13	Peñalver-Clavel Irene, Dallanave Edoardo, Westerhold Thomas, Dickens Gerald R., Sutherland Rupert and Alegret Laia - Benthic foraminiferal response to the Middle Eocene Climate Optimum in the Tasman Sea (IODP Site U1511, Southwest Pacific)
S5-14	Pezelj Đurđica, Sabol Jurica, Kovačić Marijan and Marković Frane - The Middle Miocene benthic foraminiferal assemblages from Krndija Mt. (Našice quarry, Croatia)
S5-15	Rodrigues André R., De Almeida Fabiana K., Mello Renata M. de , Grilo Caroline F., Quaresma Valéria da S. and Bastos Alex C. - Benthic foraminiferal assemblages of the Espirito Santo Continental Shelf, Southeastern Brazil (SW Atlantic)
S5-16	Ruschi Anita G., Rodrigues André R., Cetto Paulo H. and Bastos Alex C. - Paleoenvironmental evolution of Abrolhos Depression (Brazil - SW Atlantic) based on the distribution of benthic foraminiferal assemblages
S5-17	Trubin Yaroslav S., Marinov Vladimir A., Rudmin Maxim A., Smirnov Pavel V., Winkler Alina, Brit Vyacheslav A., Novoselov Andrey A. and Langer Martin R. - The Foraminifera of the Western Siberian Seas – with what sorts of treasures they filled their homes after life?
S5-18	Walsh Jared, Fietz Susanne and Bergh Eugene - Biostratigraphic and marine palaeoenvironmental change associated with the Plio-Pleistocene transition along the western continental shelf of southern Africa
S6: Automated image recognition in microscopic analysis for foraminifera studies	
S6-1	Lichterfeld Yohan, De Garidel-Thoron Thibault, Leduc Guillaume, Dewilde Fabien, Vidal Laurence and Luciani Elise - Individual foraminifera analyses: comparison of morphometric and isotopic methods and application for the penultimate deglaciation
S6-2	Siciliano Julie, Russo Bianca, Barattolo Filippo and De Bonis Alberto - Analysis of

	planktonic foraminifera abundance in ceramic samples from Pian della Tirena (Calabria, southern Italy): Application of JMicroVision software
S6-3	Plavetić Marko, Josefson Mats, Hulthe Gustaf, Hsiang Allison Yi and Asteman Polovodova Irina - Identification of environmentally relevant benthic foraminifera from the Skagerrak fjords by deep learning image modelling
S6-4	Bicchi Erica, Schweizer Magali and Rasti Pejman - Preliminary data on the application of artificial intelligence to the identification of *Ammonia* species from scanning electron microscopy images
S6-5	Nardelli Maria Pia, Vanderesse Nicolas, Moller Maryline, Zhao Yaqian, Guilhermic Corentin, Lenta Laurent and Mouret Aurélia - Automation adventures: First steps in the automatic identification of benthic foraminifera from high resolution 3D images of sediment cores
S6-6	Sabbatini Anna, Caridi Francesca, Lucarelli Anastasia and Negri Alessandra - AI for unknown marine Foraminifera
S8: Evolutionary and environmental control on coiling direction and loss of algal photosymbiosis (bleaching) in the foraminiferal fossil and recent record	
S8-1	Gebhardt Holger and Hlavatá Hudáčková Natália - The potential of changing coiling directions of the planktic foraminifer *Globorotalia bykovae* (Aisenstat) for stratigraphic correlation in the Central Paratethys
S9: Determining the processes involved in biomineralisation – how do foraminifera build their shells?	
S9-1	Borrelli Chiara, Little Emma, Scholer Margaret, Jasapara Aditi, Nagy Matthias, Heinz Petra, Bowser Samuel and Panieri Giuliana - Probing *Melonis barleeanus* agglutinating strategy: an experimental approach
S9-2	Evans David and Erez Jonathan - Determining the role of seawater vacuolisation in the biomineralisation process of the planktonic foraminifera using confocal microscopy
S10: Environmental monitoring with benthic foraminifera: assessing the Ecological Quality Status of coastal and marine systems	
S10-1	Pereira Kettollen, Camara Gabriel, Dias Andriu, Carelli Thiago and Laut Lazaro - Response of foraminifera to anthropic changes in tidal channels from a tropical lagoonal system: Maricá-Guarapina Lagoonal System, Brazil
S10-2	Disaró Sibelle T, Dissenha Joicce, Santa-Rosa Luciana C. C., Kropiwiec Isabela S., Pupo Daniel V., Guimarães Ana Tereza B and Leite Daniel M. - The contribution of different sediment layers to foraminiferal assemblages' characterization in distinct habitats from Santos Basin (Southwestern Atlantic)
S10-3	Laut Lazaro, Belart Pierre and Bonetti Carla - Foraminifera as indicators of trophic state in tropical lagoons: Rio de Janeiro, Brazil
S10-4	Bomfim Isabela, Camara Gabriel, Couto Erminda C.G., Bonetti Carla, Souza Silvia Helena M., Martins Maria Virginia A., Semensatto Jr. Décio L., Disaró Sibelle T., Belart Pierre, Pereira Kettollen, Dias Andriu, Carelli Thiago and Laut Lazaro - Living and dead Foraminiferal as the basis for environmental diagnosis in a mesotidal tropical estuary: Cachoeira River Estuary, Bahia-Brazil
S10-5	Dias Andriu, Pereira Kettollen, Camara Gabriel, Bonfim Isabela, Belart Pierre, Carelli Thiago, Ferreira Valdenira and Laut Lazaro - Foraminifera and tecamoebians from Oiapoque River Estuary, Brazil-French Guiana
S10-6	Goetz Eleanor, Hull Pincelli and Thomas Ellen - Porosity in *Ammonia* sp. as an indicator of hypoxia in Long Island Sound, USA

S10-7	Goodwin Charles, Smith Christopher and Dellapenna Timothy - A down core analysis of foraminifera from Patrick Bayou (Galveston Texas) before and after hurricane disturbances
S10-8	Martínez-Colón Michael, Ross Benjamin, Shirey Benjamin, Chauhan Ashvini, Pathak Ahish, Owens Jeremy and Bouchet Vincent M.P. - Historical foraminiferal and microbial environmental health assessment of Guánica Bay (Puerto Rico)
S10-9	Fouet Marie P.A., Schweizer Magali, Singer David, Richirt Julien, Quinchard Sophie and Jorissen Frans J. - How do morphological and eDNA data compare for biomonitoring? An example with the distribution of three *Ammonia* (Foraminifera, Rhizaria) species in estuaries of the French Atlantic coast
S10-10	Melis Romana, Figus Billy, Floreani Federico, Petranich Elisa and Terranova Kevin Gabriele - Living Benthic foraminifera as ecological and biomonitoring tools in the Marano and Grado Lagoon (northern Adriatic Sea, Italy)
S10-11	Khokhlova Anna, Gudnitz Maria N., Ferriol Pere, Tejada Silvia, Sureda Antonio, Pinya Samuel, Mateu-Vicens Guillem - Epiphytic Foraminifera in *Posidonia oceanica* Meadows as a Tool for Monitoring Heavy-Metal Pollution in the Balearic Islands (Spain)
S10-12	Elkin Adam, Lam Tristan, O'Malley Bryan, Quiambao Rafael and Schwing Patrick - Methods for Classification of Epilithic Benthic Foraminifera of the Southeastern Clarion-Clipperton Zone
S10-13	Hoff Marie, Argentino Claudio, Barrenechea Angeles Ines and Panieri Giuliana - The response of benthic foraminiferal assemblages to copper mine tailing deposits at the Repparfjord, Northern Norway
S11: Evolution, Stratigraphy, and Geological Crises	
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	Gert-Jan, de Nooijer Lennart, Lourens Lucas, de Lange Gert, Peterse Francien and Sluijs Appy - Assessing seasonal, size, and depth-related influences on planktic foraminiferal Mg/Ca ratios in the eastern Mediterranean Sea through comparison of sediment trap and surface sediment samples
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S19-4	Vilar Amanda, Vicente Thaisa, Sambugaro Julia, Nogueira Rafaela and Sousa Silvia Helena - Benthic foraminifera biomass on the continental slope and São

	Paulo plateau of Santos basin (South Atlantic, Brazil): Comparison between different cytoplasmic occupation in the test
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S22-1	Andreas Amanda and Bowser Samuel - Cytological and physiological impacts of lead and cadmium on the monothalamid foraminifer *Astrammina rara*
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S22-3	Puerto Diana, Stuhr Marleen and schmidt Christiane - Menthol-induced bleaching of *Amphistegina lobifera* and investigation on diatom photosymbiont flexibility
S22-4	Holzmann Maria and Mcgann Mary - First occurrence of the nonindigenous Asian foraminifera *Ammonia confertitesta* Zheng in the northeastern Pacific Ocean: Vancouver Island, British Columbia, Canada
S22-5	Mancin Nicoletta, Evans Julian, Guastella Roberta, Caruso Antonio and Marchini Agnese - Impact of the invasive foraminifer *Amphistegina lobifera* Larsen on infralittoral benthic foraminiferal assemblages in the Sicily Channel (Central Mediterranean)
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S24-3	Gilabert Vicente, Arenillas Ignacio, Arz José Antonio, Krahl Guilherme and Batenburg Sietske - Aberrant planktic foraminifera as biomarkers of environmental stress and/or chemical contamination across the Cretaceous/Paleogene boundary
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S24-7	Singh Vikram Pratap, Singh Ashutosh K. and Sinha Devesh K. - Quaternary Episodes of Variation in the Western Pacific Warm Pool: Planktic foraminiferal evidences from the Sulu Sea (ODP Hole 769B)
S24-8	Takata Hiroyuki, Sakai Saburo, Nomura Ritsuo, Tsujimoto Akira, Nishi Hiroshi, Soo Lim Hyoun and Khim Boo-Keun - Faunal transition of benthic foraminifera

	across the Eocene–Oligocene transition at ODP Site 744 (Kerguelen Plateau) in the Southern Ocean
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S25-3	Molina Giulia, Mega Aline, Schmiedl Gehard, Rodrigues Teresa and Voelker Antje - Paleoproductivity fluctuations at the seafloor in the Gulf of Cadiz during MIS 25-MIS 19: evidence from benthic foraminifera assemblages
S25-4	Hosono Takashi, Fujita Kazuhiko Kakumura K. Azusa, Azuma Shuko, Kishimoto Azusa, Matsuda Shoko, Fusho Ayana, Sonoda Akira and Fujikura Katsunori - Use of a standard format (DarwinCore) on an information system (BISMaL) to integrate recent foraminifera data and to estimate recent past habitat condition
S25-5	Weinmann Anna E. - Historic sediment samples as early-Lessepsian baselines for the biogeography and diversity of benthic foraminifera in the Mediterranean Sea
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S27-1	Copete Mª Fernanda, Diz Paula, Pérez-Arlucea Marta, Estrada Ferrán, Alejo Irene, Mena Anxo, Nombela Miguel Ángel and Francés Guillermo - Planktonic foraminifera assemblage in the Bight Fracture Zone during the last glaciation
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S27-3	Del Gaudio Arianna V., Piller Werner E., Auer Gerald and Kurz Walter - Pleistocene planktonic and benthic foraminifera assemblages from Fantangisña seamount in the NW Pacific Ocean (IODP Expedition 366)
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S27-10	Zhang Shuai, Yu Zhoufei, Chang Fengming and Li Tiegang - The evolution of the barrier layer in the centre of the western Pacific warm pool during the last deglacial based on planktonic foraminifera surface species
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S28-3	Schmidt Christiane, Morard Raphael, Rapp Sophia K., Amao Abduljamiu O., Rahman Shirin Nurshan, Vaughan Grace, Farrell Oliver M., and Burt John A. - Local biodiversity of recent foraminifera in three coral reefs in the extremely warm Persian/Arabian Gulf
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S29-7	Cote-L'Heureux Auden, Sterner Elinor G., Maurer-Alcalá Xyrus and Katz Laura A. - Foraminifera maintain consistent amino acid usage despite extreme codon usage bias in multiple non-monophyletic clades
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OPENING CEREMONY

Decadal Trends in Foraminiferology

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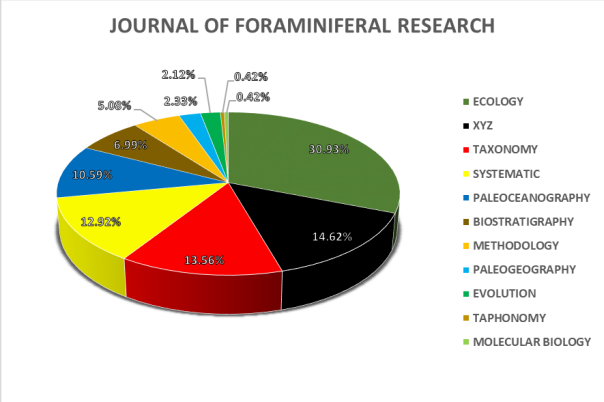
In the five-decades since the first FORAMS meeting (initially called the BENTHOS meetings) in Halifax in 1975, we have witnessed many keystone findings in foraminiferal research as well as the establishment of new directions within the broad framework of foraminiferal studies. Although fundamental knowledge in foraminiferal research is still strongly connected with traditional knowledge about documenting the fossil record and reporting new discoveries (as we know from the perspective of Palaeontologists), the actual reality is that our field may not operate under the same restrictions. One question has yet to be addressed: do we still operate within the same boundaries as the typical palaeontologist, or have we already branched out beyond the scope of our initial studies? The easiest way to answer to this question is to compare our body of foraminiferal literature with the vast body of knowledge in the broader field of Palaeontology.

To address this problem, we make a comparisons by examining two of the top journals in our respective fields that embody a cross-section of current research: The leading journal in the study of foraminifera is the Journal of Foraminiferal Research (JFR), and the other representing a wider based journal for palaeontological studies (Palaeontology, published by the Palaeontological Association). From 1975 through 2020, we sampled the papers in each journal at intervals of five years, examining their titles and internal content to determine what they mostly covered. Research topics were classified into broad 11 categories: XYZ (i.e., documenting fossils from a specific age and place), ecology, biostratigraphy, palaeoceanography, paleogeography, taxonomy, systematics, methodology, evolution, taphonomy, and molecular biology. We plotted our findings in order to portray the relative proportions of papers belonging to a given category, and how the research emphasis has changed over time.

According to our assessment, which was based on the proportions of each research category in the two journals, the JFR displays a higher level of diversity than Palaeontology during their 50-year history. In comparison to XYZ and taxonomy, which both have percentages above 30% in Palaeontology, ecological studies have formed the major proportion of articles (31.8%), with the other categories almost sharing equal portions (ranging from 5% to 15%, apart from taphonomy and molecular biology) in the JFR. While determining which subjects see considerable increase, we discovered that ecological studies have skyrocketed during the lifetime of the JFR, with a large jump occurring after 1995. Another unexpected discovery is that systematic investigations published in the JFR show a considerable increase from 1980 to 1985, followed by a decline starting after 1990. On the other hand, the bulk of XYZ and taxonomic research published in Palaeontology has fluctuated, although in general within stable limits during the entire time period, even if they later faced a considerable reduction after 2005. In Palaeontology, ecological and evolutionary studies fluctuated over the period but showed growing percentages after 2005.

Considering our comparison between the leading journals within our research areas, i.e., foraminiferology (JFR) and the wider scope journal that also covers our research area (Palaeontology), our fundamental knowledge and research areas in foraminiferology appear to be more advanced with a more diverse selection of research topics. Aside from the growth in traditional study area, we have witnessed new research topics such as molecular biology and ecological aspects of foraminifers, which have grown significantly across the timespan of almost five decades – compared with the articles published in Palaeontology that still focus on the basics such as taxonomy and XYZ. Coincidentally, several uptrends and downtrends in our findings seem to overlap with some recognisable events such as the publication of Loeblich & Tappan's book in 1987, the growth of studies based on ODP samples, and the growth of ecological studies after the publication of the first morphogroup papers in the mid 1980's.

If we compare our scientific output with that of the Paleontologists, it is obvious that Foraminiferologists have embraced new directions in our area of research over the past 50 years. We see evidence of an increasing focus on studies dealing with ecology and paleoceanography, at the expense of studies of the systematics of the foraminifera. There is no doubt that foraminifera respond to changes in the environment, whether natural or human-related, and that the response of these organisms to these changes needs to be investigated. Nevertheless we ought not de-emphasize studies on the systematics, because the scientific community will require another compilation to supplement Loeblich and Tappan's book. It is interesting to speculate what the next fifty years will bring…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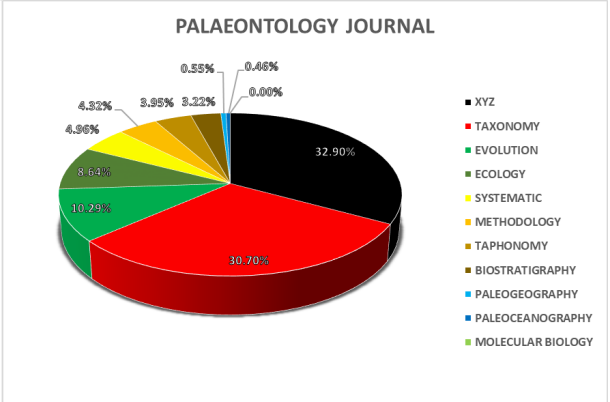
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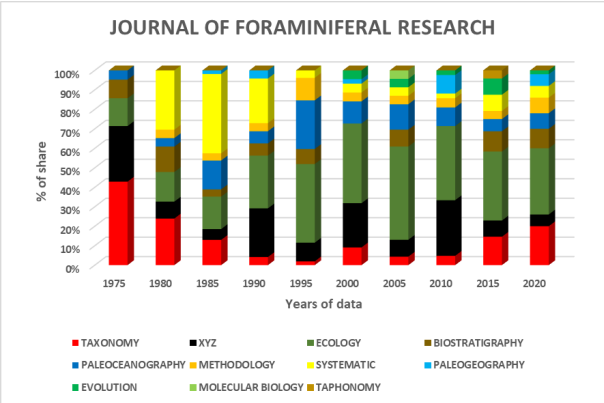
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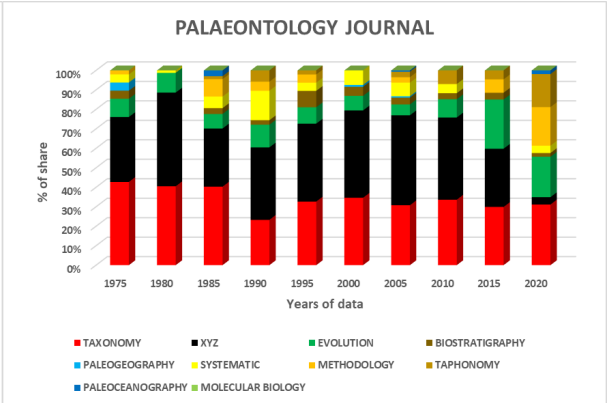
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ABSTRACTS

Reconstructing Pacific oxygen minimum zone structure through deglacial warming using planktic foraminifera

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Oxygen minimum zones (OMZs) are areas of the ocean with consistently low levels of oxygen (<0.5 mL L^{-1}) driven by high productivity and low ventilation. OMZs are expanding globally due to modern climate change with implications for ecosystem function and biogeochemical cycling. However, significant uncertainties exist in how OMZs respond to climate change on longer than decadal timescales. Planktic foraminiferal assemblages, pore size, and ventilation ages are used here to reconstruct potential drivers of OMZ change (productivity and water source) in the Eastern Tropical North Pacific (ETNP) through the most recent period of rapid warming (~20-9 ka). We focus on core MAZ1-E04 (22°54.29'N, 106°54.59'W; 1463 m depth) from the Mexican Margin where there is evidence that the OMZ intensified into the Holocene relative to the Last Glacial Maximum (LGM). We show that the relative abundance of subpolar foraminifera (primarily *Neogloboquadrina incompta*) dominated through most of the Pleistocene until a dramatic drop ~13 ka where transitional foraminifera (primarily *Globigerina bulloides*) simultaneously increased and dominated into the early Holocene (~9 ka) suggesting an increase in upwelling conditions during the Younger Dryas (~13-12 ka). Ventilation ages record relatively old bottom waters during both the LGM (~20 ka) and the Bolling-Allerod (~15-13 ka) indicating input from older, less oxygenated, southern source water during these periods. Porosity of planktic *Orbulina universa* will provide an additional proxy for OMZ position and intensity within the photic zone. Using these multiple approaches, we demonstrate that this site likely experienced lower productivity but poorly ventilated bottom waters during the LGM and the Bolling-Allerod. Conversely, the beginning of the Younger Dryas experienced well-ventilated bottom waters but higher productivity. We hypothesize that the ETNP OMZ expanded during deglacial warming due to an increase in surface productivity alongside the input of older southern source waters.

Evaluation of the effectiveness of ballast water regulation in Brazil: benthic foraminiferal morphology and eDNA metabarcoding for the biosurveillance of invasive alien species

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Today, one of the environmental concerns for the civil and scientific community is the intentional or accidental introduction of pollutants and exotic species into the marine environment that may cause significant and harmful changes in coastal ecosystems. To tackle and regulate this problem, since 2005, Brazil has issued a legal and mandatory procedure for all ships sailing in Brazilian waters: NORMAM-20 of the Maritime Authority on water pollution caused by vessels, platforms, and their support facilities. It states that the oceanic exchange of ballast water should occur at least 200 miles away from the coast in places with a minimum water depth of 200 meters. However, the analysis of the living and dead assemblages present in the surface sediments of 50 sites distributed in the inner and outer sector of the Sepetiba Bay (SB, SE Brazil) reveals the occurrence of species such as *Trochammina hadai* Uchio 1962 and *Ammonia buzasi* Hayward and Holzmann, 2021 (identified by eDNA metabarcoding in 16 sites and morphological analysis) that have never been reported in this coastal ecosystem. Analysis of the sedimentary record along cores collected in several regions of the SB (SP1-SP6, SP8, SP11) reveals that these species disappear below the first few centimeters of the sediment record. It should be noted that *T. hadai* was also recently considered as an invasive species in the Flamengo Inlet, Ubatuba, São Paulo State (Brazil). These species, which may have been introduced into the SB by the discharge of ballast water from ships that dock in the region's ports to load ore, are currently a component of the living foraminiferal assemblages of this ecosystem, reacting and responding to environmental stress in this bay, a highly anthropized and heavily polluted environment by potentially toxic elements (PTEs). While *T. hadai*, which mainly thrives in fine sand bottoms, seems to prefer low polluted conditions, *A. buzasi*, as well as *Ammonia tepida, Ammonia rolshauseni,* and *Cribroelphidium excavatum*, seem to tolerate the environmental stress caused by increasing of organic matter levels, and PTEs (mainly Cd and Zn), where the diversity of foraminiferal species considerably declines (and when all the other species reduce their abundance). Thus, this work shows the importance of better knowledge of endogenous species so that invasive species and their ecological role in coastal ecosystems are known.

Determining the toxicity of metals based on different extraction methods: a case study in the Guanabara Bay (SE Brazil)

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The scientific community has made an effort to improve methods and techniques aiming at the adequate characterization of natural ecosystems and the response of organisms to environmental stress. This effort extends to the application of foraminifera as bioindicators of environmental quality. Many works have shown the applicability of these organisms as bioindicators of ecological quality status (EcoQS). Recently, the EcoQS of impacted areas in Guanabara Bay (GB; SE Brazil) has been assessed based on foraminiferal and sedimentological data. This bay, located in the metropolitan region of Rio de Janeiro State, is highly anthropized, and some areas are polluted by potentially toxic elements (PTEs). Thus, it is important to understand if geochemical methods based on total digestion of sediment (TD) or sequential chemical extraction (SQE) allow you to effectively assess the concentrations of PTEs that most affect living organisms and, in particular, benthic foraminifera. Thus, in this work, the data of living foraminifera from 33 sites in the margins of the GB, in more or less impacted regions, were statistically compared with concentrations of PTEs obtained by TD and SQE in three phases (dissolved in water, adsorbed on organic matter, and Mn oxy-hydroxides). The main pollutants in the samples studied are Cu, Zn, and Pb, an evaluation made from TD. The principal component analysis shows an overall negative response of most species and ecological indices to metal enrichment. Despite it, the correlations between the species and the ecological indices and the concentrations of PTEs obtained by TD are generally low and not significant, even with the metals considered major pollutants. However, negative and significant correlations between species and PTEs (Cd, Zn and Ni) dissolved in water and associated with organic matter are found. Additionally, diversity and several species are significantly and negatively correlated with the PTEs associated with Mn oxy-hydroxides, probably because this is a dynamic sedimentary phase. This work sheds light on the importance of SQE to properly evaluate the effects of PTEs, to determine their bioavailability, and

ultimately, to provide measures of toxicity in marine sediment based on effects range low (ERL) and effects range median (ERM).

Late Cretaceous benthic foraminifera responses across Oceanic Anoxic Event 2 at southern high latitudes (Mentelle Basin, SW Australia)

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Oceanic Anoxic Event 2 (OAE 2), across the Cenomanian-Turonian boundary interval, shows global environmental perturbations in the carbon cycle that also affect marine biota. International Ocean Discovery Program (IODP) Sites U1513 and U1516 in the Mentelle Basin (offshore SW Australia) document a continuous benthic foraminiferal record suitable to reconstruct the paleoenvironmental conditions at the seafloor. At both sites, the benthic foraminiferal assemblages generally show low diversity with dominance of deep-water calcareous taxa, whereas agglutinated foraminifera are rare. The most abundant genera are *Gavelinella*, *Stensioeina*, *Gyroidinoides*, *Conorboides*, *Tappanina*, *Praebulimina* and the agglutinated genus *Clavulinoides*. High latitudinal diagnostic taxa *Pseudopatellinella howchini* and *Scheibnerova protindica* are found through the stratigraphic section, with the disappearance of the latter above a low carbonate interval registered within OAE 2. Paleobathymetry of both sites is interpreted at upper-middle bathyal depths.

Below OAE 2, *Gavelinella* sp., *Gyroidinoides* sp., *Stensioeina* sp. 1 and *Tappanina laciniosa* are the most abundant species. Infaunal *Laevidentalina* sp. and *Lenticulina* sp. are moderately frequent. The presence of the agglutinated cosmopolitan and opportunistic taxa *Glomospira* and *Ammodiscus* suggests low organic matter concentrations at the seafloor. The lowermost part of OAE 2 is dominated by *Gavelinella* sp., *Gyroidinoides* sp., *Stensioeina* sp. 1 and *Lingulogavelinella frankei*. *Stensioeina truncata* appears just in this interval. Infaunal taxa gradually decrease in abundance probably showing a deterioration of environmental conditions. The interval of low $CaCO_3$ content is characterized by radiolarians and calcispheres and by the absence of benthic and planktonic foraminifera. Dominance of siliceous sediments identifies an extremely eutrophic environment with a reduced water mass stratification.

Above this interval, an environmental change is registered based on the occurrence of highly diversified foraminiferal assemblages showing different composition compared to the underlying interval. The presence of the agglutinated foraminifera *Clavulinoides gaultinus* and *Spiroplectinata annectens* probably indicates increased nutrients at the seafloor. The first occurrences of *Conorboides claytonensis*, *Bulimina triangularis*, *Stensioeina* sp. cf. *S. infrafosa* are identified in this interval. Infaunal taxa, such as *Astacolus* sp., *Lenticulina* sp., *Planularia* sp., *Pleurostomella subnodosa* and *Colomia cretacea*, show a consistent increase in abundances. The assemblage indicates mesotrophic regimes with moderate oxygen conditions at the seafloor that alternates to more eutrophic episodes. The latter conditions are suggested by the high abundance of the opportunistic taxa *Praebulimina elata* and *Gavelinella* sp.

In general, the OAE 2 interval is characterized by an eutrophic regime with dominance of the opportunistic taxa *Gavelinella*, *Gyroidinoides* and *Stensioeina*, whereas infaunal taxa show low occurrences. The environmental change observed above the low carbonate interval coincides with the occurrences of a benthic foraminiferal assemblage characterized by increased species diversity, indicating enhanced nutrients influx at the seafloor and a return to a mesotrophic regime with episodic eutrophic pulses.

Cytological and physiological impacts of lead and cadmium on the monothalamid foraminifer *Astrammina rara*

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For decades, researchers have used foraminifera as bioindicators of heavy metal pollution in marine environments. Multichambered calcareous and agglutinated forams are the primary focus of such ecotoxicological studies; less is known about how heavy metals affect the physiology and shell microarchitecture of monothalamid agglutinated species. The research reported here exploits unique attributes of *Astrammina rara*, an agglutinated Antarctic monothalamid, as a model system to study the exposure effects of heavy metal toxicants, lead and cadmium. This species (1) is readily collected in Explorers Cove, which is a major hub of marine research in McMurdo Sound; (2) is comparable other Clade I

monothalamids inhabiting polar and deep-sea settings; (3) is well-suited for biochemical and morphological studies due to its large size (>1mm) and ease of isolating protoplasmic and shell matrix fractions; (4) can be maintained in the lab for years, and (5) has been used extensively in past *in vitro* studies.

In this study, specimens of *A. rara* were removed from their shells and placed in growth chambers with normal, Pb- or Cd-spiked artificial seawater and artificial sediment (plastic beads) for 5 weeks. At all sublethal exposure levels (determined by our prior respirometry measurements), these isolated cell bodies constructed shells, which were subsequently removed, rinsed with deionized water, and then either pooled for inductively coupled plasma-mass spectrometry (ICP-MS) analysis or processed for scanning electron microscopy (SEM) imaging. For ICP-MS, shells were nitric acid-digested and analysed to determine Pb and Cd concentrations in the nascent bioadhesive fraction. These data were compared to background levels adsorbed to plastic bead controls. We found that Pb bound to the bioadhesive at concentrations significantly above the bead control exposure levels, while Cd did not, suggesting that Pb has a more direct effect on matrix assembly/binding. At the ultrastructural level, the matrix appeared 'moth-eaten' in the exposure treatments, which was likely due to failure of the bioadhesive to withstand surface tension forces experienced during our ethanol fixation/air drying protocol. These findings show that Pb and Cd impact agglutinated shell morphogenesis differentially. We suggest that more emphasis be placed on monothalamids with fibrous adhesive matrices in environmental toxicology and monitoring studies.

Can we use milioline morphotype (miliolids and rzehakinids) foraminifera in pelagic environment as seawater oxygen proxies?

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Miliolids have an important role in interpreting ancient marine environments, it is assumed that they indicate oxic conditions and shallow water depth (inner shelf). The agglutinated rzehakinids are bathyal-abyssal forms and can tolerate fluctuating oxygen levels. Our study shows that miliolids and rzehakinids occur together in a hypoxic environment indicating that several mid-Cretaceous miliolid species were euryoxic.

The studied material comes from moderate to well-preserved isolated foraminiferal assemblages of the Pénzeskút Marl Formation (Jásd-42 borehole, Bakony Hill, Hungary). This 463 m succession records the local response of the microfauna to the environmental changes of the late Albian OAE1d and the Albian-Cenomanian transition within a pelagic environment. The formation consists of dark-grey marl, calcareous marl with glauconite content at the lower part, and sandstone and siltstone intercalations at the upper part. Rock samples were soaked in a 3% solution of H_2O_2, the harder calcareous rocks were treated with 99% acetic acid. From the washed residues at least 300 foraminifera specimens were picked. Quantitative analyses of foraminiferal assemblages were performed from 88 samples on the >125 μm size fraction. The co-occurrence of *Thalmanninella appenninica* and *Planomalina buxtorfi* in the lowermost samples indicates the late Albian age. The first occurrence (FO) of *Th. globotruncanoides* can be detected, which is the primary criterion for defining the Albian-Cenomanian boundary. The P/B ratio has values between 27 % and 95 %, with a decreasing tendency to the top of the section indicating an open marine environment. Non-keeled shallow-dwelling forms are the most common (70-95 % of the fauna) and are represented by hedbergellids, and there is much less half-keeled intermediate taxon *Praeglobotruncana* and keeled deep-dwelling *Thalmanninella.* The associated fauna is represented by calcareous nannofossils, calcisphaeres, ostracods, juvenile gastropods, and ammonite embryos. Ostracoda assemblages are characterized by the high dominance of *Cytherella ovata* and *C. parallela* (35-85 %, typical "*platycopa*-signal") associated with the opportunistic *Schuleridea jonesiana* (2-55 %), a total of 55-98 % indicate a hypoxic environment of a deep sublittoral-bathyal bottom through the entire section.

The isolated miliolids and rzehakinids were studied by stereomicroscope in reflected and transmitted light to measure the biometrical parameters. Oriented thin-sections were made to examine their inner structures and the texture of the wall. The miliolids are represented by *Quinqueloculina moremani, Q. stolleyi, Massilina* sp.*,* and *Adelosina* sp., while rzehakinids by *Psamminopelta bowsheri* and *P.* sp. At the lower part of the section (Pl. buxtorfi Subzone) milioline morphotype is rare (only *Q.* sp. and *P. bowsheri*), this coincides with the late Albian OAE1d. In the Th. appenninica and Th. globotruncanoides zones, these forms occur in almost every sample and have a ratio up to 14%. *Q. moremani* is dominant following *Q. stolleyi*, *Massilina* sp.*, Adelosina* sp., and *P.* spp. has low values. The most common associated benthic genera are *Gavelinella, Gyroidinoides, Osangularia, Lenticulina, Tritaxia, Praebulimina,* and *Bolivina*.

The relatively fragile rzehakinids are exceptionally well preserved, even the previously unknown long tube-shaped, non-agglutinated aperture of *P. bowsheri* was preserved, indicating that the fauna was not transported. The lack of shallow-water fauna, such as ostracods, also supports this.

Contrary to the previous views we found that miliolids were relatively common and diverse in the hypoxic, pelagic mid-Cretaceous environment. Two scenarios can be considered: 1) they could tolerate the constantly low oxygen level

environment or 2) they were opportunistic, recovered rapidly and lived in a fluctuating oxygen level environment. In both cases, the presence of these forms can indicate a fluctuating or low oxygen level environment.

Depositional and paleontological consequences of the Middle Eocene Climatic Optimum (MECO) as recorded along a shallow-water succession near Olivetta San Michele (IM), NW Italy

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This work focuses on the carbonate-siliciclastic sediments of the middle Eocene (Bartonian) Capo Mortola Calcarenite Formation from a sedimentary succession cropping out near the village of Olivetta-San Michele (Liguria, NW Italy). The succession is very rich in larger benthic foraminifera such as nummulitids and sporadic orthophragmines. Nummulitid dominance is very unstable throughout the succession and this seems to be linked with short- to long-term variations of the depositional environment. Along the succession, we observe significant paleoecological changes, likely triggered by the variation in neritic input as consequence of tectonic and climatic instabilities. The increase in water turbidity caused stressful conditions, especially for the mixotrophic taxa, which reduced their size and abundance considerably until they became rare and in the middle to upper part of the succession they almost completely disappear. However, the filter feeders, such as turritellid gastropods and bivalves (particularly oysters), became dominant, thus suggesting an increase of nutrients in suspension, favoring their development. The presence of an oyster bed indicates a significant increase in fluviatile supply, which is ideal for the survival of these taxa.

In the upper part of the succession, we have recorded an alternation between gravity flow deposits and marly sediments that are interpreted as short-term alternations between calm and intense precipitations. The gravity flows display evident erosional bases and are characterized by much more competent lithologies than the surrounding marly sediments. The gravity flows yield transported LBF (i.e., orthophragmines and nummulitids), smaller benthic and planktonic foraminifera, molluscs, and corals. In turn, marls display only few LBF and abundant smaller benthic and planktonic foraminifera. In these intervals, the increase of planktonic foraminifera suggests a deepening of the carbonate ramp coinciding with a reduction of light that did not favour the development of the LBF.

Within the marly samples, the planktonic foraminifera indicate biozone E12, which is chronostratigraphically related to the MECO event, and a dedicated isotope stratigraphy dataset confirms the climatic perturbation. The sedimentary changes registered in the uppermost part of the successions are therefore related to the climatic dynamics that occurred in the Bartonian in the western Tethys.

Non-classical crystallisation mechanisms as a part of hyaline foraminifer biomineralisation

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The exact mechanism of foraminifer biomineralisation is a matter of ongoing debate, yet establishing this is vital for confidently linking environmental parameters and proxy signals. It is, for example, not resolved in detail whether metastable phases such as amorphous $CaCO_3$ or vaterite are part of the process of crystallising a calcite test, or how organic matter is

involved in controlling calcification. To approach this question, we investigated a set of hyaline foraminifer tests on a micro- to nanometre scale. We show that the chamber walls exhibit nanogranular fracture surfaces along with a crystallite domain size of approximately 100 nm, with regions of crystallographic orientation towards the outside chamber surface on a micrometre scale. From this, we conclude that hyaline foraminifer tests are made of mesocrystals, which strongly indicates the presence of particle-mediated, non-classical crystallisation mechanisms during foraminifer biomineralisation. Given that non-classical crystallisation pathways have been observed to involve metastable carbonates along with phase transitions to stable phases, and organic matter in diverse functions, a biomineralisation mechanism via a precursor phase is likely to distinctly influence isotopic fractionation and trace element incorporation into the shell. As such, this pathway needs to be considered when mechanistically understanding proxy signal formation.

These conclusions highlight the necessity to explicitly investigate non-classical processes in the organism as well as in experimental models, to reduce uncertainties arising from vital effects, and to enable accurate and precise reconstructions.

Deep water production in Adriatic Sea during MIS3-MIS2 from foraminiferal and geochemical proxies

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A multiproxy study by means of quantitative analysis of planktic and benthic foraminifera assemblages, O and C stable isotopes measured on planktic (*G. bulloides*) and epibenthic (*C. pachyderma*) taxa has been carried out in Southern Adriatic in core SA03-11 (1126 m w.d.). The results were compared with other Adriatic sequences: cores SA03-1 (567 m w.d.) and SA03-03 (470 m. w.d.), collected on the up and the down current limbs, respectively, of sediment waves generated on the western flank of the southern Adriatic margin by the dense water cascading, and PRAD1-2 borehole, drilled in the Middle Adriatic Pit at 187 m w.d. The chronology integrated 33 (published and new) ^{14}C datings, O and C stratigraphy, tephrochronology and foraminiferal bioevents (event stratigraphy) and allowed to investigate the time interval since 37 to 12 kyrs BP.

The interstadials (up to GI-5) are marked by increase of warm water planktic taxa (*G. ruber*) and by low values benthic ^{13}C, interpreted as intervals with lower production of dense water, coherent with the increase of low-oxygen and organic matter tolerant benthic species. The LGM (chronozone) displays a moderate warming phase (increase of warm planktic taxa) punctuated by short-term oscillations, while the deep-water production seems to reach its maximum strength (highest benthic ^{13}C values and highest benthic oxygen index) in all the southern Adriatic sites, differently from the previous interval when the deepest site showed a relatively minor ventilation in comparison with the slope sites. Considering the low-stand sea level at that time the main site of deep-water production was probably limited to the southern Adriatic area. The interval corresponding to the HS1 event is characterized by a cold water planktic assemblage, although a modest warming is visible starting at 16.2 kyrs BP, just preceding the abrupt decrease of bottom ventilation (decrease of ^{13}C benthic values and peak of low oxygen benthic taxa in all the southern sites), a well-known event occurring within HS1 in the western Mediterranean and corresponding to HE1. A strong peak in low oxygen benthic taxa (*Bolivina+Brizalina*) is also present at the base of HS1 event in both the slope and deep southern Adriatic sites and we interpret it as the result of a rapid burial, rather than a decrease of general ventilation, considering the high sedimentation rate obtained by the chronology. However, HS1 interval shows, in the slope site, also the occurrence and increase of shelf benthic taxa, considered as a proxy of the cascading process. This may be interpreted as the beginning of the reactivation of dense water production in northern Adriatic (NAdDW) after LGM, as consequence of a sea level rise during HS1 event. We do not rule out a Levantine Intermediate Water intensification concurring to this high sedimentation rate. In the central Adriatic, evidence of diffuse riverine runoff confirms the surrounding glaciers melting. After the abrupt warming at the base, the GI-1 interval displays the general cooling trend coherent with the known literature, as well as a quite intense cascading process in the slope site. However, in the southern Adriatic the ventilation appears stronger in the slope site rather than in the deep site, where ^{13}C values still decrease in the deep site since the middle HS1 event (switching between northern and southern Adriatic dense water production?). During the GS-1 event the sluggish ventilation at the base and its strong recovery at the top are confirmed by ^{13}C and benthic assemblages along with the cascading proxy. This recovery is not coherent with ^{13}C signal of the western Mediterranean records (activation of NAdDW production because of sea-level rise drowning the northern area and/or more influence from the Siberian High?). At last, HS3 and HS2 events show an articulated structure, showing an abrupt decrease in ventilation in the middle of the interval (H3).

Amphistegina lobifera Larsen life cycle mode in a stressed coastal environment: The Vravron site, Aegean Sea Greece, revisited

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Representatives of the Amphisteginidae family are nearly omnipresent contributors to shelf carbonate facies through most of the Cenozoic. *Amphistegina lobifera* Larsen, 1976 is one of the most successful invasive species in coastal ecosystems of the eastern Mediterranean, being a significant carbonate producer of shoreline sediments as well as an ecosystem quality indicator.

This study reports a year-long (November 2021–October 2022) study of an *Amphistegina lobifera* population collected monthly from algal samples (mostly *Halopteris scoparia, Amphiroa* and *Jania*) in the Vravron/Attica rocky substrate coastal ecosystem of the south Evoikos Gulf (Aegean Sea). Comparison with a previous study performed over a decade ago at the same site (2008–09) indicates higher sea-surface temperatures consistent with the Mediterranean's general warming trend during the last decades. Prominent variations in salinity (38.50-35.50) and pH values mostly below 8 are associated with both natural and anthropogenically stressed environmental conditions. Our results show two major peaks of *A. lobifera* dead specimens observed with simultaneous decrease of living individuals in March and June/July; the latter time interval is featured by the restricted presence of white (reproducing) specimens and is followed by a slight increase of juvenile individuals (less than 0.5 mm in diameter) in August. An increasing trend of dead specimens is also observed in November. Overall, the juvenile individuals are prominently reduced when compared to the over a decade ago data, slightly exceeding 10%, in respect to the juvenile abundances of up to 60% during the summer reproduction period over a decade ago. Abundance of *A. lobifera* living specimens was remarkably prominent in February 2022 (more than 380 living specimens/100 cm^2). The associated epiphytal foraminiferal fauna revealed notable contribution of miliolids and *Textularia agglutinans* d'Orbigny, 1839 in the assemblages, with the latter practically exceeding *A. lobifera* abundances in most of the monthly samplings. *Peneroplis* spp. and particularly *P. planatus* (Fichtel & Moll, 1798) are clearly increased when *A. lobifera* was almost absent, e.g., during June/July, implying the outcompeting role of the latter vs. the native *Peneroplis* species in the Aegean ecosystems.

Although *A. lobifera* has been recorded to reproduce primarily during the summer in the coastal ecosystems of the Aegean Sea, when asexual and sexual reproduction takes place simultaneously, the present study indicates a noted reproduction mostly in size classes previously considered pre-adult implying potential failure/mortality of embryons and/or successive asexual generations of megalospheric forms that are better adjusted in environmentally stressed conditions.

Benthic foraminiferal palaeothermometry in deglacial sediments off NW Africa: how accurately is Mg/Ca recording bottom water temperature changes in the past?

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The need to reconstruct deep water temperatures to understand the role of ocean circulation in the climate system has drawn growing interest in using Mg/Ca of benthic foraminifera as a paleotemperature proxy. There are now several bottom water temperature (BWT) records published for timescales of thousands to millions of years. Many of these records are based on the common deep-sea infaunal foraminifera genus *Uvigerina,* with numerous core top calibrations from different areas of the Atlantic and Pacific oceans.

However, low recovery and poor preservation of this genus in shallower sites, or specific environmental conditions in the geological record that limit the occurrence of *Uvigerina,* make it necessary to investigate other species groups as potential bottom water paleothermometers. Intermediate to deep infaunal foraminifera like *Cassidulina* spp., *Nonion* spp., *Globobulimina* spp., and *Melonis barleeanus* have been used in paleotemperature reconstructions of the (mainly western) North Atlantic and the Nordic seas.

Benthic foraminifera Mg/Ca is sensitive not just to temperature, but also to other environmental parameters and parallel records may isolate confounding factors. In this research, we tested the potential of Mg/Ca ratios of common intermediate

infaunal *Melonis barleeanus* and deep infaunal *Globobulimina turgida* from site GeoB9512-5 (water depth 794 m) in the tropical East Atlantic, to reconstruct BWT changes at intermediate depths during the last deglaciation. In the process, we evaluated the possible correlation of other paleoenvironmental factors affecting Mg/Ca uptake from these species that could influence paleotemperature reconstructions.
The comparison of Mg/Ca ratios and BWT estimates from *Melonis barleeanus* and *Globobulimina turgida* with *Uvigerina mediterranea* records, show that *M. barleeanus* does not record the same Mg/Ca-based paleotemperatures as *U. mediterranea* and *G. turgida*, furthermore no fixed offset can be calculated. Our Mn/Ca data suggests, that as *U. mediterranea* and *G. turgida*, remain at relatively constant depths in the sediment, *M. barleeanus* seem to have migrated vertically due to bottom water oxygenation and trophic levels variability, potentially affecting Mg uptake during calcification. Moreover, a strong correlation between Mn/Ca and Mg/Ca from *M. barleanus* and low correlation of these two parameters in *U. mediterranea* supports our findings. This suggests that *M. barleeanus* is not a suitable species for paleotemperature reconstructions in the NE Atlantic and highlights the importance of local Mg/Ca calibrations and multi-species measurements in paleoceanographic studies.

Impact of sediment discharges on benthic faunas in coastal Mediterranean Sea

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Since the 1950's, benthic foraminifera are more and more widely used as marine bio-indicators of ecosystem quality. For this purpose and in the context of the Water Framework Directive, biotic indices have been developed to define the ecological quality status of water masses. Biotic indices based on indicative species, such as Foram-AMBI, TSI-Med and FSI, are currently used in the Mediterranean Sea. They are based on the classification of the different species of foraminifera into 1 to 5 ecological groups according to their sensitivity to a gradient of organic matter enrichment. However, this kind of indices may not be suitable for detecting physical or chemical perturbations.

In this study, we focus on the impact of sediment discharges from dredging activities on soft bottom ecosystems. The study area, located in the Gulf of Lions close to Port la Nouvelle, was subject to two types of dredging activities at the time of sampling: 1) regular dredging for the maintenance of access channels and sufficient water depth in harbour basins, and 2) temporary dredging for the harbour expansion works due to the future installation of offshore wind farm. Comparing these two types of sediment discharge areas was interesting since their localisation, volume, frequency and grain size characteristic were different. In this context, we studied the living foraminiferal fauna at 10 stations located along a transect at ~25-30 m water depth parallel to the coast, crossing two different dumping zones and reference conditions. Other parameters such as quantity and quality of organic matter, grain size analyses, macrofauna communities, sediment interface pictures and videos of the seafloor were studied for the same stations.

The impact of sediment discharges on benthic ecosystem was highlighted by the different parameters studied. For foraminiferal faunas, diversity indices and densities were significantly lower in the dumping zones compared to the reference zones and assemblages were different as well. It was also possible to detect faunal differences between impacted stations according to the total volume of sediment discharged in the last months before sampling. Not surprisingly, the biotic indices based on the sensitivity of species to eutrophication were not adapted to identify the impact. However, the GPBI (General-Purpose Biotic Index) proposed for macrofauna, based on the loss of abundance of sensitive species in impacted sites compared to reference sites, gave promising results with regards to the assessment of physical disturbances such as sediment discharges.

Distribution of benthic foraminifera in the Gulf of Lions, Mediterranean Sea: Response to trawling activity or natural variability?

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The Marine Strategy Framework Directive (MSFD) is a major step forward for the management of marine environments by extending the monitoring to the entire Exclusive Economic Zone. On the continental shelf, the major human disturbance of soft-bottom sea floor is due to demersal fisheries. Recently, abrasion maps, expressed as swept area ratio (SAR), have been produced thanks to the Vessels Monitoring Systems (VMS) to quantify the pressure from bottom-contacting gears. These analyses show that little areas are left untouched from this anthropogenic activity, and it is therefore complex to define reference conditions in order to evaluate the ecological quality status of soft-bottom habitats in this area.

In this context, the IMPEC project aims at investigating different environmental and biological parameters to evaluate the impact of trawling activity on benthic ecosystems. Ten stations were sampled along a gradient of SAR (from ~0.5 to 3 SAR/year) in the Gulf of Lions, Mediterranean Sea, at around 100 m water depth. Geochemical and sedimentary analyses, including organic matter characterisation, were performed to provide proxies for the impact of *in situ* sediment reworking, which can be used to complement and/or precise the monthly abrasion maps available. Several benthic organisms (epibenthic megafauna, macrofauna, nematodes and foraminifera) were used as biological indicators integrating the various environmental consequences of this trawling activity. These were studied using different approaches including *in situ* imagery and sediment sampling.

The preliminary results of the living foraminiferal analyses reveal high density and diversity in all stations. However, there is a shift in major species representation between western stations (e.g. *Gyroidina umbonata, Cancris auriculus*), located west of the Lacaze-Duthiers Canyon, and eastern stations (e.g. *Uvigerina peregrina*, *Bulimina* aculeata), characterised by finer sandy sediments. It is difficult to disentangle if these changes in faunal assemblages are the result of natural variability or a response to different trawling intensity. The ongoing analyses of dead foraminiferal assemblages in long sedimentary cores will inform us about the benthic ecosystem before the onset of trawling activities on the continental shelf. In the absence of actual reference conditions, this approach could help to evaluate the impact of bottom fisheries on benthic ecosystems.

Foraminifera eDNA assemblages from arctic methane cold seeps

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The foraminiferal communities in methane seeps have been characterized based on the morphology of living or dead assemblages. These assemblages generally included hard-shelled (calcareous and agglutinated) multi-chambered foraminifera. However, little work has been done on the single-chambered (monothalamous), usually soft-walled (organic or finely agglutinated) foraminifera that can be abundant in methane seeps. Here, we present the first eDNA metabarcoding study of the methane seeps foraminiferal fauna encompassing both multi- and single-chambered taxa. Samples were collected from shallow sites in the Barents Sea and deep active pockmarks off NW Svalbard. The sampling focused on typical seep microhabitats, such as sediment with methane bubbling, microbial mats, tubeworm, and gastropod zone. In addition, reference samples within and outside the pockmarks were also recovered. The eDNA metabarcoding data provide an overview of the foraminiferal community, including soft-walled and small sized species not comprised in traditional studies. This study also identifies potential methane-tolerant species that could be used as indicators of methane seepage. Monothalamous species, which were the most abundant in all samples and some of which were present only in the microbial mat, are potential candidates to be methane indicators. As expected, in addition to differences in water depth and geographical distance from the selected areas, each microhabitat has a different composition.

Looking for a geochemical imprinting of sea-ice environment in the planktic foraminiferal *Neogloboquadrina pachyderma*

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Polar sea-ice is a unique habitat for virus, bacteria, microalgae and zooplankton, which are enclosed in an ice matrix at low temperature (down to - 20°C) and low light levels, where the only liquids are high salinity brines (up to 82 PSU) in channels and pockets. Survival in these conditions requires a complex series of physiological and metabolic adaptations, but organisms thrive in the sea-ice, and their prolific growth play a fundamental role in polar ecosystems and carbon cycle.

The planktic foraminifer *Neogloboquadrina pachyderma* (Ehrenberg, 1861) is the only taxon among sea-ice zooplankton to secrete a calcareous test (= shell). At present, *N. pachyderma* specimens are abundant in the Antarctic sea-ice, but very rare in the Arctic sea-ice. They have likely adopted different test-building and biocalcification strategies depending on whether they grow in the seawater column or sea-ice. Recent culture experiments with juvenile and pre-adult *N. pachyderma* collected from sea-ice during the austral winter in the Antarctic Weddell Sea (ANT-XXIX/6 of RV Polarstern in 2013) have shown that they can actually biocalcify in extreme salinity conditions mimicking those of the sea-ice brines. Trace element analyses on these cultured *N. pachyderma* specimens, reveal increased values of test Mg/Ca, Sr/Ca and Na/Ca ratios at higher salinities and stress the strong influence of high salinity brines on the Mg/Ca paleothermometer. Consequently, the temperatures of this proxy may be overestimated.

We analyzed specimens from the upper and lower layers of sea-ice cores collected during the austral winter in the Weddell Sea (ANT-XXIX/7 of RV Polarstern in 2013) and from seawater column sampled during a subsequent cruise during the austral autumn (Polarstern PS112 in 2018). We performed NanoSIMS (MNHN, Paris) intra-test mapping with nanoscale lateral resolution (< 100 nm) of Ca, Mg, Na, K and Sr following the sub-micrometric growth structure of the test's chambers, characterized by an alternation of organic and calcitic layers. We found a heterogeneous distribution of Mg/Ca, Na/Ca, K/Ca, Sr/Ca ratios within the test, characterized by alternating enriched and depleted bands parallel to the test surface. The Na and K banding are highly correlated, whereas there is no obvious correlation between the banding of the other trace elements. Na and K enrichments are observed around thin organic layers interspersed with calcitic layers, associated with the sequential chamber formation of the test. Mg enrichments are observed both around the organic layers between the calcitic layers and within the calcitic layers, the latter being possibly related to the continuous thickening of the calcitic layers once formed. In addition to the impact of high salinity, the intra-test distribution of Mg in the analyzed individuals also shows a significant biological control on Mg incorporation during test construction.

Comparison of intra-test distribution patterns of Mg/Ca, Sr/Ca, K/Ca and Na/Ca between specimens collected from sea-ice and the seawater column confirms that *N. pachyderma* appears to be able to calcify in Antarctic sea-ice within brine pockets and channels, and that their test has a characteristic geochemical sea-ice signature. Furthermore, the comparison of Mg/Ca, Na/Ca, K/Ca and Sr/Ca ratios between the last and first chambers may provide new insights into the life cycle of this fascinating species of planktic foraminifera that thrives in polar environments, including sea-ice. A better understanding of the incorporation of these key trace elements in *N. pachyderma* tests taken from sea-ice may help to use them as multi-proxies of sea-ice palaeoenvironments and their evolution in the past.

Disentangling biogeographical patterns through the integration of fossil data: *Alveolinella quoyi* in the western Indo-Pacific Warm Pool

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In present-day Indo-Pacific coral-reef settings, only *Alveolinella* H. Douvillé, 1907 (Early Miocene–Recent) and *Borelis* de Montfort, 1808 (late Eocene–Recent) represent the alveolinoid larger foraminifera. Three present-day species of *Alveolinella* and *Borelis* have been identified: *A. quoyi* (d'Orbigny, 1826), *B. pulchra* (d'Orbigny, 1839) and *B. schlumbergeri* (d'Orbigny, 1839). *Alveolinella quoyi* occurs in the Central Indo-Pacific Ocean (CIP) with its northernmost record from the shallow-water settings in Okinawa Jima (central Ryukyu Islands, Japan).

We collected literature data of the long-known *Alveolinella quoyi* of the western Pacific area. Besides assessing its fossil record and their palaeobiogeographical distributions, we investigate its range over the past c. 10 Myr and investigated when this species plausibly appeared in the Ryukyu Islands, its northernmost Indo-Pacific record.

Alveolinella quoyi possibly first appeared in the Tortonian of Indonesia. During the Pliocene *A. quoyi* was constrained within the CIP. After the initiation of the Kuroshio current in the latest Pliocene, the northward migrants arrived in the central Ryukyu Islands in the Calabrian–Chibanian (Early–Middle Pleistocene). The northward dispersal route of *A. quoyi* was constrained by complex coastlines and numerous islands. The Kuroshio current favoured the migrants arriving in the shallow-water carbonate settings of Okinawa Jima where the species is still thriving. Likely, during the Late Pleistocene, following the unrestricted stronger Indonesian Throughflow that connected the western Indo-Pacific Warm Pool with the Indian Ocean and Western Australia, the westward *A. quoyi* migrants moved into the western CIP giving rise to the present-day Maldivian and Réunion occurrences.

Did Upper Eocene short-lived corallinacean-foraminiferal carbonates form in mesotrophic paleoenvironments along the Alpine convergent margin?

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The actualist paradigm of restricting large forms of hyaline larger benthic foraminifera (LBF) to oligotrophic environments is challenged by their rock forming occurrence in short-lived, Upper Eocene corallinacean carbonates of the external, sedimentary nappes of the Alps (Helvetic, Chaînes Subalpines and Lombardian Southern Alps).

Abundant large forms of orthophragminids, nummulitids and other rotaliids occur with over 20 species in grey limestones recently attributed by us to SBZ 19 and 20 (Priabonian, Sanetsch Formation) in several Helvetic and N-Helvetic nappes of Western Switzerland and the Haute Savoie, France. In this deepening upwards formation, the upper lithofacies (Pierredar Limestone Member) are largely dominated by coralline rhodophyceans: melobesian and peyssonneliacean crusts, rhodoliths and abundant bioclasts of geniculate rhodophytes. The matrix of the bioclastic limestones contains variable amounts of fine-grained lithics, such as quartz, feldspars, mica and some charcoal fragments. The darkest lithologies give off a smell of kerogen, contain <10 μm framboidal pyrite, as well as larger pyrite aggregates, frequent in the matrix, indicating dysoxic conditions in bottom waters and/or beneath the sediment surface. In sections weakly affected by alpine burial diagenesis, LBF reveal a pristine, intrinsic cathodoluminescence unlike recrystallized specimens from shallow water environments. Hence, there is evidence of displacement of LBF, exhumed from shallower, well-oxygenated domains into the dysoxic depositional sites. On the other hand, even the lowest, shallower, cross-bedded parts of the sections show oxidized pyrite, charcoal fragments, and abundant quartzo-feldspathic material.

Modern coralline rhodophyceans occupy a wide range of habitats from tropical to temperate zones. They dominate in the "marginal reefs" or "turbid reefs" recently described from many mesophotic and mesotrophic shelfal areas of the Atlantic and elsewhere, alas, without mention of LBF.

Prevailing mesotrophic conditions during formation of the Priabonian carbonates are suggested by the occurrence of extensive pavements of the large oyster *Pycnodonte gigantica*, common irregular echinoids, bryozoans, serpulids and solitary corals, while hermatypic scleractinian corals are rare and restricted to genera, at present-day tolerant to mesotrophic and/or mesophotic, soft sediment conditions, such as *Cladophora*, *Porites* and *Caulastrea*. Except for miliolids, porcelaneous LBF are rare.

Mesotrophic and probably turbid conditions prevailed, because Upper Eocene carbonates formed off estuarine/deltaic areas shedding terrestrial material from the north (Black Forest, Vosges) into the Helvetic realm and from the advancing South Alpine nappes into the Lombardian South Alpine Realm, where Priabonian shallow water carbonates are known from deep-water resediments only (Ternate Formation).

While Eocene orthophragminds have no recent representatives, modern nummulitids, such as *Operculina* spp. have been dredged off Brunéi Darussalam (NW-Borneo) under the mesotrophic fringe of the South China Sea from depths down to the shelf edge (140 m) where they lived on muddy substrates under mesophotic/mesotrophic conditions. Further investigations of deeper mesotrophic shelf areas may perhaps reveal modern equivalents of the Upper Eocene corallinacean, LBF-rich carbonates.

Larger benthic foraminifera from the Azuero Peninsula (SW-Panama) define Eocene accretionary events and an arc gap along the trailing edge of the Caribbean Plate

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The Azuero Plateau, the trailing edge of The Caribbean Large Igneous Province (CLIP), is overlain by ribbon-cherts dated by radiolarians as Coniacian-Santonian. Proto-arc dikes crosscut the Azuero Plateau and the unconformably overlying Upper Cretaceous sediments. The latter consist of hemipelagic carbonates, the Ocú Formation (Fm.), and of volcaniclastics, the Quebrada Quema Fm., both dated by globotruncanids as Late Campanian to Maastrichtian. Upper Cretaceous larger benthic foraminifera (LBF) and rudist fragments were reported by early workers in the Ocú area, suggesting the presence of carbonate shoals on early arc volcanic edifices. A recently published crystallization $^{238}U/^{206}Pb$-age of zircons dates the oldest (Cerro Montuoso) batholith of W-central Azuero as 66.4±0.3 Ma (latest Maastrichtian).

The Azuero Plateau is bounded towards the SW by the Azuero-Soná Fault Zone and the adjacent Azuero Subduction Mélange that contains fragments of oceanic seamounts dated by globotruncanids as early Maastrichtian.

The *Azuero Accretionary Complex* occupies the SW-corner of the Azuero Peninsula. It is principally composed of two well-preserved oceanic seamounts. The Hoya seamount to the W is made of intrusives, subaerial and submarine lava flows with interbedded carbonates. Pelagic carbonates yielded *Morozovella* sp. indicate a late Paleocene – early Eocene age. Shallow water carbonates yielded the association of *Neodiscocyclina barkeri*, *Euconuloides* sp. cf. *E. wellsi* and *Amphistegina undecima*, indicating an early Eocene age.

The Punta Blanca Seamount to the E is characterized by a several km thick sequence of submarine/subaerial basaltic lava flows regularly interbedded with carbonates. Most shallow water facies only contain rhodophytes and bivalve bioclasts. Only one calcarenite yielded *Pseudophragmina anconensis* and orthophragminids suggesting an early-middle Eocene age.

The Covachón Fm. is the first overlap sequence in which chaotic deposits with up to 50 m sized blocks document the accretion of the seamounts. LBF collected from several localities indicate a middle Eocene age of the accretionary events. These resulted in a shutdown of the arc between 49 and 36 Ma (late Ypresian – earliest Priabonian), reflected by a lack of $^{238}U/^{206}Pb$ zircon ages from intrusives. Covachón facies range from distal volcaniclastic turbidites to chaotic megabreccias and up to nearshore conglomerates, documenting fast tectonic uplift.

At Puerto Escondido, a stratigraphic base of the Covachón Fm., is formed by cross-bedded detrital limestones unconformably on seamount basalts. They contain winnowed small LBF: *Eoconuloides* sp., *Amphistegina grimsdalei, A. praegrimsdalei* and *Pseudophragmina* sp. suggesting a Middle Eocene age. In the chaotic facies at Covachón Beach the matrix of the debris flows yielded *Asterocyclina* ssp., *Neodiscocyclina marginata*, *Lepidocyclina* spp. and *Polylepidina* sp. suggesting a middle Eocene maximum age. Detrital zircons form the turbiditic facies yielded a 42 Ma minimum age (late Lutetian).

The Tonosí Fm. represents a several 100 m thick deepening upwards forearc series that ranges from paralic to turbiditic facies of late Eocene to Oligocene age. Its base onlaps time-transgressive on older formations and basements documenting progressive drowning of the Azuero Arc Complex. The youngest zircons of the upper Tonosí yielded $^{238}U/^{206}Pb$ ages around 36 Ma (Priabonian). The Río Pedregal paralic facies include polymict conglomerates and encroach unconformably on accreted seamount rocks and deformed packages of Covachón Fm. The conglomerates contain pavements of oysters (*Pycnodonte* sp.) and a detrital matrix with abundant large *Lepidocyclina* ssp., pseudophragminids and *Asterocyclina* spp. indicating a late Eocene age.

The Guerita River exposes herringbone cross-bedded bioclastic limestones, unconformably overlying the Upper Cretaceous Rio Quema Fm. They are made of abundant *Operculinoides* spp., suggesting an Oligocene age. Another inland outcrop is rich in large *Lepidocyclina* spp., among them *L. tournoueri* and *L. undosa* with an Oligocene age.

Strontium isotope and biostratigraphy of the Namibian continental shelf and associated palaeoenvironmental changes during the Neogene to Quaternary

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The Namibian continental shelf is rich in phosphorite with large economic potential. The stratigraphy, ages and palaeoenvironments of these deposits have previously not received much attention. An understanding of how

palaeoenvironments changed over time under changing oceanographic conditions of the Northern Benguela Upwelling System along the margin also lacked.

Exploration and environmental studies rely on accurate stratigraphic information. Foraminifera provide an excellent proxy to determine the stratigraphy through isotopes and biostratigraphy. This study investigated 20 cores from the northern and central Namibian continental shelf (199 to 400 m). Lithological units were studied, and sedimentary components identified under binocular microscopy. Samples from the cores were analysed for strontium isotopes in sedimentary components such as foraminifera, mollusc shell, cetacean and fish bone, as well as in phosphorite grains to determine ages for the different lithological units. Faunal analyses were conducted to determine how the environments changed during the identified ages obtained from strontium isotope stratigraphy and biostratigraphy.

The sediments from the cores were found to largely be biogenic in the older olive-green mud units, containing mostly foraminifera. Phosphatic material dominated the sedimentation in the darker, younger sediments with an increase in large biogenic components to the top of the cores. Foraminifera formed minor to moderate components in the darker phosphatic units. Foraminiferal taxa and indicator species were identified and used to determine the biostratigraphy. Results from the study indicated the oldest age at the base of these cores to be in the Langhian (middle Miocene), between 15.2 and 14.1 million years ago, confirmed by both strontium isotope stratigraphy and biostratigraphy (indicator species *Globoquadrina dehiscens* and *Trilobatus bisphericus*). The foraminiferal assemblages indicated the palaeoenvironment to have shifted from a deep-water, oligotrophic environment, with warm tropical-subtropical-like conditions during the middle Miocene to shallower colder and more nutrient-rich environments during the Pleistocene-Holocene. The ages of major phosphatisation with an increase in productivity were found to be in the Pleistocene-aged darker sediments when Benguela upwelling intensified. Foraminiferal faunal analyses also indicated different assemblages during the early, middle and late Pleistocene, related to increasing amplitude sea level changes.

This study therefore provided ages to the different lithological units on the northern and central continental shelf and its associated palaeoenvironmental changes, which can be associated with global and regional climate and oceanographic changes.

Gene expression of *in situ* preserved kleptoplastidic *Nonionella stella* from an aphotic sulfidic anoxic setting

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Nonionella stella (known by some as *Nonionella* sp. T4) is a benthic foraminifer thriving in euxinic marine sediments in the Santa Barbara Basin (Southern California, USA). *N. stella* maintains functional diatom chloroplasts, sequestered from *Skeletonema pseudocostatum* or its close relative, despite inhabiting the aphotic zone (~560-595-m water depth). While we have documented *N. stella*'s gene-expression previously, those specimens had been exposed to sunlight briefly during the sampling effort and also during the isolation process. To identify the metabolic capabilities mediated by both the kleptoplasts and host cells never exposed to sunlight, we collected *N. stella*-laden sediments that were preserved *in situ* on seafloor. Thus, the data accurately represents the biology and gene expression of the host and their chloroplast endosymbionts while in their natural environment. At the time of collection, the bottom-water oxygen concentrations were undetectable, sunlight was undetectable (via PAR), and the *Beggiatoa* (bacterial) mat spanned many square km of the seafloor. We sequenced and assembled metatranscriptomes and metagenome-assembled genomes (MAGs) to determine *in situ* gene expression and genomic context for genes of interest, respectively. Our data analysis confirms prior observations that *N. stella* is capable of respiring both nitrate and oxygen but also reveals novel insights into the adaptations that make this benthic foraminifer so successful in such an extreme habitat.

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Preliminary data on the application of artificial intelligence to the identification of *Ammonia* species from scanning electron microscopy images

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Ammonia is one of the most abundant cosmopolitan taxa among foraminifera dwelling in neritic environments. The high morphological variability of this genus led to a confused and controversial taxonomy at the species level, challenged by molecular studies in the two last decades.

From an inventory at the global scale, the DNA based data delineated more than fourteen phylotypes, different enough to be considered as separate species. Three phylotypes (T1, T2 and T6) found along the European Atlantic coast in intertidal areas are morphologically very close and still difficult to distinguish without molecular analyses. Unfortunately, these analyses are expensive, time-consuming and may represent drawbacks in routine taxonomical recognition. In addition, molecular analyses are usually bound to living individuals and are more difficult to apply to Holocene/Pleistocene fossil material.

Hence, the researchers have attempted to combine molecular and morphological approaches to achieve fast and reliable identification of species based on selected morphological characters, which can be applied to present and fossil foraminifera.

Recently, by combining morphometric and molecular analyses, two discriminant morphological characters were identified to clearly distinguish the three species of *Ammonia* commonly found in European mudflats: *Ammonia veneta* (T1), *A. aberdoveyensis* (T2) and *A. confertitesta* (T6). These two morphological criteria are (i) the pore size of the penultimate chamber based on semi-automated standardized measurement (pore number, pore area and porosity), and (ii) the raised or flush character of the sutures on the spiral side. Therefore, the direct observation of these morphological characteristics allows recognizing these different species under a stereomicroscope without the need for molecular analysis.

Although these new criteria make it possible to avoid using DNA analysis, it is still rather time-consuming as one must analyse the scanning electron microscopy **(**SEM) images of each specimen.

With recent advances in computer software, automated identification processes have become possible. These processes help reduce the cost and time of studies while also enhancing their reproducibility. In this study, deep learning algorithms were developed and used to identify various *Ammonia* species based on SEM images. The algorithms were tested on two groups of images from *Ammonia* specimens collected from the Northeast Atlantic Ocean (SEM images of sequenced specimens) and coastal sites in Western Madagascar (SEM images of not sequenced specimens).

Deep learning addresses complex prediction problems using neural networks with high capacity. These networks are highly non-linear functions with numerous parameters, and their estimation usually requires a large amount of annotated training data. Transfer learning or domain adaptation is a common solution to this problem. The idea is to learn high-capacity models on large alternative source data sets whose content is sufficiently correlated with the target application and then transfer the learned knowledge to the target data.

This study performed a supervised transfer using classical weight freezing and fine-tuning. The knowledge was transferred from the well-known image classification task ILSCVR 2012 (ImageNet). Model architectures optimised for this task were used, and the hyper-parameters were optimized over a validation set. The deep network optimised for the data set was small compared to the knowledge encoded in the source data (ILVSRC). Therefore, "classical" and well-known high-capacity models for the ILVSRC task, namely VGG16, and ResNet50, were used. Among all possible combinations of freezing layers that were tested, the model with freezing at the first 3 layers and fine-tuning the other layers on the validation dataset returned the best performance of 98.3%.

Nitrogen isotopic signals in tissue of planktic foraminifers in the northern South China Sea from the shelf to the open ocean and implications for the foraminifer-bound nitrogen isotope paleo-proxy

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Marine nitrogen (N) cycling is key to reconstructing ecosystems in past oceans and directly links to global climate feedbacks through the marine carbon pump and CO_2 sequestration. Information on marine ecosystems is encoded in the N isotopic composition ($\delta^{15}N$) of organic matter produced by organisms such as planktic foraminifers. A part of the organic matter is preserved within foraminifer tests, which makes fossil shell-bound $\delta^{15}N$ a valuable tool to investigate past changes in surface ocean nitrogen cycling.

The interpretation of the planktic foraminifer shell-bound $\delta^{15}N$ requires comprehensive knowledge about ecosystem parameters and processes relevant for the formation of this signal in living foraminifer biomass. To investigate the imprint of N cycling processes in different environments on $\delta^{15}N$ of planktic foraminifer biomass, we collected planktic foraminifers, seawater, and organic particulates (particulate organic N, PON) from the water column in the northern South China Sea during late summer monsoon at locations from the shelf near the Pearl River Estuary to the open ocean. The $\delta^{15}N$ of tissue from three different species, *Trilobatus sacculifer*, *Globigerinoides ruber albus*, and *Globigerinita glutinata* were analyzed from the surface to 80 m water depth in combination with the isotopic composition of nitrate and the $\delta^{15}N$ of PON.

We find that the $\delta^{15}N$ in planktic foraminifer tissue is distinctly lower (by ≥ 2 ‰) than the nitrate at thermocline depth at open ocean stations, which we interpret to be associated with ammonium recycling. In comparison, on the inner shelf and the shelf edge, the $\delta^{15}N$ of the foraminifer tissue is higher and more variable than the open ocean stations. This implies that a complex interplay of smaller scale processes may be more relevant for shelf than open marine environments. Further, we show species-specific and depth-resolved $\delta^{15}N$ signals, which are consistent with the different trophic niches and habitats of these species. The results allow to refine our understanding of the connection between ecosystem parameters and $\delta^{15}N$ in foraminifer biomass and provide a foundation for accessing traces of past N cycling contained in the sedimentary planktic foraminifer record in this region and beyond.

Microbiome analysis of Baffin Bay *Neogloboquadrina pachyderma* reveals the first evidence for kleptoplasty in planktonic foraminifera

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Neogloboquadrina pachyderma is the only true polar species of planktonic foraminifera. It therefore plays a crucial role in the calcite flux, and in reconstructions and modelling of seasonality and environmental change within the high latitudes. The rapidly changing environment of the (sub)polar regions of the North Atlantic and Arctic Oceans poses survival challenges for this species in terms of temperature, sea ice melt, calcite saturation and ocean pH, and competition from Atlantic species. To model the potential future for this important high latitude species, it is vital to investigate the modern ocean community structure throughout the annual cycle of the Arctic to understand the inter-dependencies of *N. pachyderma*. We use 16S rDNA metabarcoding and transmission electron microscopy (TEM) to identify the microbial interactions of *N. pachyderma* during the summer ice-free conditions in Baffin Bay. We demonstrate that the *N. pachyderma* diet consists of bacteria and diatoms. The core microbiome is defined as the 16S rDNA amplicon sequencing variants (ASVs) found in 80% of individuals investigated. This core microbiome consists of two diatom ASVs and seven bacterial ASVs and accounts for, on average, 50% of the total ASVs in any individual. The bacterial ASVs represent hydrocarbon degrading bacteria, and those found routinely in the diatom phycosphere. On average the two chloroplast ASVs compose 40% of the core microbiome. However, significantly, on average 55.7% of all ASVs in any individual are of chloroplast origin. TEM highlights the importance of diatoms to this species, by revealing that chloroplasts are sequestered in the foraminiferal cytoplasm in large numbers, indicating potential kleptoplasty. Whilst some species of benthic foraminifera are known to be kleptoplastic, utilising diatom chloroplasts in this way, this adaptation has never been observed in planktonic foraminifera. However, the close association between *N. pachyderma* and diatoms in the pelagic Arctic realm provide an ideal opportunity for kleptoplasty to develop, where diatoms are a significant component of the phytoplankton population. Such an adaptation is likely to confer advantage to this species but could become an Achilles heel if the diatom species utilised are restricted to a small pool of species, that become impacted by climate change.

Benthic Foraminiferal Faunal Response to The Middle Miocene Climatic Transition From Greenhouse to Icehouse Conditions Along Central California, USA

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The Monterey Formation, consisting of siliceous and calcareous biogenic sediments, was deposited during the transition from a relatively warm greenhouse climate in the early Miocene to the cooler temperatures of icehouse climatic conditions during the early middle to late Miocene. This cooling event is associated with global paleoclimatic and oceanic changes assumed to be related to the deposition of organic carbon-rich sediments into the marginal basins of California.

The distribution of benthic foraminiferal assemblages found in the middle to late Miocene benthic foraminiferal faunas was controlled by both local tectonic, environmental, and depositional events and global variations associated with the climatic transition from greenhouse to icehouse conditions, including changes in water mass stratification, changes in productivity, and eustatic cycles.

The local and regional environmental parameters changed in space and time related to the Neogene evolution of the continental margin basins along central and southern California. Comparing faunal distributions across the continental margin benthic foraminiferal assemblages occurring in the outer and inner margin basins will establish the possible relationship between climatic-controlled oceanic events and faunal responses.

At the end of the Mid-Miocene Climatic Transition (MMCT) in the mid-Serravalian (~ 13.1 Ma), there is a distinctive faunal change in the benthic foraminiferal assemblages readily recognized by a change in several species and genera common in the MMCT and have their highest stratigraphic occurrence immediately below the contact between a change in sedimentation between an older calcareous clay-dominated section to siliceous-dominated deposition in the Monterey Formation. This faunal turnover is related to the climatic and oceanographic changes associated with the onset and further expansion of the East Antarctic Ice Sheet.

Middle Miocene Foraminifera of the Ross Sea Continental Shelf, IODP Exp. 374

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The Miocene paleoclimatic record of the Ross Sea can provide crucial insight into the Antarctic ocean-cryosphere system. The Miocene Climate Optimum (MCO, ~16.9-14.7 Ma) was a global warming event with atmospheric CO_2 concentrations higher than today, followed by the Middle Miocene Climate Transition (MMCT, ~14.7-13.8 Ma) marking the shift to colder conditions and major growth of the East Antarctic Ice Sheet. The MCO and MMCT would have had a profound impact on the ice sheet dynamics, continental shelf evolution (i.e., progradation), water mass behavior, and productivity in the Ross Sea. One way to determine the degree of impact on the Ross Sea system is by examining the foraminifera from the continental shelf. Here we investigated the early to middle Miocene foraminiferal assemblages from IODP Site U1521 located on the central Ross Sea continental shelf to: 1) identify distinct benthic biofacies; 2) constrain the timing of the continental shelf evolution; and 3) compare the recorded assemblages with other Ross Sea Paleogene and Neogene drill sites.

The preliminary late early Miocene to middle Miocene foraminiferal assemblages from Site U1521 are variable in composition and abundance, shifting between and within lithologic units. Lithologic unit IV is a sandy diamict (upper-lower Miocene, MCO) containing a diverse assemblage including high abundances of *Uvigerina*, *Globocassidulina*, and *Melonis*, as well as rare *Antarcticella antarctica*. We infer high continuous percentages of *Uvigerina*, found in unit IV, can be used as a tracer for the continental shelf edge suggesting that the continental shelf prograded northward during the early Miocene. Unit III is a diatom bearing/rich mudstone (lower middle Miocene, MCO) has a low and variable foram recovery with only ~30% of the examined samples containing foraminifera. We suggest the low recovery may be due to dissolution associated with open water and high productivity. The transition into unit II, a muddy diamict (middle Miocene, MMCT), records an increase in foram preservation with *Globocassidulina* and *Elphidium* as the dominant genera. This may represent a sub-ice shelf assemblage. High abundances of these two genera suggest the presence of modified Circumpolar Deep Water (*Globocassidulina*) on a shallower, prograded (*Elphidium*) continental shelf. In addition to assemblage differences between lithologic units, muddy intervals inferred by high gamma ray values contain more foraminifera than intervals rich in biogenic silica (low gamma ray values) where foraminifera are typically rare to absent.

Pleistocene Foraminifera of the Ross Sea Continental Slope and Rise, IODP Exp. 374

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The Ross Sea continental margin provides a dynamic setting for studying the ocean-climate history of Antarctica. Multiple processes along the slope and rise potentially influenced the abundance and diversity of foraminiferal assemblages, including depositional modes, current activity, sea ice coverage, productivity, and changes in water masses. Here we investigated the Pleistocene foraminifera from IODP Sites U1525 and U1524 to learn more about the glacial-interglacial depositional and oceanographic processes along the continental margin. We were interested in determining: 1) what controlled foraminiferal presence and absence during the Pleistocene; 2) when foraminifera are present, what can they tell us about the environmental conditions along the eastern Ross Sea continental margin; 3) if the benthic assemblages defined by previous Ross Sea studies can be recognized at these deeper continental margin sites, and 4) whether specific benthic foraminiferal biofacies are useful tracers of discrete water masses. Foraminifera from Holes U1525A and U1524A are uncommon. Rare occurrences of subpolar and temperate planktic species (*Neogloboquadrina incompta, Globigerina bulloides, Globigerina falconensis, Turborotalita quinqueloba*, and *Globoconella inflata*), suggest periods of open marine, high productivity, and possible incursions of the warmer Ross Sea Gyre into the Ross Sea. Peaks in benthic foraminifera (at least 20 specimens), observed in only 10 samples, were used to define four benthic biofacies; *Globocassidulina, Globocassidulina-Eponides, Epistominella*, and *Miliammina*. The *Miliammina* biofacies represents open marine conditions, high productivity, and High Salinity Shelf Water (HSSW) exported off the continental shelf via the Hillary Canyon. The *Epistominella* biofacies, the only biofacies recognized at both sites, indicates less sea ice and open marine conditions in response to the spring bloom of phytoplankton. The *Globocassidulina* biofacies suggests possible incursions of Circumpolar Deep Water (CDW) into the Ross Sea. The *Globocassidulina-Eponides* biofacies suggests high productivity associated with the spring bloom of phytoplankton in addition to the influence of CDW. Together, these biofacies illustrate the dynamic interplay between deposition, climate, water masses, and the Antarctic ice sheet during the Pleistocene.

Living and dead Foraminiferal as the basis for environmental diagnosis in a mesotidal tropical estuary: Cachoeira River Estuary, Bahia-Brazil

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The Cachoeira River Estuary is the largest in southern Bahia (Brazil) and hosts a rich biodiversity, including extensive mangrove areas. However, the region has a well-known history of environmental impacts from industrial, urban, and rural (cocoa cultivation) sources that have affected the ecosystem's health and made it one of the most vulnerable in the country. Under this scenario, identifying and mapping impacted areas are extremely important to support future environmental monitoring plans. Thus, aiming to contribute to the scientific knowledge in the region, this study applied the benthic foraminifera fauna (bio- and taphocenosis), supported by sedimentological and physicochemical parameters as a tool for ecological and hydrodynamic characterization to establish a database that can be used in environmental management and biomonitoring of Cachoeira River Estuary. The sediment sampling was carried out in November 2016, with an Ekman Grab, in triplicates, in 30 pre-established stations scattered from the river mouth to the innermost part of the estuary. The physicochemical parameters were measured using a portable probe at the water-sediment interface. As a result, 80 species of benthic foraminifera were identified, of which 57 taphocenosis species in the (D - 9 agglutinated and 48 calcareous) and 49 in the biocenosis (L - 19 agglutinated and 30 calcareous). The Detrended Correspondence Analysis pointed out that the

distribution of L species is related to sanity, alkaline pH, and total dissolved solids (*Quinqueloculina* spp., *Textularia* spp., *Miliolinella subrotunda*, *Buliminella elegantissima*, *Nonionella auris*, and *Pseudononion japonicum*) as well as chlorophyll and turbidity (*Elphidium excavatum*, *Ammonia parkinsoniana*, *Trochammina inflata*, and *Haynesina germanica*). Dead species were positively correlated to organic matter (*T. inflata*, *Paratrochammina clossi*, and *Quinqueloculina seminulum*) and salinity, turbidity, alkaline pH, and dissolved oxygen (*P. japonicum, B. elegantissima, Fissurina agassizi, M. subrotunda, Quinqueloculina milletti, Bolivina translucens*, and *Rosalina bradyi*) were the most important. The cluster analysis showed few similarities between the analysed assemblages, which may be related to the hydrodynamic conditions and seasonal environmental variations. At the same time, the high hydrodynamics is evidenced by the distribution of Assemblage A (*B. elegantissima*_D and *N. auris*_D), which corresponds to inner-shelf organisms transported throughout the entire estuary. The boundary of the inner estuary, pointed by Assemblage C (*Discorbis peruvianus*_L and D), occurs 5 km from the river mouth. A region with higher chlorophyll concentration and more turbid waters can be identified 10 km from the mouth and is marked by assemblages D (*A. parkinoniana*_L) and G (*A. tepida*_L), representing the region under the greatest influence of the waste from the sewage treatment plant and corresponds to the middle estuary. The disturbance caused by the treatment plant did not allow us to identify the middle estuary end boundary and the upper estuary beginning. The results allowed the identification of estuarine compartments and regions of higher organic matter accumulation. These data indicate foraminifera as a proxy for coastal environmental characterization and, possibly, biomonitoring tools.

Environmental changes in the Barents Sea over the last millennia: benthic foraminifera evidence

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Characterising natural climate-environment variability is essential to evidence the recent anthropic impact and to simulate realistic projections. This is particularly relevant for the Barents Sea, a unique and highly sensitive shallow water polar ecosystem that is one of the world's most productive. Over the last decades, this region experienced a warming of sea surface temperature (SST) related to the expansion of the warmer Atlantic Water (AW) into the area, a phenomenon commonly referred to as "Atlantification". Moreover, the Arctic region stored in its sediment methane gas hydrates which are sensitive to climatic variations. These large gas reservoirs also depend on tectonic activity and climate change. In this regard, benthic foraminifera represent a handy proxy to reconstruct paleoecological and paleoenvironmental changes as their diversity and distribution are strongly related to environmental parameters. Here we combined foraminiferal data and stable isotope analyses to reconstruct the paleoenvironmental history in the Barents Sea over the last millennia. The study is based on sediment samples from the cores HH1141 and HH1181 (74.015533°N 21.071100°E, -285 m depth, and 74.081600°N 21.362300°E, -298 m depth, respectively), collected during the cruise CAGE 18-4 (on July-August 2018) on the R/V Helmer Hanssen. The distributional pattern of benthic microfauna commonly related to the AW water mass inflow (*Trifarina angulosa, Melonis barleanus, Epistominella nipponica, Buccella frigida, Nonionellina labradorica, Adercotryma glomeratum, Reophax* sp. and *Spirulina vivipara*) enabled to increase our understanding of the Atlantic incursion toward the Barents Sea. Furthermore, the stable isotopic signature of benthic tests and the ratio of calcareous versus agglutinated species allowed evidence of the relationship between climate variations and methane release. This investigation points out the usefulness of the foraminifera data to understand the past variability of the Atlantification phenomena considering the dynamic of methane seepage in the Barents Sea, providing a longer perspective on the global change.

Probing *Melonis barleeanus* agglutinating strategy: an experimental approach

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Melonis barleeanus is a calcareous benthic foraminifer often used in paleoceanographic reconstructions. Recently, it was demonstrated that sedimentary particles were present within the test of this species making *M. barleeanus* a calcareous and agglutinated species. Interestingly, this is not an isolated case among calcareous foraminifera. Similar observations were made on other benthic foraminiferal genera, such as *Cibicides*, *Stomatorbina*, and *Uvigerina*, suggesting that an agglutinated strategy might be more common than initially thought among rotaliids.

This study aims to start tackling the unusual biomineralization strategy of *M. barleeanus* using an experimental approach. In particular, here we present the results of culturing experiments designed to investigate the selectivity of *M. barleeanus* towards sedimentary grain size and mineralogy. Sediments collected in the Barents Sea at ~1200 m depth were sieved at 63 μm and placed in two separate beakers. To one of these beakers, glass (quartz) beads ranging 0.5-11 μm were added to the sediment. The experiments were run in parallel for about five months under controlled pH, salinity, oxygen, and temperature conditions. Calcein was introduced in the experimental medium (i.e., artificial seawater) to help identify the calcite deposited by foraminifera while in culture. Dead *Phaeodactylum tricornutum* was used as the food source and added once a week.

For each experiment (with and without glass beads), ~100 specimens were isolated and analyzed. An epifluorescence microscope was used to identify those individuals that deposited one or more chambers during the experiments. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were performed to investigate the presence of sedimentary particles within *M. barleeanus* tests and to collect qualitative chemical data on those grains. Our results showed that many of the specimens examined grew under controlled conditions and contained sedimentary particles within their tests. These results confirmed the previous finding that *M. barleeanus* is a calcareous and agglutinated foraminifer and shows a certain degree of selectivity towards the grains incorporated within the calcite frame of its test.

Mid Oligocene climate and Antarctic ice-sheet instability: evidence from clumped-isotope thermometry

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Ice-volume reconstructions derived from deep-sea oxygen isotope records suggest large fluctuations in East Antarctic ice volume between 29 to 26 million years ago (Ma), in the mid Oligocene. According to these reconstructions, changes in ice-volume were primarily paced by 100-kyr eccentricity cycles. The largest fluctuations involved complete melting of a modern-sized East Antarctic ice-sheet, while smaller fluctuations suggest reduction to one third to one half of the peak volume attained during glacial intervals. Sea-level reconstructions support large variations in ice volume in the mid Oligocene, but such cyclical large-scale fluctuations are difficult to reconcile with our understanding of ice-sheet dynamics. Even when ice-sheet models are forced with large changes in atmospheric CO_2 (>700 ppm), a full melting of a modern-sized ice-sheet is not reached due to strong hysteresis.

A major limitation of oxygen isotope-based ice-volume reconstructions is that the oxygen isotope signal in calcite is also controlled by seawater temperature. To address the behaviour of the Antarctic ice-sheet, we measured clumped isotope ($\Delta47$) temperatures on benthic foraminifera at ODP Site 699, in the Atlantic sector of the Southern Ocean, between 27.2 and 28.2 Ma at a 34 thousand year (kyr) resolution. Clumped isotope thermometry is independent from the oxygen isotope composition of seawater, hence the temperature component in the foraminiferal $\delta^{18}O$ signal can be isolated. With our new record, we are able to track the 100 kyr-eccentricity cycles and test whether deep ocean temperature can explain the large fluctuations in $\delta^{18}O$ observed in the mid Oligocene, which would eliminate the need for continental-scale waxing and waning of the East Antarctic ice-sheet.

Late Neogene Evolution of modern deep-dwelling plankton

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The fossil record of marine microplankton provides insights into the evolutionary drivers which led to the origin of modern deep-water plankton, one of the largest components of ocean biomass. We use global abundance and biogeographic data, combined with depth habitat reconstructions, to determine the environmental mechanisms behind speciation in planktonic foraminifera over the past 15 Myr. We also obtain similar data for calcareous nannofossils, another major component of ocean plankton. We compare our microfossil datasets with water column profiles simulated in an Earth system model. We show that deep-living planktonic foraminiferal (zooplankton) and calcareous nannofossil (mixotroph phytoplankton) species were virtually absent globally during the peak of the middle Miocene warmth. The evolution of deep-dwelling planktonic foraminifera started from subpolar–mid-latitude species, during late Miocene cooling, via allopatry. Deep dwelling species subsequently spread towards lower latitudes and further diversified via depth sympatry, establishing modern communities stratified hundreds of meters down the water column. Similarly, sub-euphotic zone specialist calcareous nannofossils become a major component of tropical and sub-tropical assemblages during the latest Miocene to early Pliocene. Our model simulations suggest that increased organic matter and oxygen availability for planktonic foraminifera, and increased nutrients and light penetration for nannoplankton, favoured the evolution of new deep-water niches. These conditions resulted from global cooling and the associated increase in the efficiency of the biological pump over the last 15 Myr.

Virgin or Aged does not matter: Microplastic leachates alter the behavior and the proteome of the kleptoplastidic foraminifera *Haynesina germanica*

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Plastic pollution in marine environments was first reported in 1970, with concern growing until the mid-1980s. The 5 to 13 Mt of plastic dumped into the oceans each year is expected to grow to as much as 90 Mt/year by 2030 if nothing changes, due to the exponential growth in plastic production (from 1.5 Mt in 1950 to 368 Mt in 2019) and the mismanagement of plastic waste (in 2010, one third of the plastic waste (32 Mt) from 93% of the world's population was considered to be mismanaged in 2010). Plastic debris are persistent in the environment and are dispersed over great distances by winds and ocean currents due to their intrinsic durability. They can then sink to the seafloor and are often buried in unvegetated and vegetated sediments in subtidal and intertidal coastal environments where they become a potential threat to biodiversity. Their toxicity comes from additives, *i.e.*, primary leachates (e.g. plasticizers, flame retardants, UV stabilizers, antioxidants, and antistatic molecules) incorporated into plastic during the manufacturing process to modify the physical properties and durability of the polymers (hereafter called virgin plastics), but also from contaminants already present in seawater, *i.e.*, secondary leachates (from another source of pollution) that are adsorbed onto the surface of the plastic debris when they are exposed to weathering processes (hereafter called aged plastics). Thus, benthic species in soft-bottom sediments face a new threat that may hinder their survival. In this work, we studied the kleptoplastidic benthic foraminifera *Haynesina germanica*, a key species in intertidal European mudflats. The effects of virgin and aged microplastics (MPs) leachates (at environmentally relevant concentrations) were evaluated at different levels. Firstly, at the behavioral level, the pseudopodial was significantly impaired in the presence of aged MPs leachates. Secondly, at the cellular level, significant alterations in the proteome of the foraminiferal individual and the stolen plastids were observed upon exposure to virgin and aged MPs leachates. This work confirms the potential hazard of plastic leachates to benthic foraminifera and the urgent need to address this issue for soft-bottom meio- and macro-benthic organisms.

Single cells ecosystem engineers: foraminiferal role in bioturbation processes

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The role of benthic foraminifera in the benthic ecosystem functioning, and the associated functional diversity is an untapped question. The movement ability of intertidal foraminifera suggests that they may have a role, yet to be quantified, in benthic-pelagic coupling through their movement on the sediment surface, at the sediment-water interface and within the sediment. Based on the literature, we hypothesized that foraminiferal vertical movements may *(i)* have major impacts on the stability and erodibility of the surficial sediment layer, *(ii)* produce a substantial downward transport of particles and *(iii)* enhance fluxes of dissolved oxygen and solutes at the sediment-water interface.

Our laboratory experiments over the last years, investigating the behavioral traits of 5 benthic foraminiferal species typical of European temperate mudflats (*Ammonia tepida*, *Haynesina germanica*, *Quinqueloculina seminulum*, *Miliammina fusca* and *Cribroelphidium williamsoni*), revealed an unexpected functional diversity in benthic foraminifera. Specifically, *C. williamsoni* belongs to the epifaunal-biodiffusors, *A. tepida* belongs to the surficial-biodiffusors, and *H. germanica, Q. seminulum* and *M. fusca* are considered gallery-biodiffusors. The classification of benthic foraminifera in these functional groups implies that they would contribute differently to benthic-ecosystem functioning. For instance, although *C. williamsoni* is larger than *H. germanica* and that both species displayed similar travelled distance, the latest was more efficient to rework the surface sediment.

In details, the specific experiment conducted with *H. germanica* showed that its infaunal behaviour leads to the creation of one-end tube within the first centimetre of sediment. In addition, a vertical trail following behaviour was described for the first time in foraminifera, which may be linked to the sustainability of the biogenic sedimentary structures. Therefore, *H. germanica* produces a vertical transport of both mud and fine sediment fractions. Furthermore, the potential link between the intensity of sediment reworking and the functional group of a species is not straightforward; suggesting we are still at the very early beginning in our understanding of bioturbation processes in benthic foraminifera. Noticeably, we also observed that features like velocity, activity, tortuosity, and density may mediate sediment-mixing intensity.

We also showed that foraminifera motion-behaviour increased the oxygen penetration depth and decreased the total organic content. Their activity in the top 5 mm of the sediment affected the prokaryotic community structure. Indeed, in bioturbated sediment, bacterial richness was reduced and sulfate reducing taxa abundance in deeper layers was also reduced, probably inhibited by the enhanced oxygen penetration depth. Since they can affect both particulate and dissolved fluxes, foraminifera should be considered as bioturbators. They are further able to mediate the prokaryotic community, suggesting that they play a major role in the benthic ecosystem functioning and may be the first described single-celled eukaryotic ecosystem engineers.

Unlocking the paleoceanographic archives of the Humboldt Current System through the foraminiferal record: A case study from the Bahía Inglesa Formation, northern-central Chile

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The Atacama Desert has experienced long periods of hyperarid conditions which possibly date back to the early Miocene. Reduced landward moisture flux due to the northward transport and upwelling of cold waters by the Humboldt Current System (HCS) has been identified as one of the main drivers of hyperaridity in today's Atacama Desert. However, the evolution of paleoclimatic variability and the palaeoceanographic conditions are poorly constrained. The microfossil content of marine sediments exposed along the Chilean coastline provide a unique palaeoceanographic archive of the HCS that allows us to study drivers of paleoclimate in the Atacama Desert during the Neogene.

Miocene to Pliocene marine deposits in Chile 26°45'-28°S are summarized as Bahía Inglesa Formation. These sediments, in particular thick successions of diatomaceous mud, potentially allow the characterization of Neogene HCS properties at orbital-scale resolution. However, the depositional age of the Bahía Inglesa Formation is not sufficiently well constrained, and quantitative studies on the microfossil content are missing. Here we present a refined integrated stratigraphic framework for the Bahía Inglesa Formation at Quebrada Tiburón (27°S) and a preliminary paleoceanographic assessment based on planktic and benthic foraminifera.

The marine sediments exposed at Quebrada Tiburón are composed of ac. 9m-thick succession of laminated diatomaceous muds with intercalated sandy deposits. Preliminary results from bio- (planktonic foraminifera, calcareous nannoplankton, diatoms), chemo- ($\delta^{18}O$ of benthic foraminifera, Sr isotopes), tephro- and magnetostratigraphy suggest a late Tortonian age of c. 8.7 Ma for the initial transgression and a late Messinian (< 6 Ma) to early Pliocene (> 3.6 Ma) age for the intermittent emplacement of the diatomaceous muds.

Benthic foraminiferal assemblages and test morphology reveal a shift from trochospiral and planospiral (predominantly epifaunal) to serial (infaunal) morphotypes between sands and diatomaceous muds, respectively. Together with plankton assemblages dominated by diatoms and the planktonic foraminifera *Globigerina bulloides* and *Neogloboquadrina pachyderma*, the diatomaceous muds reflect a highly productive coastal upwelling regime and low oxic, eutrophic conditions at the seafloor. However, occasional layers of bioturbation within the diatomaceous succession also imply phases of relaxed upwelling conditions. In the next step, the quantitative assessment of planktic and benthic foraminiferal assemblages and shell geochemistry will allow a more detailed characterization of sea surface temperatures and bottom water oxygenation. These integrated results will highlight the significant changes in the Neogene palaeoceanographic properties of the upwelling system which will allow us to better understand the variability of the prevailing hyperaridity in this area and to relate it to the long-term climatic forcing, which may have been experienced, and which is thought to concomitantly control marine deposition.

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Rhizarian stercomata: Experimental notes on their potential for fossilization

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Stercomata are micrometer-scale, intra-test agglomerations of fine particulate waste. They are typically composed of mineral grains, clay particles, and fragments of biogenic materials (diatom frustules, sponge spicules, invertebrate body parts). Stercomata are cytoplasmic and/or extracellular features of all *Gromia* spp. studied to date, as well as certain benthic Foraminifera (e.g., *Bathysiphon* spp.), especially the Xenophyophorea and Komokiacea. The function(s) of stercomata are poorly understood; possibilities include buoyancy control and the reduction of food value to predators.

We report here the results of experiments designed to test the resistance of stercomata to agents known to solubilize cytoplasm or disaggregate shale. The source of stercomata resulted from a happy accident: Twenty-five years ago, a laboratory environmental room failed and warmed to room temperature for one week, resulting in the death of ~1,000 specimens of cold-adapted *Gromia* sp. collected from McMurdo Station, Antarctica. Since that time, stercomata sourced from the decayed gromiid remains have been stored refrigerated in 120ml polystyrene tubes. Despite long-term storage in oxygenated, bacterized seawater, these stercomata retain all the structural features of those seen in live specimens. The parameters examined include ultrastructure, size and aspect ratio, and close association with refractile granules (xenosomes). We found that stercomata are resistant to disaggregation by sonication, overnight dissolution in 5% sodium hypochlorite, boiling in 5% hydrogen peroxide, and ashing for 24 hours at 500°C. Sonication in surfactant/detergent solutions (Triton X-100, NP-40, Quaternary O) also failed to disrupt stercomata. The only agent tested that disaggregated stercomata was

sodium dodecyl sulphate (SDS). These findings indicate that stercomata are highly refractory, and are likely to be useful markers for identifying microfossils of putative Rhizarian protists.

Controls on B/Ca in Planktic Foraminifera

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The B/Ca ratio of foraminifera shells has been developed as a proxy for past ocean carbon chemistry. However, despite numerous culturing studies investigating this proxy system, there is little consensus as to which physical or chemical environmental parameter exerts the strongest control on foraminifera B/Ca, particularly in planktic species. Suggestions include dependencies on $B(OH)_4^-/HCO_3^-$, CO_3^{2-}, pH, light intensity, shell size/mass, phosphate concentration, seawater saturation state and temperature. If B/Ca is to be used as a seawater carbonate proxy, it is vital to identify the primary controls on B/Ca in foraminifera.

We present B/Ca data from a comprehensive culturing study of *Orbulina universa*, grown under conditions where DIC, pH, CO_3^{2-}, temperature, [Mg] and [Ca] are independently varied. Within this broad matrix of conditions, we show that *O. universa* B/Ca is most strongly correlated with seawater $B(OH)_4^-/(CO_3^{2-})^{0.5}$. This variable alone predicts 96% of the variance in the data and including additional experimental variables offered no improvement in the ability to predict B/Ca. $B(OH)_4^-/(CO_3^{2-})^{0.5}$ alone is sufficient to predict B/Ca across a wide range of temperature and seawater chemistry conditions. Our ability to identify this as the main predictor of B/Ca is made possible by the wide range of conditions and decoupled of seawater carbon chemistry considered in these experiments, which allow us to exclude proposed dependencies on other aspects of carbon chemistry, temperature, [Mg] and [Ca].

We further asses whether this relationship is also able to explain trends in previously published culture and core-top data. We find that $B(OH)_4^-/(CO_3^{2-})^{0.5}$ is the best predictor of B/Ca in all studies of cultured planktic foraminifera to date, but that the relationship is less clear core-top data. This is likely attributable to the variability in additional environmental factors (light intensity, shell size/mass, phosphate concentration) that were not varied in culture studies.

Mn/Ca as a potential recorder for bottom-water oxygenation

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Deoxygenation is currently one of the most significant environmental challenges facing marine ecosystems. This issue is primarily caused by warming, increased water stratification, and higher biological oxygen demand, with future warming likely to exacerbate the problem, particularly in temperate and subpolar regions. In addition, human-induced eutrophication, increased freshwater input, and hydrographic changes in coastal zones also contribute to declining ‚dissolved oxygen concentrations, resulting in the expansion of hypoxia. As a result, there is a pressing need for a framework to understand the severity and potential outcomes of these changes and to develop evidence-based strategies for managing the environment. This framework can be derived from paleoenvironmental records during periods when comparable events happened in the past, but to develop this context there is a pressing need to expand and further advance proxies for bottom-water oxygenation to accurately reconstruct past $[O_2]$ in marine settings. However, it is challenging to obtain accurate quantitative proxies for $[O_2]$, and efforts are ongoing to improve and expand such proxies. One potential approach involves using manganese-to-calcium ratios (Mn/Ca) in biogenic calcium carbonates such as benthic foraminifera tests to determine bottom-water oxygenation conditions.

To explore the feasibility of this approach, we analyzed the Mn/Ca ratios of two living benthic foraminifera species (*Bulimina marginata* and *Nonionellina labradorica*) in Gullmar Fjord, Swedish west coast, which offers a range of

oxygenation conditions. Our data suggest that *Bulimina marginata* has the potential to be a useful proxy for low-oxygen conditions, while *Nonionellina labradorica* was found to be less sensitive to environmental variability. We also used synchrotron-based scanning X-ray fluorescence (XRF) nanoimaging to explore Mn distribution across *B. marginata* tests, revealing Mn/Ca shifts by chambers that reflect bottom-water oxygenation history and/or ontogeny-driven life strategy preferences. We further investigate the potential biologically controlled mechanisms that could explain the species-specific response observed in this study.

Overall, our findings suggest that selecting sensitive candidate species can help to further develop the Mn/Ca proxy for quantitative oxygen reconstructions in the low-oxygen range, which is critical for understanding the past and present state of marine ecosystems.

Studying morphological variation across space and through time using existing museum collections

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Museum collections provide unique opportunities to generate large, global datasets. This is particularly valuable for planktonic foraminifera, where sample collection and identifying and picking of specimens is a time-consuming process that limits the size of a dataset that can be generated by individual researchers. Here, we present the first results of a new project that will digitise the planktonic foraminifera collection housed at the Yale Peabody Museum. This collection contains picked assemblage slides from hundreds of core-top samples from all over the world. Slides are imaged at high resolution and made publicly available for morphological analysis. We showcase the first results of variation within and among species around the world and highlight opportunities for future research.

Environmental drivers of developmental plasticity distinguished from genetic change in the fossil record

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The fossil record holds the most direct evidence of large-scale biodiversity change on Earth, but fundamental paleontological-ecological gaps limit our ability to interrogate the processes involved. A particular issue concerns the role of environmentally induced phenotypic variation, which is ubiquitous in contemporary populations but typically undetected using traditional paleontological methods. Here we develop a novel method to reconstruct reaction norms in deep time by comparing multiple morphological and environmental measurements made on the same individual. We studied macroperforate planktonic foraminifera, which preserve their entire ontogeny in their fossil remains and record environmental conditions at the time of calcification. We developed high throughput x-ray micro-CT and Laser Ablation Inductively Coupled Plasma Mass Spectrometry protocols to reconstruct coupled morphological and environmental change records from the same specimens. Generalised additive mixed effect models show that growth rates are inversely correlated with calcification temperature, as reconstructed from Mg/Ca, across three sister species of the Pliocene *Menardella* genus, but reaction norms vary among species. By contrast, architectural traits such as shell trochospirality and the angle between subsequent developmental stages are driven by across-species developmental constraints not environmental variation. Our results show for the first time that studying developmental plasticity in deep time is feasible. Integrated data protocols shed new light on developmental plasticity in the fossil record and help establish a framework to better understand the mechanisms by which environmentally induced trait variation led to the generation and proliferation of life on Earth.

Multivariate analyses on benthic foraminiferal assemblages: Two case studies from the Late Cretaceous Western Interior Seaway

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The fossil record of benthic foraminifera is widely used to reconstruct environmental conditions across marine settings but studies limited to a single stratigraphic section often muddle the interplay between local, regional, and global drivers of environmental conditions. Moreover, they alone cannot lead to a better understanding of basin-wide dynamics or ecological trends, which are useful for untangling local and regional drivers of change. In contrast, multivariate analyses allow for sediment samples from various stratigraphic sections to be co-analyzed on a common scale, facilitating inter-basin comparisons.

Here we present two case studies from the Cretaceous Western Interior Seaway (WIS) that exemplify the utility of multivariate techniques for co-analyzing benthic foraminiferal assemblages across a single basin. To prepare each dataset, proportional abundance data was collected from previously published studies and taxonomically standardized. Then, species or genus concepts were summarized into taxonomically agnostic groups of morphotypes or guilds to test ecological coherence in the absence of taxonomic information. The datasets were subjected to multivariate techniques most appropriate for the proposed research objective. In the first case study, we employ Principle Components Analysis (PCO) to test for spatial patterns in the response to environmental change associated with late Cenomanian Oceanic Anoxic Event 2 (OAE2). We found that benthic forams were primarily affected by changes in the availability of oxygen and food at the seafloor, conditions driven by water mass change. This study underscores how local environmental changes overshadow the expression of global events. In the second case study, we use distance-based redundancy analysis (db-RDA), a constrained ordination, to test whether benthic foram assemblages from Campanian to Maastrichtian seep environments are distinct.

This study showed that although seep environments draw their benthic foraminiferal faunas from the surrounding metacommunity, assemblages reflect the environmental conditions present at individual seeps. This study also emphasizes the significance of local drivers in ecological signals. Importantly, both studies also show ecological coherence between the taxonomic, morphotype and guild-level analyses. This coherence suggests that morphotypes are a good substitution when species concepts might disagree or be poorly established due to preservation. The use of unconstrained (PCO) versus constrained (db-RDA) ordinations demonstrates how useful multivariate methods are for testing multiple hypotheses about what controls the distribution of benthic foraminifera. These case studies show that multivariate techniques are an important tool for leveraging the extensive and detailed fossil record of benthic foraminifera.

New Bajocian shallow-water agglutinated foraminifera from the basal D1 member of the Dhruma Formation west of Riyadh, Saudi Arabia

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The Dhruma Formation is part of the middle Jurassic succession in Saudi Arabia. The formation is subdivided into seven members and assigned an age of Bajocian–Bathonian based on ammonites. This study concentrates on the agglutinated foraminifera from the basal member, the Balum (D1) Member of early Bajocian age (upper part of the Discites Zone to lower part of the Laeviuscula Zone). We previously reported a new *Ammobaculoides* species (*Ammobaculoides dhrumaensis* Kaminski, Malik and Setoyama, 2018) from the green shale of the D1. This study represents a continuation of this preliminary study concentrating on the smaller agglutinated foraminiferal assemblage of the basal Dhruma Formation.

For the purpose of this study, we sampled the basal part of the Dhruma Formation near Hafirat Nisah, southwest of Riyadh. At this locality the thickly bedded limestones of the overlying D2 member forms a prominent ridge that is visible from a distance. A total of 30 samples were collected bed-by-bed from the green shales and marls exposed in a small man-made excavation dug by local farmers. The entire stratigraphic sequence exposed at the locality was sampled up to the base of the D2 member. Samples from the basal shale subunit were disaggregated by gently boiling in water with a small amount of dishwashing liquid. Marly samples were disaggregated using the acetic acid method. Samples from the basal part of the exposure are clay-rich, and the majority of samples contain a rich benthic assemblage consisting of gastropods, echinoderm fragments, holothurian sclerites, and smaller benthic foraminifera.

The foraminiferal assemblage has been previously mentioned as the "smaller agglutinated fauna". We describe nine new smaller agglutinated benthic foraminiferal species (*Haplophragmoides* sp. 1, *Pseudobolivina*? sp. 1, *Trochammina* sp. 1, *Trochammina* sp. 2., *Gaudryinopsis* sp. 1, *Gaudryinopsis* sp. 2, *Gaudryinopsis* sp. 3, *Gaudryinopsis* sp. 4, and *Gaudryinopsis* sp. 5) from the lowermost Balum (D1) Member of the Dhruma Formation. The assemblage at the studied locality is comprised of 70–80% of agglutinated species, while the remaining species mainly consist of calcareous nodosariids and polymorphinids. The newly reported species are well preserved and account for less than 5% of the assemblage.

The Middle Jurassic sediments of Saudi Arabia are renowned for the presence of endemic species of ammonites, foraminifera, gastropods, and echinoids. It therefore comes as no surprise that the basal unit of the Dhruma Formation also contains smaller agglutinated foraminifera that are new to science. The taxonomic composition of the whole assemblage will be the subject of future work.

Using seafloor substrate experiments to acquire, assess, and describe populations of *Cibicidoides wuellerstorfi* recruiting to plastics over the course of months to years

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The epibenthic foraminifera, *Cibicidoides wuellerstorfi*, has been observed on elevated substrates for decades. Recent deep-sea experiments have been deployed across the Pacific Ocean at water depths ranging from 80 to 4000 m for between 6 months and 3 years. Herein, we report details of colonization of different plastic substrates, ratios of different reproductive morphology, and the composition and morphology of cysts commonly covering attached *Cibicidoides wuellerstorfi* and *Cibicidoides wuellerstorfi* var *lobatulus*.

Deployed Seafloor Epibenthic Attachment Cubes (SEA^{3}s) are composed of a variety of plastic materials including PLA (Polylactic Acid), ABS (acrylonitrile-butadiene-styrene), PP (polypropylene), and an unknown material likely to be polyethylene (PE). Colonization densities between various plastic materials do not seem significantly different, with the exception of the possible PE plastic which consistently possessed fewer individuals than any other plastic material. This relationship may be due to the antimicrobial nature of PE plastic. Overall, plastics may be a desirable attachment substrate due to the fine scale texture of these surfaces.

Differences between reproductive morphologies may vary with length of deployment of the colonized substrates related to generational reproduction progressing from the initial recruitment populations. Quantifying ratios of sphericity (micro vs megalospheric forms) may reveal an ability to assess establishment and maturity of colonizing populations.

Most, if not all, *C. wuellerstorfi* have been observed to be covered by a cyst material with branching arms securely attached to the substrate. Observations of these cyst materials under SEM-EDS (Energy Dispersive Spectroscopy) point to these materials being composed primarily of silica, suggesting they are minerals being acquired by these epibenthic foraminifera from the water column, perhaps from material resuspended in bottom currents.

Assemblages attached to these experimental substrates show a great deal of difference compared to the populations of the surrounding sediment, suggesting these substrates have a unique ecologic role in deep sea ecosystems. Deployments of experimental materials have been used to acquire *C. wuellerstorfi* from locations in modern ocean environments where their presence is rare in the sediments. Therefore these experimental substrates have demonstrated their usefulness when trying to investigate new faunal proxies using epibenthic species such as *C. wuellerstorfi*. Additionally these materials can serve as a means to conduct *in-situ* experiments likely to provide insights into colonization, reproduction, and biomineralization of this important epibenthic species.

Attributes allowing for long species duration in benthic foraminifera

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Benthic foraminifera have flourished throughout the Phanerozoic and are abundant today, ranging from barely brackish coastal waters to the deep-sea abyss. Their species durations can be relatively long, on the order of 40 my for deeper water species. In marine invertebrates with a fossil record, macroevolution has been effectively studied by looking at genus or species duration compared to factors such as abundance and geographic distribution. Not surprisingly, ecological versatility has also been recognized as a main contributor to longevity. But in the benthic foraminifera, it has been shown that neither

abundance, geographic range, nor frequency of occurrence have a significant positive relationship with duration, which is perplexing. Why do benthic foraminifera have such longevity; what makes them so successful through time? This paper reviews past work and provides some new data to address these questions. One overriding attribute ensuring survival of species is dispersal method. Living benthics can disperse through the use of resting propagules, and ensuing populations exhibit a log series distribution in space and time. The fossil record shows that dispersal is very rapid, and characteristic biogeographic and evolutionary patterns can be observed in shallow and deeper water communities. Another important attribute of benthic foraminifera promoting species survival is their ability to tolerate extreme and/or changing environmental conditions. For example, some living benthic species can prosper in oxic or anoxic environments, switching from aerobic to anaerobic respiration when needed. Shallow water forms may be abundant during vast changes in temperature and salinity, and some can easily tolerate pollutants. Even with high levels of heavy metals in their shells, as seen in new test analysis data presented herein, species can thrive.

Insights into Middle to Late Miocene conditions in the eastern Mediterranean region (Cyprus) from stable isotope and trace element analysis

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Dynamic climate changes and regional tectonic convergence/collision were fundamental factors in the formation of the earth, ocean and climate systems during the Middle to Late Miocene. CO_2-driven global warming of the Middle Miocene Climatic Optimum (MMCO) has been proposed as an analogue for future anthropogenic climate change. However, the nature and extent of both the MMCO and the subsequent Middle to Late Miocene cooling are poorly constrained in the eastern Mediterranean region. This region was affected by the closure of key ocean gateways to the Indian Ocean during the Middle Miocene and to the Atlantic Ocean during the Late Miocene. New planktic foraminiferal stable isotope and trace element/Ca records provide fresh insights into the evolution of sea surface temperature and ocean chemistry. Two main Middle-Upper Miocene sections in Cyprus (Kottaphi Hill and Lapatza Hill) were sampled at 5–25 cm resolution and correlated using calcareous nannofossil biostratigraphy and bulk rock stable isotope data, supported by field observations, x-ray diffraction and x-ray fluorescence data. Our new data reveal how both global climate changes and the local to regional effects of ocean gateway closures affected the eastern Mediterranean during this time interval. An improved understanding of Middle to Late Miocene conditions in the eastern Mediterranean highlights how 'two-phase' reef development in Cyprus was controlled by a complex interplay of climate, tectonic events and related sea-level changes. Our research further demonstrates how sampling of pelagic sediment outcrops, such as those on Cyprus, can yield effective geochemical records.

Benthic foraminiferal assemblages from the Lower Cretaceous of the Neuquén Basin, Argentina: paleoecological and paleoenvironmental constraints

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The Agua de la Mula Member of the Agrio Formation (Neuquén Basin, Argentina) represents shallow marine environments and consists of high-frequency sedimentary sequences characterized by mixed siliciclastic-carbonate deposition. Five stratigraphic section encompassing the Agua de la Mula Member were analyzed across the Neuquén Basin, revealing differences between proximal and distal sectors. An integrated approach based on the benthic foraminiferal record (species composition, morphogroups, alpha diversity analysis, epifaunal/infaunal ratio) and multivariate statistical methods (cluster analysis, RDA, partial-RDA, PERMANOVA, PCoA), allowed to evaluate the paleosynecological and paleoenvironmental significance of the foraminiferal fossil associations (FFAs) identified. Relative sea-level changes influenced variations in sedimentation rate, oxygenation and food availability, and are here considered as main controlling factors in the distribution of benthic FFAs. A total of 7,709 specimens of benthic foraminifera were identified, distributed into 52 species in 31 genera, 15 families and 5 suborders. Calcareous tests dominate the foraminiferal assemblages with

hyaline forms being the most common throughout the Agua de la Mula Member and Suborder Lagenina the most abundant, while Robertinids dominate among aragonitic tests. Agglutinated benthic foraminifera represent 18% of the total fauna. Ten FFAs were defined based on benthic foraminiferal species composition. Samples were collected from poor lithified pelites of high-frequency (6th-order) sequences. Four associations (*Guttulina* sp., Polymorphinids, *Spiroplectammina* sp.2-*Haplophragmoides* sp.1, and *Planularia madagascariensis*) are mostly made of foraminifera with planispiral tests and lenticular, flattened and elongated morphotypes, related to shallow infaunal life habit and bacterial and detritivorous scavenger trophic strategies. The other six FFAs (*Epistomina hechti-Epistomina australis*, *Reinholdella hofkeri*, *Haplophragmoides* sp.1, *Patellina subcretacea-Trocholina infragranulata*, *Trochammina depressa*, and *Trochammina depressa-Reinholdella hofkeri*) are mainly represented by active herbivorous and detritivorous epifaunal foraminifera with opportunistic behavior, as suggested by high percentages of planoconvex, biconvex and conical tests forms. In order to assess the paleoenvironmental significance of the benthic FFAs, these paleosynecological entities were evaluated in relation to sampled geographic localities (i.e. latitude and longitude), ammonite biozones, sedimentary facies, and position into 3rd- and 4th-order depositional sequences. Shallow infaunal-dominated FFAs largely occur in coarser facies within 3rd-order regressive systems tracts, and they were considered indicative of well oxygenated conditions and food availability in sediments below the sediment-water interface, as well as associated with high sedimentation rates. Such conditions are well developed in the most proximal sections of the basin where shallow infaunal FFAs are common. Associations dominated by epifaunal foraminifera occur in fine-grained, dark shales within 3rd-order transgressive systems tracts, and were interpreted as related to oxygen and food stressed environments with organic matter likely confined at the seafloor due to long exposure favored by low sedimentary input within the more distal position. This paleoecological and paleoenvironmental study revealed that the high frequency sequences (6th-order) of the Agua de la Mula Member of the Neuquén Basin, as well as distribution of foraminiferal assemblages, were likely influenced by major relative sea-level changes. Such assessment can also be applied to other basins where comparable shallow marine conditions were developed.

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Exploring the distribution and diversity of modern planktonic foraminifers under multiple climatic stressors: FORCIS database

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The distribution and diversity of modern planktonic Foraminifera are affected by different environmental stressors such as the anthropogenically forced ocean and climate change. Up to now, historical changes in the distribution of planktonic foraminifer species have not yet been assessed at the global scale.

The FORCIS (FOraminifera Response to Climatic Stressors) project aims to collect information from published and unpublished data since 1910 to today regarding the planktonic foraminifer diversity and distribution from the global ocean and compile a comprehensive database. The FORCIS database is composed of more than 180,000 samples, including ~157,000 Continuous Plankton Recorder (CPR), ~16,500 net tow, and ~7,000 sediment trap samples.

Our database provides a first insight into the distribution patterns of planktonic foraminifers in the global ocean at different scales over the past decades. The relationships between the abundance of the modern planktonic Foraminifera species and the different size classes and water depth ranges have been assessed. It enables us to model the total abundance in the test size fraction larger than 100 µm. Historical changes in the distribution patterns indicate a poleward increase of foraminifer abundances during the past 30 years. In the low latitudes, spinose symbiont barren deep dwelling species showed a vertical and latitudinal migration toward higher latitudes due to the deepening of the thermocline. However, most of the spinose symbiont-bearing species presented a northward migration only. In the mid latitudes, herbivorous symbiont barren species migrated northward following the food availability. While omnivorous and carnivorous symbiont-bearing species migrated to greater water depth and to higher latitudes. Other species seem not affected by the changes in the environment and do not show any habitat changes such as *Pulleniatina obliquiloculata* and *Globigerinoides ruber ruber*. Second, a decrease of tropical and subtropical species occurred in the mid latitudes. A loss in equatorial species seems to be compensated by an increase in diversity in mid latitudes. Finally, an abundance decrease in almost all species was recorded over the past decade that could be related to several abiotic and biotic factors. The response of the planktonic Foraminifera to these factors is species-specific and leads to a redistribution of the planktonic Foraminifera ecological niche, and new assemblages have emerged. However, the poleward migration of species is a striking feature since the $\Omega_{calcite}$ in higher latitude is predicted to decrease to unsuitable values for Foraminifera to calcify.

Age constraints of Fusulinid Foraminifers and U-Pb Detrital Zircon from Conglomerates in the western margin of Indochina Block, Thailand: Evidence of Paleogeography and Indosinian Orogenies

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This research aims to reconstruct paleogeography, depositional environment and to define the provenance of conglomerates from the Huai Hin Lat Formation. This formation is generally represented the succession of Triassic conglomerates which have been widely exposed in the western margin of Indochina Block, Thailand. Unfortunately, the detailed studies on these conglomerates are not well examined. In order to achieve those goals, many attempts such as detailed field survey, paleontology and sedimentology analyses, clast-morphometric measurements, detrital zircon U-Pb dating, and tectonic concepts must be integrated. The exposures of conglomerate in this area form as undulating terrane, high and small hills. Conglomerates from two localities were collected: conglomerate area A and area B.

The succession of conglomerate area A is about 500 meters thick. Conglomerate area A is prominently clast-supported, polymictic conglomerate with reddish brown, very fine to coarse-grained sandstone as a matrix. Conglomerate area A's clasts are composed of mainly limestone, sandstone, chert and silicified rock, petrified wood and some volcanic rocks. Conglomerate area B is also represented by clast-supported, polymictic conglomerate and reddish brown, fine to coarse-grained sandstone as a matrix. Its clasts consist mainly of volcaniclastic rocks with few limestone, sandstone and mudstone clasts. Fusulinid limestone pebbles were collected for age and original depositional environment studies. Two and one samples of fine-grained sandstone in conglomerate's matrix from area A and B, respectively were collected for U-Pb detrital zircon age dating. Sedimentary structure such as bedding, lamination, cross bedding, channelling feature can be clearly observed. No fossils have been seen in the matrix. Based on fossil study from limestone conglomerates in areas A and B, they do not show the different in age. Limestone clasts from both areas contain fusulinids (*Profusulinella, Nankinella*, *Pseudofusulina Chalaroschwagerina, Presumatrina*, *Parafusulina*, *Yangchienia*), coral, bryozoan, crinoid, sponge, ostracod etc. showing various ages of Pennsylvanian to Middle Permian. The rock type of limestone clasts contains oolitic grainstone, peloidal packstone-grainstone, calcareous mudstone, wackestone and crinoidal packstone. However, detrital zircon separated from sandstone samples in area A shows 242-229 Ma (YSC), 243 Ma (YC) and 261 Ma (unmix age). The ones from sandstone sample in area B displays 211 Ma (YSC), 237 Ma (YC) and 216 Ma (unmix age). U-Pb detrital zircon age from sandstone sample in area B is younger than the ones from area A.

Based on the studies of fusulinid-limestone pebbles show that carbonate platforms existed during Middle Permian and were composed of several sub-environments such as intertidal, lagoon, reef and slope environments. Carbonate platforms started to uplift and erode at least or after Middle Permian time. These events have caused the major unconformity (or Indosinian I unconformity) which was represented by the presence of conglomerate area A derived from collapsed Permian carbonates. The detrital zircon age (242-229 Ma; YSC) from area A shows that the conglomerates were deposited during late Middle to early Late Triassic (Anisian to Carnian). This age is also implied to the time of Indosinian I characterized by the compression tectonic between South China and Indochina blocks. Moreover, the age of U-Pb detrital zircon from sandstone sample in area B; 211 Ma (YSC) is represented the depositional age of conglomerate area B around Late Triassic (Norian) and can be referred to the Indosinian II unconformity.

Lithium incorporation and isotopic fractionation in large benthic foraminifera under decoupled pH/DIC conditions

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The chemical weathering of continental silicate rocks removes CO_2 from the atmosphere and exerts a fundamental control on the Earth's climate over geological timescales. Characterizing silicate weathering in the past is therefore crucial for understanding the climate system. The lithium isotopic composition (δ^7Li) of carbonates is considered to be a reliable

archive of past seawater δ^7Li values, which are useful as a tracer of silicate weathering. However, the Li isotopic fractionation during biogenic carbonate formation is complex, and local conditions such as carbonate system parameters could impact δ^7Li values in marine calcifiers. For example, δ^7Li values have been shown to be dependent on either pH or DIC in two studies using large benthic foraminifera. Those results are enigmatic, since both studies used similar species of the genus *Amphistegina* but reported differing controls on δ^7Li values.

The aim of this study was to address the earlier contradictory results on the Li isotope behaviour in the hyaline species *Amphistegina lessonii*. We performed culture experiments under decoupled pH/DIC conditions, and analysed the δ^7Li values and Li/Ca ratios in the foraminifera tests. Two different light treatments (light/dark and dark) were also implemented to investigate the potential role of the symbionts.

Contrary to the two previous studies, no links between either pH or DIC and δ^7Li or Li/Ca values were observed for any of the treatments in our experiments. Additionally, growth rates also did not seem to influence the Li incorporation or isotopic fractionation. However, an effect of different light treatments was observed, probably due to different physiological processes of the symbionts occurring in dark conditions. Overall, these findings appear to support the use of Li isotopes in large benthic foraminifera to reconstruct past seawater chemistry and to infer changes in chemical weathering during carbon cycle perturbations over the last several hundred million years of Earth history.

Trophic interactions between foraminifera and diatoms in a French mudflat using a long monitoring period

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The ecological significance of mudflat meiofauna to the marine ecosystem functioning is increasingly recognized, particularly for abundant meiobenthic populations such as foraminifera. Due to their small size, high turnover rate, and specific ecological requirements, mudflat foraminifera may be used as bioindicators to detect both natural seasonal variations and anthropogenic pressures across the surface sediment record. Foraminifera have intricate trophic strategies and a broad range of mechanisms for adapting to carbon and nitrogen resources from primary producers such as diatoms. These complex trophic interactions play major roles in the food web, and biogeochemical cycles and thus may drive mudflat ecosystems and biodiversity. Previous experimental and metabarcoding studies have revealed that foraminifera (grazers) - diatom (preys) relationships have more specific interactions than previously thought. However, there is still no evidence that the dynamics of foraminiferal populations can be explained by the population dynamics of various diatom species due to the challenge of counting and identifying the species over a long monitoring period.

This study benefits from the MUDSURV program which, aimed to generate decadal time-series of sediment geochemistry, microphytobenthos, and foraminifera data, at a pilot site located south of the Loire estuary in the Bourgneuf Bay mudflat (French Atlantic Coast). Specifically, we observed seasonal patterns regarding the four main foraminiferal species living there: *Ammonia confertitesta* (T6) and *Haynesina germanica* which reproduced twice per year almost at the same periods in spring and autumn, whereas *Elphidium oceanense* was abundant in autumn and *Elphidium selseyense* was present only in late spring. Here, we investigated the seasonal dynamics of these foraminifera regarding the major diatoms species through a DistLM (Distance-based Linear Models) analysis over 27 months. The DistLM routine uses the best possible combination of predictor variables (i.e., the relative abundance of diatoms species) that could significantly explain variations in foraminifera abundances. This analysis highlighted trophic relationships between foraminifera and diatoms and showed that the presence of specific diatom combinations could serve as indicators of foraminifera abundance. We showed that *Ammonia confertitesta* preferentially feeds on six diatom species characterized by different sizes (large, medium, and small), elongated shapes, and two life forms (epipelic and epipsammic). *Haynesina germanica* showed a restrictive diet, feeding on four large elongated epipelic diatom species. *Elphidium oceanense* presented the most varied diet, preferentially feeding on nine diatom species of different sizes, simple and complex shapes, and three life forms (epipelic, epipsammic, and pelagic). No diatom species correlated with *Elphidium selseyense* temporal variability, perhaps due to its non-optimal habitat or non-diatom food preferences.

Our work suggests that the temporal dynamics of the most common foraminifera species in temperate mudflats can be explained by the seasonal variability of diatom species. Interestingly, we noted that some diatoms were preferentially preyed by only one foraminiferal species while others consumed by different foraminiferal species, which might suggest competition for food.

Addressing the segmentation challenge posed by 3D pore patterns and thickness of foraminiferal tests

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Over the past two centuries, coastal regions have experienced various anthropogenic environmental stressors such as ocean acidification, pollution, warming, and deoxygenation that have impacted benthic marine life. Understanding the severity and potential outcomes of such changes is crucial for supporting effective environmental management strategies. Benthic foraminifera, protists with calcite tests, have long been recognized as excellent recorders of past bottom-water conditions. Morphological parameters of the shell, such as thickness and pore patterns, are of great interest for environmental reconstruction. Shell thinning is a known consequence of ocean acidification, and pore patterns are increasingly used as a proxy for bottom water oxygenation. However, the relationship between these two parameters is not well defined due to challenges posed by species-specific traits, shell curvature, and limited access to test thickness or pore blockage.

Recent advances in morphological analysis of foraminiferal tests using microcomputed tomography (μCT) have led to significant progress in generating 3D reconstruction tests. The 3D approach enables a non-destructive study of the morphology, which is beneficial for further geochemical analyses or studying legacy museum collections. To draw statistically valid conclusions, it is necessary to scan as many tests as possible and work at sub-micrometer resolution for measurement accuracy. Synchrotron light-based approaches can be used to achieve these objectives. However, extracting the required parameters from 3D tests remains challenging due to the limitations of image processing and computational capacity; therefore, optimizing post-data analysis is crucial.

Previously, it was described a post-data routine for analyzing entire tests in 3D from *Elphidium clavatum* specimens that recorded environmental conditions in the Baltic Sea entrance from the early industrial (the 1800s) and present-day (the 2010s) conditions. The 3D time series of morphological parameters revealed that modern specimens have on average 28% thinner tests and 91% more pores than their historical counterparts. These morphological changes were interpreted as the result of gradual environmental changes in the Baltic Sea inlet that have intensified since the start of the industrial era, linked in particular to a decline in pH and an increase in the duration and severity of hypoxia in the region.

Here, we have extended the analyses to *Elphidium clavatum* specimens to explore changes in their pore patterns from a selected chamber. The challenge of achieving 3D pore patterns remains, particularly concerning cropping a chamber from an image stack and segmenting and reconstructing pores in 3D. We detail the following parameters: porosity (%), pore area (μm^2), crop area (μm^2), number of pores, pore density, maximum pore size, minimum pore size, standard deviation of pore sizes, and average pore size. Thus, the main interest is therefore to continue to gain efficiency in image processing and to rapidly generate large databases of 3D morphological parameters. To accelerate the adoption of this semi-automated approach, we developed a routine using open-source software in ImageJ and Matlab (student version). The perspectives of this work are multiple, as it would allow for a better understanding of how the morphology of the shell varies during ontogeny or culture experiments under controlled conditions.

The response of benthic foraminifera to disaerobic event – example of the Valanginian Weissert event based on the reference Vergol and La Charce sections, Vocontian Basin, Southeast France

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The Valanginian sequence of the Vocontian basin is revisited based on a foraminiferal study of material collected in the Vergol and La Charce sections. The Vergol Section consists in a good sedimentological record of the Valanginian Weissert event, whereas the outcrop of the La Charce locality is more favourable to observe the uppermost Valanginian succession. The Weissert Event is the earliest major perturbation of the global cycle of the Cretaceous System. The event occurred after a long period of relative quiescence and displays a significant positive $\delta^{13}C$ anomaly. The causes for the Valanginian carbon isotope excursion and associated paleoenvironmental changes are still a matter of debate. This research aims to analyse the structure and composition of the foraminiferal assemblages using the modern knowledge and methodological approaches about the ecological affinities of the selected taxa and their evolution across the different intervals of the Weissert Event. To

do so, the great sensibility of the microfauna to environmental changes, was used to enable the identification of variations of the sea-level, as well as nutrient and oxygen availabilities.

During most of the Early Valanginian, the negative $\delta^{13}C_{carb}$ excursion and the major sea-level lowstand was associated with the abundance of agglutinated, erected infaunal to semi-infaunal suspension feeders and detritivores. These forms are mainly found in poorly oxygenated deep-water environments, located beyond the shelf break. As suggested by the succession of deep-water assemblages, alternating with rich outer shelf – epibathyal and mesobathyal / infrabathyal forms, the late Early Valanginian to earliest Hauterivian was characterized by a major second-order lowstand during which multiple high-amplitude transgressions flooded the platform. Starting from the *N. platycostatus* subzone, *K. inostranzewi* zone, the basis of the Weissert event is represented by a negative excursion of $\delta^{13}C_{carb}$. following by evenly increasing values of $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$, reaching their maximum in the *S. verrucosum* Zone/Subzone. This period is associated with the abundance of poorly diversified infaunal morphogroups evolving detrivorous feeding strategies. It suggests high influx of organic matter on the sediment-water interface and associated disaerobic conditions. A bloom of *Lenticulina*, usually considered as an opportunistic taxon, was observed at the basis of the *S. verrucosum* zone, associated with higher fertility of marine waters. During the latest Valanginian, the $\delta^{13}C_{carb}$ excursion contains many returns to less positive values. Synchronously, the occurrence of agglutinated, elongated, infaunal detritivore (dorothiniids) together with diversified calcareous, elongated, infaunal active deposit feeders, herbivores, and bacterial scavengers, suggests sporadic increase in oxygen concentration (moderate dysoxic conditions), which favoured the recolonization of bottom waters.

The reason for fluctuations in the composition and diversity of foraminiferal assemblages are complex. Indeed, the Valanginian was a period of major climate changes. Enhanced atmospheric CO_2 and subsequent climate warming associated to the development of volcanic activity is assumed as a trigger for the Weissert event. During the Valanginian, an increase in continental weathering and run-off, probably due to humid conditions and low sea-level, may have been the consequence of higher marine productivity, enhanced level of organic matter and disaerobic conditions on the sea-floor. During the latest Valanginian, short-term ameliorations of bottom waters were concomitant with decreased pelagic carbonate production in a context of cooler marine temperatures, development of polar ice caps and subsequent sea-level fall.

Benthic foraminiferal bioevents through the Italian geological sheet N. 377 "Trasacco" (CARG Project)

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Geological mapping represents a valuable tool to understand the past settings and future evolution of the Earth system. Through the several activities involved for the final release of an official geological survey, biostratigraphy may have a pivotal role. This is true in particular when fossil-rich rock succession crops out into the studied area, and even more when shallow-water carbonate units have to be characterized and mapped in detail. The lithostratigraphy of the Mesozoic and Cenozoic units of carbonate platform is, usually, intimately related with the fossil content, benthic foraminifera among others, and to the relative stratigraphic extension for each taxon or assemblages. We present an example coming from the succession cropping out into the Apennines (Central Italy), included into the geological sheet n. 377 "Trasacco" (CARG Project), that has been characterized by applying a micropaleontological analysis based on benthic foraminifera and algae. Even not completely calibrated against the chronostratigraphic scale, the shallow-water zones here used help to define the relative position of taxa through time, supporting the characterization of the lithostratigraphic units and the recognition of stratigraphic gaps. The observation of foraminifera by hand lens has first permitted to establish some unit boundaries in the field, whereas refined biostratigraphy by using thin sections helped to solve problems at the mesoscale.

The shallow-water succession encompasses great part of the Jurassic and Cretaceous with 'Bahamian-type' facies, overlain by Lower Miocene succession made of heterozoan carbonates. This has helped to broadly resume the bioevents recorded through the platform, especially during the Mesozoic. Through the Lower Jurassic only oligotypic foraminiferal associations developed, constrained by the environmental conditions of supratidal and near-emersion settings. The Middle to Upper Jurassic succession records a recovery of larger foraminiferal species included into the family Pfenderinidae, among others. Through the Lower Cretaceous some larger agglutinated and porcelaneous foraminifera typify the benthic association, among representative of the genera *Akcaya*, *Mesorbitolina*, *Praechrysalidina*, *Cribellopsis* and *Archaeoalveolina*, associated with green algae and the bivalve *Chondrodonta*. The Cenomanian records high diversity with *Cisalveolina*, *Sellialveolina*, *Rotorbinella*, several soritids and nezzazatids, among others, which underwent mostly extinguished soon after at the Cenomanian-Turonian boundary (related to the Oceanic Anoxic Event 2). The following Upper Cretaceous succession records a post OAE2 diversification of several groups of larger benthic foraminifera such as the lamellar perforated rotaloideans whose evolution started by small representatives that likely survived to the Cenomanian-

Turonian boundary extinction. The Lower Miocene benthic coenosis was inhabited by the foraminiferal genera *Neorotalia*, *Elphidium*, *Cibicides*, *Ammonia*, *Heterostegina* and *Operculina*, most of them still thriving in Recent seas.

New insights on the benthic Foraminifera at the Cenomanian-Turonian boundary (OAE2) aftermath and the role of the genus *Rotorbinella* Bandy through the Late Cretaceous

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The Late Cretaceous was characterized by extremely high temperatures. The modeled CO_2 concentration in the atmosphere is among the highest of the entire Phanerozoic and it has been considered the main driver of such trend. The gradual warming started in the Albian and culminated during the Cretaceous Thermal Maximum (KTM) across the Late Cenomanian and early Turonian where sea-surface temperatures reached ≥30 °C in the tropics and ≥20 °C in the southern mid- to high latitudes. This has produced the flooding of large portions of continents and created shallow water environments suitable for the development of carbonate platforms and their associated benthic biota.

Data at our disposal on rotaloidean Foraminifera place their very first appearance in shallow-water platforms shortly before the KTM, in the early Cenomanian, or during the late Albian. They were represented by small r-strategist *Rotorbinella* and *Pararotalia*, thought later extinct at the Cenomanian-Turonian Oceanic Anoxic Event 2 (OAE2), along with all the Cenomanian larger foraminifera. The KTM was followed by a long-term gradual cooling which lasted until the Maastrichtian, where Tethys benthic foraminifera experienced a striking diversification. Rotaloideans evolved and diversified independently, following biprovincial and/or endemic patterns. The genus *Rotorbinella* is known in the Santonian-Campanian of the central-western Atlantic Tethys (Pyrenean gulf) and central Tethys (e.i. isolated platforms of the Apennines and Adriatic area) occurring along with other several rotaloideans. In the eastern Tethys (Arabian platforms) and westernmost Tethys (Caribbean) an apparently hybrid association with endemic species is recorded in the Santonian-Campanian timespan. Several species are also described from the uppermost Cretaceous of the Caribbean, southern Spain and the Arabian platform.

Such an outstanding richness of rotaloideans was poorly known, and several of these morphotypes have been systematically described in recent decades only. The high diversity roots on the possible survival of some small Cenomanian r-strategist across the OAE2 with capability to survive or stay in quiescence. It is thus of a key aspect to understand what was the evolutionary history of the group nearby the Cenomanian-Turonian boundary (OAE2) and how really this event impacted or boosted on its evolution. To do so we have sampled a Cenomanian-Turonian shallow-water succession cropping out in the Friuli region (Adriatic Carbonate Platform), and performed a detailed temperature trends with absolute estimations at a very high temporal resolution. Furthermore, we have also collected inedited data from the very poorly known "*Rotalia skourensis*" assemblage of the Coniacian-Santonian of Iran (Arabian platform).

Results show that i) in the Adriatic, *Rotorbinella* occurs in the late early Turonian, along with several Late Cretaceous 'newcomers', including the genus *Rotalispira*, once temperatures started dropping; ii) in the Arabian platform, *Rotorbinella* thrived along with a species closely related to the genus *Orbitokathina*, which represents a further Late Cretaceous 'newcomer'.

The pervasive occurrence of *Rotorbinella* in the Cenomanian, late early Turonian, as well as in the rest of Late Cretaceous represents a key aspect that highlight the fundamental role of such a basic morphotype as a pioneer for the recovery and diversification of benthic foraminifera after the most impactful global events, such as the Cenomanian-Turonian. A pattern comparable with that here observed is also displayed through the end-Cretaceous and Paleogene (K-Pg) times.

Planktonic foraminifera assemblage in the Bight Fracture Zone during the last glaciation

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Oceanographic changes in the North Atlantic Ocean during the Pleistocene have been well documented by many works. Nevertheless, past circulation across deep-ocean passages and their associated sedimentary processes are relatively few known. In this study, planktic foraminifera assemblages from a core retrieved at Bight Fracture Zone (BFZ) are presented to infer surface water dynamics during Marine Isotope Stages (MIS) 3 and 2.

The BFZ, which is a deep and narrow passage situated at the southmost of Reykjanes Ridge (57º 54.26' N; 32º 44.448' W), is connecting the Iceland basin with the Irminger and Labrador basins. The main water masses through this passage are the North Atlantic Central Water (NACW), Sub-Artic Water (SAW) and Sub-Artic Intermediate Water (SAIW) as surface waters, intermedial waters like the Labrador Sea Water (LSW) and the deep Iceland-Scotland Overflow Water (ISOW). The last constitute one of the most important branches of the North Atlantic Deep Water (NADW), which is formed in high latitudes of the Norwegian Sea. It is expected that dynamic interaction between these water masses is going to determine sedimentation processes at the bottom of this passage, as well as fluctuations of the Polar Front and marine ice coverage determine the composition of the planktonic foraminiferal community.

The core BFZ21-GC01 was obtained in the westernmost end of the BFZ (57º 7.06' N; 35º 16.354' W) onboard the B/O Sarmiento de Gamboa during the cruise BOCATS2-BFZ21 in 2021. Parametric echosounder records reveal the presence of channel-related contourite deposit and frequent slide or resedimented bodies.

The combined use of AMS 14C age model, the stable oxygen isotope record in *Neogloboquadrina pachyderma* (syn.), planktonic foraminiferal assemblage analysis, and sedimentary and tomographic facies identification allowed us to reconstruct surface water conditions and the paleo-circulation in the BFZ during Marine Isotope Stages (MIS) 3 and 2 and the deglaciation.

During the analyzed interval *Neogloboquadrina pachyderma* (syn.) is the dominant species, but it is represented by five sinistral coiling morphotypes, analogous to those previously described in other regions of the Northern North Atlantic. Other frequent individuals are the dextral coiling forms that many works have considered as *Neogloboquadrina incompta* (Cifelli, 1961).

The main results of this research indicate that during the relatively colder intervals, the assemblages were dominated (80-90%) by the polar specie *N. pachyderma*, with the subpolar *Turborotalita quinqueloba* secondary specie (10-15%), while the subpolar species *N. incompta* corresponded low to 5%. Furthermore, the spherical and compact morphotypes of *N. pachyderma* were predominant, suggesting the influence of nutrient laden Arctic waters. In contrast, during the relatively milder intervals, the assemblages show an increment of subpolar and transitional species *T. quinqueloba* (30%), *Globigerina bulloides* and *Globigerinita glutinata* (30-40%), as well as the increment of transitional and subtropical species *Globoconella inflata* and *Orbulina universa* (10 %), respectively. During these relatively warm intervals, the abundance of the elongated and lobulated morphotypes of *N. pachyderma* increases. This is interpreted as indicative of the influence of low-nutrient surface Atlantic waters.

Submarine sulphur springs in Northern Adriatic (Koper Bay) and benthic foraminiferal assemblages: extreme conditions or not?

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Northern Adriatic, a shallow-water basin (less than 50 m in deep), is considered a vulnerable area to climate or anthropogenic caused changes. The submarine sulphur springs offshore of Izola (Koper Bay) where samples were taken have been known since the 17th century for the healing characteristics of the warm water. In this study, we correlated the spatial distribution of benthic foraminifera in the Žumrove kotanje area, water depth between 25 and 32 m to the physicochemical properties of the surrounding water and the mineralogical, granulometric and geochemical properties of the sediments. The objective was to (1) determine the composition of the benthic foraminiferal assemblages as a function of distance from the springs, (2) compare the differences between the "living" (rose-bengal-stained foraminifera) and total assemblages and (3) interpret relation between sedimentological, geochemical, and paleontological data. Three categories of indices were considered: biodiversity (species richness, Shannon H', dominance), *Ammonia-Elphidium* (IAE), and sensitive-tolerant species occurrences (Foram-AMBI, EcoQs).

The studied revealed moderately diverse, species rich, and structurally monotonous benthic foraminiferal assemblages. With 61 benthic species, the species richness fits well with the distribution of a typical shallow-water benthic foraminiferal fauna in the eastern Adriatic and exceeds previous species counts for stressful environments. Representatives of the genera *Ammonia* and *Elphidium,* which are known to tolerate a broad range of salinity, temperature, oxygen concentration, and low

pH, dominated all assemblages. Six different species of *Ammonia* were recorded, with *A.* ex gr. *tepida* and *A. beccarii* represented in all assemblages, the euryhaline *A. parkinsoniana* only near the active spring, while *A. aberdoveyensis*, *A. falsobeccarii*, and *A. neobeccarii* contributed to specific assemblages. Epifauna to shallow-infaunal functional groups prevailed, whereas the infaunal forms are rare.

The IAE values reached 73.17% in total assemblages and 76.47% in biocenosis. Our results show higher diversity (in total assemblages, in assemblages with time average) or high diversity (in living assemblage) at sites with lower oxygen levels. A positive correlation was observed between IAE and EcoQs and Foram-AMBI indices. Slightly polluted (organic - rich) environments corresponding to hypoxic conditions are located near the sulphur spring.

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Preliminary study of proteins involved in the biocalcification of Rotaliid Foraminifera

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Biomineralization expresses the ability of organisms to construct and assemble inorganic material in an organized way. Foraminifera, as unicellular shell-producing microorganisms, perform this function with extreme efficiency. Biominerals are produced under strict biological control, so it is important to consider the role of the foraminiferal macromolecules in determining shell structure. In rotaliids, the biocalcification process begins with the eversion of the pseudopods from the opening of the last chamber. Precipitation of calcium carbonate starts from the primary organic sheet (POS) and occurs on both sides of the latter: meaning that part of the organic cytoplasmatic component remains incorporated into the shell.

Considering this, the current study hypothesizes the involvement of pseudopod plasma membrane proteins in the process of biocalcification. Indeed, the objective of this study is to identify the possible presence of a group of annexins in the shell organic matrices. Annexins are a family of membrane proteins generally involved in physiological mineralization in humans and membrane-cytoskeleton interactions, and they are present in other unicellular eukaryotic organisms as, for example, the freshwater foraminifer *Reticulomyxa filosa*. All annexins share a conserved C-terminal core domain made up of at least four similar repeats, each about 70 amino acids long. These subunits usually contain characteristic calcium binding sites. Starting from 400 specimens belonging to the genus *Ammonia* (*A. tepida* and *A. parkinsoniana*), a protocol for the extraction of membrane proteins was tested and replicated several times. Samples of membrane proteins extracted from the shell organic matrices were subjected to SDS-page electrophoresis. Finally, Western blot analysis was performed using different polyclonal antibodies directed against three human annexin types (Ab anti ANX-A6, Ab anti ANX-A5 and Ab anti ANX-A13).

The preliminary results revealed the presence of proteins similar to human Annexin A13 in the organic shell matrix of both foraminiferal species. In contrast, antibody assays conducted to test the presence of Annexins A5 and A6 did not produce positive results. The presence of Annexin-like proteins in foraminiferal calcitic shells represent a significative advance in determining the molecular processes involved in biomineralisation.

We may assume 1) the presence of membrane cytoplasmatic proteins in the shell organic matrices and 2) the engagement of Annexin-13 as calcium-binding protein in the site of calcification. These outputs will shed new lights on how foraminifera build their shells and will contribute to debate on complex processes involved in shell development and pseudopodial activities.

Foraminifera maintain consistent amino acid usage despite extreme codon usage bias in multiple non-monophyletic clades

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Codon usage varies widely across the eukaryotic tree of life, though the forces driving codon usage have primarily been investigated in model organisms for which complete genome sequence data are available. Prior to our work, members of the genus *Plasmodium* exhibited the most extreme compositional bias, where composition is largely driven by mutation bias generating an AT rich genome. Other organisms, such as *Saccharomyces cerevisiae*, have relatively unbiased overall genome composition, but show strong codon preferences in highly expressed genes. Here, we combine single-cell transcriptomics and phylogenomics to explore patterns of molecular evolution in uncultivable Foraminifera. We sample broadly from all major clades of Foraminifera, and after careful curation, generate a dataset of 1,044 gene families from 49 individuals representing 27 diverse genera. We find extreme codon bias among multiple non-monophyletic clades, with average GC-content at silent sites in some organisms well below 10%. Despite this extreme bias, amino acid usage remains highly constrained, showing little variation across all taxa. This contrasts to patterns in biased *Plasmodium* species, which are more likely to use amino acids whose codons are more AT-rich (e.g. the FYMINK amino acids) compared to their less biased relatives. Codon usage correlates with expression in a complex manner that may hint at underlying transcriptional and translational mechanisms. Together, our analyses demonstrate a remarkable consistency in amino acid usage among Foraminifera despite highly variable codon usage and lead to broad insights on the evolution of translational mechanics and the genetic code.

Shelf ecosystem response to the Eocene-Oligocene Transition

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The Eocene-Oligocene transition (EOT) is one of the most dramatic climate shifts of the Cenozoic with severe consequences for reef ecosystems. The onset of continental Antarctic glaciation is associated with widespread environmental change, resulting in a global peak in biotic turnover. Whilst numerous studies of the biotic response to the changes at the EOT have been carried out, most high-resolution studies consist of open ocean records of foraminifera and nannofossils. However, this is not representative of the ocean system as a whole. The shelf seas and reefs are some of the most diverse and fundamentally important ecosystems of the oceans. Long-term diversity loss across the EOT has been shown in several macrofossil studies, but mainly at low resolution, and recovery is not well understood. Larger benthic foraminiferal records provide a higher resolution insight to this event, both in terms of biodiversity, physiology and shallow water geochemical records. Additionally when integrated with records of other shelf organisms (e.g. molluscs, algae, bryozoa) this provides a powerful overview of whole ecosystem response. Many shelf species are ecosystem engineers whose loss and recovery have profound implications for the entire ecosystem. Understanding these interactions will provide insights into shallow marine ecosystems and their response to major climate perturbations.

The Tanzanian Drilling Project EOT record (TDP 11, 12, 17) is recognised globally for its completeness and exceptionally preserved calcareous microfossils. It is most importantly, though, a rare record of both shallow water organisms and open ocean plankton. Here we draw together a unique dataset of high-resolution larger benthic foraminifera, planktonic foraminifera, mollusc, Dasycladaceae, bryozoan, coral, shallow water trace element and isotope records from the EOT. The response and recovery of these species is compared with known, modern physiology of each group to provide a complete picture of the shallow marine ecosystem response. Following rapid extinctions in the larger foraminifera at the Eocene/Oligocene boundary, molluscs, Dasycladaceae and bryozoans all show increases in abundance, indicating a major shift in shelf ecosystem composition. These assemblage changes are coincident with a period of more positive values in $\delta^{13}C$ of planktonic foraminifera and changes in trace element values. Comparison with the open ocean record of planktonic foraminiferal, pteropod, and nannofossils confirm fossil increases are a biological, rather than sedimentological response and additionally support a transition to more eutrophic conditions during the transition. The interaction of these groups, within an environmental framework of traditional and novel geochemistry indicate that increased nutrient fluxes, rather than the temperature change directly, played a pivotal role in restructuring shelf ecosystem dynamics, and offer new insights into our understanding of the EOT.

Pre-Middle Eocene Climatic Optimum warming in the North Sea Basin

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The Middle Eocene Climatic Optimum (MECO) is a rapid global warming event that occurred ~40 Myr ago and lasted ~500 kyr. It induced major biotic and seasonal changes across high to low latitudes, the extent and nature of which have not yet been fully assessed, particularly with in shallower settings. The MECO is characterized by a significant negative anomaly in both $\delta^{13}C$ and $\delta^{18}O$ values of benthic and planktonic foraminifera, indicating up to 6°C warming in sea surface waters. Recently, a work on Ocean Drilling Project Site 647 in the Southern Labrador Sea recognised an additional, likely regional, pre-MECO warming event associated with an incursion of the planktonic foraminiferal genus *Hantkenina*. However, until now this has not been identified outside of this northerly region.

The Kysing-4 borehole is located in the eastern part of the North Sea Basin and provides a near continuous record of the Eocene to Oligocene sediments, including the MECO. The longer borehole record is tied to global stratigraphy by magneto-, calcareous nannoplankton, foraminiferal and marine palynomorph stratigraphy. Here we present preliminary high-resolution, integrated records of planktonic foraminiferal size and assemblage data, ostracode assemblage data, biostratigraphy, Tex86 and XRF analyses across the Middle Eocene. Tex86 records indicate a spike in temperatures of up to ~30°C in the lower part of magnetochron C18r, with corresponding changes in the XRF and foraminiferal datasets, followed by a second temperature increase within C18n. We interpret these as the pre-MECO warming, followed by the MECO itself. The earlier event correlates well with the timing of the *Hantkenina* incursion event and warming seen in the Labrador Sea. Though preliminary, this data suggests this pre-MECO event extends into the North Sea Basin and therefore may be less localized than previously thought.

Metabolome of foraminiferal species from Bourgneuf bay characterizated by GC-MS approach

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Foraminifera are present in all types of environments, though most foraminifera are marine benthic and are found from the deep ocean to the intertidal zone, exposed to various environmental stresses. They stand out for their rapid response to stresses and their resistance to extreme living conditions. However, little is currently known about their biology, and specifically their metabolism and physiology.

In order to better understand foraminiferal lifestyle strategy in a coastal mudflat environment, we studied the metabolome of kleptoplastic and non-kleptoplastic species from Bourgneuf bay. To this end, gas chromatography-mass spectrometry (GC-MS)-based experiments were set up. It is a method of separation of anlytes by gas chromatography and analysis by mass spectry allowing for both qualitative and quantitative analysis of polar and semi-polar low molecular weight organic compounds (amino acids, sugars…). The critical step in the protocol that required adjustment was optimization of the sample size. Indeed, on the one hand, it is necessary to work on enough cells so that the extracted metabolites reach a detectable concentration. On the other hand, foraminifera specimens collection from sediment samples is a very low process. Foraminifera are collected individually with the help of a brush under the binocular microscope which causes a drift in relation of metabolites within cells to the sampling time in the field. We carried out the experiment with samples at different sizes 600, 300 and 200 foraminiferal cells for each species, we have found that 200 individuals might be enough to observe most of the molecules detectable by this technique. We manage to create a foraminiferal library of more than one hundred mass spectra, which comprise identified and non-identified metabolites. We used it to investigate the difference in metabolite in three foraminiferal species selected for their abundance and differences in trophic lifestyles *Haynesina germanica* (kleptoplast photosynthetically active), *Elphidium oceanense* ("kleptoplast" without photosynthetic activity) and *Ammonia sp.* (morphogroup *tepida* mainly phylotype T6; non-kleptoplast). Our results revealed specific metabolic profiles for each foraminiferal species. These data suggest that a metabolomic approach using GC-MS analysis is an effective analytical method to differentiate biochemical compositions of different foraminiferal species. Thus, the experiment allows us to identify candidate molecules of interest for the study of the different trophic types. GC-MS provided us with the first's foraminifera metabolomes, highlighting metabolic specificities and showing the interest of this technique to study the different trophic life styles of these foraminifera.

Seasonal dynamics of respiration and photosynthesis of benthic kleptoplast foraminifera inhabiting an intertidal mudflat: what ecological roles?

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Foraminifera display varied trophic strategies, from opportunistic to highly specialized (selective herbivory with few diatom species), as well as complex life strategies including symbioses and mixotrophy. For instance, some foraminiferal species are known to retain in their cytoplasm chloroplasts from diatom preys, a phenomenon called kleptoplasty. However, the precise function of kleptoplasts in foraminiferal metabolism is still poorly understood. Photosynthetic activity has been demonstrated in some kleptoplastic foraminiferal species such as *Haynesina germanica* inhabiting photic zones. Here, we compare the metabolism of kleptoplastic and non-kleptoplastic species to better understand the mixotrophic lifestyle strategy and the advantages provided to foraminifera by kleptoplasty in a coastal mudflat environment.

This study is based on the MUDSURV project (Mudflat survey, OSUNA, LPG), initiated in 2016 and aimed to monitor over a decade the foraminiferal assemblages and sediment geochemistry of Bourgneuf Bay (French Atlantic Coast). We conducted a monthly monitoring of respiration and photosynthesis of kleptoplastic (*Elphidium oceanense*-phylotype S3-, *Elphidium selseyense* -phylotype S5-, and *Haynesina germanica*) and non-kleptoplastic foraminiferal species (*Ammonia sp.*, morphogroup *tepida* mainly phylotype T6). For this purpose, oxygen productions or consumptions were measured by oxygen microelectrodes in light and darkness conditions at field temperature. The results suggest that each foraminiferal species exhibited seasonal variation in respiration, with a significant correlation to temperature. Throughout the study period (september. 2020 to may 2022), the oxygen rates observed in light conditions for *Ammonia sp.*, *E. selseyense* and *E. oceanense* were very close to those observed in the dark indicating an absence of photosynthesis. Although *E. oceanense* and *E. selseyense* are known to have kleptoplasts, no photosynthetic activity was detected during our monitoring. Therefore, it is assumed that sequestered plastids are not necessarily photosynthetically functional. Conversely, *H. germanica* showed photosynthetic activity, with a greater variation in oxygen rate in light than in darkness until net photosynthesis was reached. However, the photosynthetic activity of *H. germanica* varied seasonally, with almost no activity observed in late summer/early autumn and early spring, while net oxygen production was observed in late autumn and early winter. In addition, we observed that *H. germanica* was more abundant when photosynthetically active, suggesting that active kleptoplastidy is benefitial probably when food competition is high. Our results suggest that 1) kleptoplasts are not necessarily used for acquiring photosynthetic function in the photic zone; 2) photosynthetically active kleptoplast species show a seasonal variation of their net photosynthesis; 3) the ability to use actively kleptoplasts is an advantage; 4) different foraminiferal species adopt different life strategies which may play different roles in the ecosystem. This study improves the understanding of foraminiferal ecology and highlights the importance of long-term monitoring in elucidating the complex interactions between species and their environment.

The genus *Turborotalita* in the Arctic Ocean: *quinqueloba, egelida* and *exumbilicata*

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Planktonic foraminifera assemblages in the modern Arctic Ocean north of 80 □N are composed almost exclusively of the polar species *Neogloboquadrina pachyderma*. Incursions of the subpolar genus *Turborotalita* at several horizons in multiple

Central Arctic Ocean (CAO) sediment cores are, therefore, anomalous and allude to significantly warmer-than-modern conditions during the past one million years. This finding is important palaeoclimatologically; however, unclear taxonomy is complicating progress with applications. Crucially, the stratigraphically 'upper' and 'lower' *Turborotalita* incursions to the CAO, which have been associated with Marine Isotope Stage (MIS) 5 and MIS 11 respectively, involve two different *Turborotalita* morphotypes: *T. quinqueloba* s.s in MIS 5 and '*T. egelida*' during MIS 11. There are two issues with this. First, clear taxonomic concepts and reference images needed to distinguish these morphospecies, both from each other and from a deceptively similar morphotype of *N. pachyderma*, are unsatisfactory or lacking, leading to misidentification and misinterpretation. Second, the taxonomic concept of *T. egelida* itself is problematic, leaving questions about its usage.

To address these problems, we conducted taxonomic, morphometric and wall texture analysis of extant and fossil Quaternary planktonic foraminifera belonging to the '*T. quinqueloba* plexus', from the northern North Atlantic, subarctic seas and CAO through the intervals of interest. We conclude that the stratigraphically upper turborotalitids from the CAO (morphotype-1) can be assigned to *T. quinqueloba* s.s., having a tightly coiled test and a tear drop-shaped final chamber, although the CAO forms are smaller than typical and lack gametogenetic thickening. Morphotype-2 (stratigraphically deeper horizon), is shown also to be spinose, thus supporting a *Turborotalita* affiliation; however, it deviates from *T. quinqueloba* s.s. in having more evolute coiling, an open umbilicus surrounded by relict apertural lips, and a more rounded final chamber that does not extend into the umbilical region. Morphotype-2 also commonly dominates assemblages across all size fractions, with only scarce *N. pachyderma*, unlike the younger *T. quinqueloba* s.s.-rich intervals in which *N. pachyderma* reaches 40-70 %. Furthermore, we show that a loosely coiled thin-walled morphotype of *N. pachyderma* that has 5 chambers in the final whorl, has previously been confused with *Turborotalita* morphotype-2. Differences in test shape and wall reflectiveness can help distinguish the latter using optical microscopy but the two are most clearly differentiated under SEM, which reveals the non-spinose wall of the thin-walled *N. pachyderma* morphotype.

We conclude that *Turborotalita* morphotype-2 is sufficiently different morphologically and stratigraphically from *T. quinqueloba* s.s to warrant taxonomic distinction. However, we expose confusion surrounding application of the currently used name '*egelida*', which was defined from the living plankton (thus sub-mature specimens) recovered in plankton net hauls. We argue that a more appropriate name for morphotype-2 is *'exumbilicata*', described from a core sample from Alpha Ridge, CAO in 1974. These taxonomic clarifications provide an improved framework for recognizing modern and fossil morphospecies of *Turborotalita* useful for Quaternary biostratigraphic and paleoceanographic reconstructions in the CAO. It remains unclear whether (i) *T. exumbilicata* exists within modern populations outside the CAO, (ii) what its true relationship is to *T. quinqueloba*, and (iii) if the '*T. exumbilicata* zone' is equivalent to MIS 11c or, if it is older. More broadly, this study emphasizes the need for publishing quality images to underpin all biostratigraphy, assemblage and palaeoclimate studies, which must be considered as primary data.

Late Cretaceous foraminifera from Eastern Lower Narmada Valley as part of the marine seaway through Central India

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The Late Cretaceous marine transgression resulted in a ~800 km long seaway through the ENE-WSW trending Narmada rift basin in India. The relics of this marine incursion are preserved in the highly fossiliferous Bagh Group of rocks (Turonian–Coniacian) in the lower Narmada valley. Most of the paleoenvironmental reconstructions of this marine incursion are based on macrofossils such as echinoids, gastropods, bivalves, brachiopods, and ammonites. The present study focuses on a quantitative analysis of benthic and planktic foraminifera of Bagh Group to infer marine paleoenvironmental conditions during Turonian-Coniacian in the Eastern part of Lower Narmada Valley.

Twelve isolated patchy outcrops were explored in the Bagh-Jeerabad area, Dhar district of Madya Pradesh, India. Four of studied outcrops (Soyla, Jeerabad, Rampura, and Avral) yield friable lithologies (Hence, easy to extract microfossils) and were investigated for foraminiferal assemblages. The typical marine carbonate succession of the studied sections consists of an older Nodular limestone Formation (NLF; mudstone-wackestone) overlain by the Bryozoan limestone Formation (BLF; packstone-planar laminated rudstone). The clay/marl horizons in the NFL yield benthic foraminifera including agglutinated-walled genera such as *Ammobaculites, Haplofragmoides*, *Ammodiscus, Lagenammina, Bathysiphon*), hyaline-walled genera such as *Gavelinella, Cibicides, Gyroidinoides, Dentalina, Nonionella, Praebulimina, Lenticulina, Planularia, Bolivina, Fursenkoina*, and porcelaneous-walled forms such as *Quinquiloculina* and *Spiroloculina*. The planktic assemblages consist of opportunistic shallow-water genera of *Planoheterohelix, Muricohedbergella,* and *Whiteinellia*. The lower part of NLF was likely deposited during Lower-Middle Turonian in a low-energy, upper intertidal-supratidal depositional environmental conditions in an epicontinental, semi-enclosed sea. The upper NLF was deposited during Late Turonian in a warm, low-energy, shallow subtidal (open-marine) condition. These inferences are consistent with the previously reported invertebrate fossil and sedimentological evidence. Other coeval records (e.g., Benue trough, Nigeria; Bight Basin. Australia; Bohemian

Cretaceous Basin, Central Europe; Turonian drill site, Tanzania) record variability in foraminiferal assemblages likely linked to paleoenvironmental changes regulated by eustasy, local tectonics and/or sediment supply.

Biodiversity of Larger Benthic Foraminifera (LBF) from the Bartonian succession of Capo Mortola promontory (Liguria, NW Italy)

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The present study focuses on the taxonomic description of the LBF from the Capo Mortola Calcarenite Formation cropping out along the Capo Mortola promontory in Liguria (NW Italy). The promontory is within a protected area and rock sampling is only permitted by concession of the local authorities that granted us access for this study.

We measured almost 50 meters of sedimentary log, from its basal contact with the Cretaceous limestone of the Trucco Formation, to the contact with the overlying Olivetta San Michele Silty Marl Formation, which crops out (poorly) at the top of the succession. From the entire section, we treated 48 samples to retrieve loose material from which we collected isolated LBF tests. We sectioned along the equatorial plane 175 nummulitids (i.e., *Assilina* and *Nummulites*) and 53 orthophragmines (as yet, only belonging to the genus *Discocyclina*).

The species retrieved throughout most of the section point to an early Bartonian age, specifically SBZ 17 according to the most recent biozonational scheme. The assemblages are dominated by relatively few taxa, such as *Nummulites perforatus*, *N. biarritzensis* and *N. brongniarti*, which are most abundant in the lower to middle part of the section. All the *Assilina* specimens belong to the *A. exponens*, they are more abundant in the middle to upper part of the succession, and lack in the uppermost part of the section. Their disappearance may correspond to the SBZ 17/SBZ 18 boundary.

Orthophragmines abound in the uppermost part of the succession and all of them belong to the genus *Discocyclina*; the following species and subspecies are most abundant: *D. pulcra baconica*, *D. dispansa sella*, *D. dispansa* ex. interc. *dispansa-sella*, *D. pratti pratti*, *D. augustae olianae* and *D. trabayensis elazigensis*. The orthophragminid assemblages point to a Bartonian age, specifically to the orthophragminid zones OZ 12, OZ 13, OZ 14 and to the shallow benthic zones SBZ 17 and SBZ 18a, according to the most recent biozonations.

Phylogeny of Late Neogene and Quaternary planktic foraminifera: a temperate Southwest Pacific perspective

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The Subtropical Frontal Zone (STFZ) in the Southwest Pacific has been an incubator for Late Neogene and Quaternary temperate planktic foraminiferal evolution. It is also a region where morphometric studies have been used to distinguish species on the basis of simple features, such as the number of chambers in the outer whorl, and the presence or absence of a peripheral keel. For example, morphometric studies in the 1980's demonstrate that populations of *Globoconella puncticulata* (unkeeled 4-chambered forms) evolved in the early Pliocene from late Miocene populations of *Gc. conomiozea* (keeled <4.5 chambered forms), via transitional populations of *Gc. sphericomiozea,* and in turn gave rise to late Pliocene populations of *Gc. inflata* (inflated <4 chambered forms). More recent studies have identified other keeled globoconellid species (*G. mons* and *Gc. pliozea*) and transitional early Pliocene globoconellid populations, but they do not support the taxonomic validity of *Gc. sphericomiozea,* because the ratio of keeled and unkeeled specimens shows "glacial–interglacial" scale variations and the number of keeled specimens does not always decrease. In this respect, the presence of transitional globoconellid populations is possibly an artefact caused by the mixing of unkeeled subantarctic and keeled subtropical populations within the STFZ.

Local biostratigraphic studies also support the presence of transitional globoconellid populations between *Gc. puncticulata* and *Gc. inflata,* but the identification of new unkeeled species, early Pliocene populations of *Gc. puncticuloides* (moderately compressed 4-chambered forms), *Gc. pseudospinosa* (subangular 4-chambered forms) and *Gc. triangula* (subangular <3.5 chambered forms), and late Pliocene populations of *Gc.* cf. *triangula* (inflated subangular <4.5 chambered forms) means the concept of a simple morphological transformation between these species needs to be reviewed. Based on the range of morphological variation amongst these globoconellids, and local biogeographic and biostratigraphic data, two

phylogenetic groups are recognized: 1) *Gc. inflata* group, that first appears in the Miocene and evolves within the STFZ (*Globoconella puncticuloides – Gc. puncticulata – Gc. inflata*); and 2) *Gc. triangula* group, that colonizes the STFZ in the early Pliocene and evolves in the Pliocene (*Globoconella pseudospinosa – Gc. triangula – Gc.* cf. *triangula*). Both groups include morphospecies with high-arched apertures and a partially pustulose surface ultrastructure – distinctive features that are diagnostic of the clade *Globoconella.*

The clade *Truncorotalia,* that is characterized by morphospecies with low slit-like apertures and a distinctive pustulose surface ultrastructure, is also a major contributor to Late Neogene and Quaternary planktic foraminiferal assemblages in the Southwest Pacific. Local biostratigraphic studies suggest unkeeled Pliocene populations of *Tr. crassaformis* (ventrally extended 4-chambered forms) evolved from late Miocene populations of *Tr. juanai* (biconvex 4-chambered forms), via transitional populations of *Tr. neojuanai,* and in turn gave rise to keeled Quaternary populations of *Tr. crassacarina* (ventrally extended 4-chambered forms). This group invades the STFZ at least three times in the late Miocene, before it colonizes the STFZ permanently and evolves. Another group of truncorotalids is also recognized that is comprised of Pliocene populations of *Tr. crassaconica* (weakly keeled ventroconical forms with 4-chambers in the outer whorl) and Quaternary populations of *Tr. truncatulinoides* (keeled ventroconical forms with >4.5 chambers in the outer whorl). The juxtaposition of these morphospecies contrasts with the North Atlantic, where biostratigraphic studies suggest keeled populations of *Tr. truncatulinoides* evolved from unkeeled populations of *Tr. tosaensis,* and it suggests the evolution of *Tr. truncatulinoides* is more complex than we thought.

Biostratigraphically constrained Quaternary chronologies from the Hikurangi margin of north-eastern Zealandia

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Highly resolved biostratigraphically constrained chronologies have been developed to help elucidate the complex stratigraphy of tectonically deformed Quaternary sediments from the Hikurangi subduction margin of north-eastern Zealandia. The biostratigraphic framework that underpins the dating is based on well documented and dated 0–1.2 Ma planktic foraminiferal records from ODP Site 181–1123 on the Chatham Rise, just north of the Subtropical Frontal Zone. Biostratigraphic subdivision is derived from the tops and bases of short-lived climatically tempered influxes of *Hirsutella hirsuta, Hr. praehisruta, Truncorotalia truncatulinoides, Tr. crassacarina, Globigerinoides ruber,* and *Neogloboquadrina pachyderma.* Most of these biostratigraphic markers are not unique, but sequences of markers that are unique to each marine isotope stage provide an unprecedented level of biostratigraphic detail and chronological dating when they are used within the contextual chronological framework of keystone biostratigraphic markers.

The detailed biostratigraphic framework has been used to date three sites on the mid to lower slope of the accretionary prism (IODP Site 372-U1517, 375-U1519, 375-U1518) and two sites east of the deformation front (Hikurangi Trough Site 375-U1520 and Tūranganui Seamount Site 375-U1526). The dating indicates sedimentation rates are very high and variable on the accretionary prism (0.2–9.6 m/kyr), especially during the Last Glacial Maximum (LGM) when downslope redeposition from the continental shelf and upper slope is very common. Sedimentation rates at Hikurangi Trough Site 375-U1520 are also variable (0.01–3.0 m/kyr) and they increase markedly as the incoming site approached the deformation front, especially during the LGM, in tandem with increased downslope redeposition from the inner to mid shelf. The incoming Quaternary section at Tūranganui Seamount Site 375-U1526, is characterised by low sedimentation rates (0.04–0.4 m/kyr) and the sequence is punctuated by hiatuses that shorten in duration as the site approached the deformation front. The shorter hiatuses are attributed to the site moving away from the core flow of the Deep Western Boundary Current and closer to the supply of clastic sediment from the hinterland.

New benthic foraminifera from the island of Brač (Croatia): further evidence for high foraminiferal diversity in Campanian inner platform settings

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The informal group of larger benthic foraminifera (LBF) generally exhibits a high potential for biostratigraphy, palaeoenvironmental interpretations, and palaeobiogeographic comparisons in Neotethys especially during the Cretaceous

greenhouse period. They comprise representatives from the three main high order ranks, lamellar-perforate rotaliids, porcelaneous miliolids, and agglutinated taxa.

The so-called Late Cretaceous Global Community Maturation Cycle (GCMC) encompasses the Turonian–Maastrichtian interval, and represents a special period of increasing diversity of LBF in shallow water settings. The LBF suffered seriously from the palaeoenvironmental disturbations associated with the Cenomanian–Turonian boundary event (OAE-2) leading to an almost complete extinction of the group. Among the few survivor taxa, not all can be considered as LBF due to comparably small size and simple test structure. Generally, Turonian shallow water carbonates are characterized by very poor assemblages of benthic foraminifera among nezzazatids, cuneolinids, dicyclinids and a few others. In the Coniacian–Santonian, the LBF of various groups already underwent a remarkable diversification in a wider area from Spain, southern France, Italy, Croatia, Greece to Turkey associated with widely distributed extensive platform carbonate evolution. From Campanian inner platform facies, numerous taxa of LBF have been reported especially from Spain, S-Italy, Greece and Croatia, here namely the island of Brač, a central Dalmatian island situated alongside the eastern Adriatic coast. From here five taxa (including four new genera) have been described from thin section material of these outcropping strata: *Neobalkhania bignoti*, *Fleuryana adriatica*, *Reticulinella fleuryi*, *Cretaciclavulina gusici*, and *Braciana jelaskai*.

Ongoing studies have revealed additional four new taxa (including one new genus) of LBF described from lower-middle Campanian inner-platform carbonates of the island of Brač, Croatia. Two of the new taxa are also reported from time-equivalent strata of the Gavrovo-Tripolitza Platform (SW Greece) providing further evidence for the pronounced Campanian diversification within the Late Cretaceous Global Community Maturation Cycle of larger benthic foraminifera in inner platform facies of the Mediterranean Adriatic Carbonate Platform.

The response of benthic foraminifera to environmental impact in the Sepetiba Bay (SE Brazil): metabarcoding and morphology-based analyses

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The Sepetiba Bay (SB, western region of Rio de Janeiro State, SE Brazil) is an estuarine system bordered by the Marambaia barrier island. In recent years, SB has been an area of intense economic exploitation in response to ore transport, industrial and port activities, and expansion of population growth. The intense anthropic activities have affected this ecosystem with the discharge of organic and inorganic pollutants and the alteration of the sediment substrate. In the present work, we analyze the response of benthic foraminifera to such environmental quality deterioration. For this purpose, 16 samples of bottom sediment collected from the inner and outer sectors of the SB were analyzed for foraminiferal diversity using the morphology-based approach and eDNA-based metabarcoding sequencing. Sediment samples were also characterized with grain-size and geochemical data (total organic carbon, elemental concentrations). The number of taxa inferred through metabarcoding (518 amplicon sequence variants - ASVs) is much higher than that identified through the standard morphological method (310 species). Monothalamous (soft-walled single-chambered) species largely dominate the eDNA dataset. Since no genetic database of foraminiferal species has been developed for the South Atlantic, only a minor

part of the ASVs has been assigned. The statistical results on living foraminifera assemblages based on the morphological dataset (principal component analysis and cluster analyses) show that the highest diversity of foraminifera tends to occur in areas less impacted by organic matter and metal pollution, namely Zn and Cd, the two main pollutant metals in the SB. Both analyses reveal that *Ammonia* species dominate the foraminiferal communities (i.e., morphological and molecular) in the most polluted areas. However, the eDNA analysis reveals that the most impacted areas contain large numbers of reads of monothalamous species, rarely reported in other coastal environments. Thus, this work reinforces the importance of using molecular analysis and morphological methods in environmental impact assessment studies.

Beneath the Ross Ice Shelf, Antarctica: A perspective of West Antarctic Ice Sheet History from Miocene Benthic Foraminifera

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In 1977-78 and 1978-79, the Ross Ice Shelf Project (RISP) recovered sediments from beneath the ice shelf at Site J9, 450 km from the calving front and open marine waters at ~82°S, 168°W. This is one of the most southern sites for marine sediment recovery in Antarctica. One important finding was discovering no benthic meiofauna, but an active pelagic macrofauna sustained below the ice shelf so far from open waters. The sediment has a thin, unconsolidated upper unit (up to 20-cm thick) and a lower unit (>1-m thick) containing reworked early and middle Miocene diatom and calcareous benthic foraminiferal assemblages. A post-LGM unconformity separates the upper unit (~7 kya–modern?) agglutinated foraminiferal assemblage, from the lower unit consisting mostly of reworked Miocene calcareous species, including *Trifarina fluens, Elphidium magellanicum, Globocassidulina subglobosa, Gyroidina* sp.*,* and *Nonionella* spp. The presence of *Neogloboquadrina pachyderma* and *Antarcticella antarctica* supports the late Miocene diatom age for the matrix of the lower unit. The microfossil assemblages indicate periods of ice sheet collapse and open water conditions south of site J9 during parts of the early, middle, and late Miocene.

The upper unit foraminiferal assemblage is unique to the Ross Sea and is found in two other areas of West Antarctica. *Cyclammina* is dominant in the proximal grounding line in the western Antarctic Peninsula (Bellinghausen Sea) that contains a low diverse assemblage of mostly agglutinated species and only occurs when the total foraminiferal counts are low. This potentially serves as an analogue to RISP. Low diversity and low foraminiferal abundance in the western Antarctic Peninsula and RISP indicate a stressed environment, which could potentially be related to the position of the grounding line and extent of the ice shelf. Under conditions where the grounding line is more distal from the edge of the ice shelf, low organic carbon availability would be expected where *Cyclammina* is one of the few taxa that could tolerate and survive such conditions. *Cyclammina* is also dominant along the continental slope of the eastern Ross Sea, directly north of RISP. Today *Cyclammina* is known as a deep bathyal to abyssal taxon. At the LGM, the seafloor was about 500 meters deeper at ~1000 m, and the ice sheet was grounded at the edge of the continental shelf. Following the LGM, *Cyclammina* likely followed the retreating grounding line to RISP before isostatic rebound. Alternatively, *Cyclammina* at Site J-9 may be associated with corrosive High Salinity Shelf Water derived from the western Ross Sea. An absence of live meiofauna in the surface sediment suggests that the agglutinated assemblage at RISP may be a relict post-LGM assemblage.

Re-evaluating Water Mass Influence on Late Cretaceous Deep-Sea Benthic Foraminifera

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The unique physical and chemical properties of water masses (e.g., NADW, AABW) were once thought to control the composition of foraminiferal assemblages found in the deep-sea. Over time, that idea was abandoned in favor of more localized parameters, such as the flux of food to the seafloor and dissolved oxygen content. We re-evaluated this concept by looking at a ~13-myr late Campanian – early Danian benthic foraminiferal assemblage record at Shatsky Rise in the northwest Pacific. Stable carbon and oxygen isotopes reveal at least 12 water mass changes that likely originated from the northwest Pacific, Southern Ocean, and perhaps the Indian Ocean (Tethys) and/or Caribbean.

Q-mode cluster analyses of the assemblages show 12 distinct and sharply defined groupings that are closely correlative with shifts in oxygen isotopes. Of note is the start of long-term cooling beginning in the latest Campanian (~74 Ma), with

major assemblage changes around the Campanian-Maastrichtian Biotic Event (CMBE, ~72 Ma) marked by a sharp increase in infaunal taxa (*Praebulimina, Aragonia*), followed by further cooling during the early Maastrichtian and an elevated abundance of inoceramid clams (71 Ma; Inoceramid Acme Event, IAE). The mid-Maastrichtian Event (MME; 70 Ma) was an abrupt warming that terminated the presence of inoceramids at Shatsky Rise followed by another rapid cooling event during the late Maastrichtian (68 Ma), culminating in a two-step warming during the end-Maastrichtian (~67 Ma). This is followed by a slight cooling at the K/Pg boundary and further warming in the early Danian.

One take away from this study is that specific taxa are not diagnostic of individual warming or cooling trends, although the changes in the cluster packages are highly indicative of changes in water mass. Many of the clusters are defined by abrupt shifts in taxa abundance, including the decline of *P. elevata, O. umbonatus*, and *G. pyramidata* at the MME, and the emergence of *Tritaxia*, sharp increases in *G. becariiformis*, and *Reussella*, followed by *P. hillebrandti* and *Adercotryma.* Assemblage changes were subtle, but associated with both cooling and warming events, likely driven by water mass buoyancy flux changes and vertical migrations of intermediate and deep water masses over Shatsky Rise, as well as changes in sources of deep/intermediate water masses during the study interval.

Foraminiferal shell preservation under mudflats colonised by electrical cable bacteria

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Cable bacteria activity (CBA) redesigns diagenetic processes generating strong pH gradients within the first few centimetres of sediment. Since their discovery ten years ago, their environmental distribution has been documented from freshwaters to coastal and seabed environments. The impact of sediment acidification induced by this bacterial activity on living benthic foraminifera and the preservation of their tests were investigated in intertidal mudflats. In September 2020, sediment cores were collected from three stations on the macrotidal estuary of the Auray river (Atlantic coast, France). Contrasted CBA were observed by oxygen and pH microprofiling with values ranging from 6.8 to 5.8. Cable bacteria density was assessed by q-PCR analyses that showed CB densities from 7 to 75 $m.cm^{-3}$. According to a dissolution scale based on SEM observations of *Ammonia* spp. and *Haynesina germanica*, sediment acidification below the oxic zone led to dissolution of the shells of living calcareous foraminifera, ranging from slight test alterations to complete exposure of the inner organic lining. Therefore, foraminiferal test dissolution can be used as a CBA indicator. Samples from other estuarine intertidal mudflats of French Atlantic coast have also shown test dissolution features, suggesting the active CB occurrence. Similarly, re-investigation of 1995-96 samples in the Auray estuary did not show foraminiferal test dissolution, suggesting recent colonisation of these mudflats by CB. Furthermore, in mudflats inhabited by CB, dead foraminiferal assemblages revealed a strong calcareous-test loss with an organic lining accumulation throughout depth. CBA past episodes may be tracked by examining the foraminiferal preservation state, possibly back to their first occurrence in the environment. Ecological monitoring and archival studies using foraminifera as bioindicators and paleoproxies should take account of CBA by considering these changes in both living and dead foraminiferal assemblages.

Potential for conventional trace elements in *Globorotaloides hexagonus* as proxies for the pelagic Oxygen Minimum Zone

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Conditions within the low-oxygen, low-pH regions known as Oxygen Minimum Zones (OMZ) play a key role in global climate and marine nutrient cycles. However, a scarcity of proxies for the pelagic OMZ frequently limits our understanding of how OMZ environments have changed in the past. Here we present multiple trace element to calcium ratios from the shells of the foraminifer *Globorotaloides hexagonus*, recovered live from discrete depth (MOCNESS) tows through the

upper oxycline and OMZ in the Eastern Tropical North Pacific (21°N, 118°W). Laser ablation ICP-MS was used to obtain individual foraminifera mean values of Mg/Ca, Sr/Ca, Mn/Ca, and Zn/Ca. We discuss temperature, oxygenation, and carbonate chemistry as potential drivers of geochemical variability. Low oxygen correlates with low Sr/Ca, high Mn/Ca, and high Zn/Ca. We hypothesize that the trends in Mn/Ca and Zn/Ca result from decreasing oxygen and pH deeper within the OMZ. A strong correlation with Sr/Ca is likely mediated by shell growth rate in response to low oxygen. Results suggest that all three elements, especially Sr/Ca, have potential for reconstructing the intensity of paleo-OMZs. Some applications of these potential proxies are complicated by diagenesis, and we present *G. hexagonus* trace element data from the deglacial Eastern Equatorial Pacific (TR163-33; 0°24.6' N, 92°9.6' W; 2,730 m depth) that exemplifies this problem. However, Sr/Ca is less susceptible to post-depositional alteration and Sr/Ca records from *G. hexagonus* at TR163-23 would indicate an intensification of the pelagic OMZ over the last deglaciation.

The influence of submarine canyons processes in the benthic foraminifera distribution on the Espírito Santo Basin, SW Atlantic

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Submarine canyons are features with a more complex topography than the adjacent slope, which may result in differences in the composition of the benthic assemblages. In order to understand how trophic, hydrological and sedimentological conditions in submarine canyons can influence the distribution of benthic foraminifera, and to use this information to corroborate paleoenvironmental interpretations for the Holocene, we investigated recent benthic foraminiferal assemblages (total fauna > 63 μm) and sedimentological data in two canyons (CANWN and CAND) in the Espírito Santo Basin (ESB) between 18°20' and 21°20' S. Eighteen surface sediment (0-2 cm) samples were collected inside the canyons (150 to 1300 m water depth) and in shelf-slope adjacent transects (50 to 1300 m water depth) during an oceanographic cruise in 2013. After sample collection, the sediment was not stained which only allowed a total benthic foraminiferal census. The assemblage composition of benthic foraminifera varies according to depth and location. The Q-mode cluster analysis allowed us to recognize five major groups (I, II, III, IV, and V) that represent five benthic foraminiferal assemblages, which reflect a depth gradient and a heterogenous bottom morphology at the ESB. Three groups (V, III, and I) are present in different bathymetric sectors; Group V: outer shelf (50 m), Group III: upper, and middle – lower slope (150 to 400 m), and Group I: middle – lower slope (1000 to 1300 m). Groups II and IV show no characteristic bathymetric distribution and are present only in CAND and in CANWN, respectively. Group V consists of species that are almost limited to the outer shelf, such as *Hanzawaia boueana*, *Peneroplis planatus*, and *Quinqueloculina lamarckiana*. In Group III *Globocassidulina rossensis* is dominant, and *Trifarina* spp. is more abundant. The species that contribute most to Group I are *Globocassidulina crassa*, *Bolivina lowmani*, *Gavelinopsis versiformis*, *Alabaminella weddellensis*, and *Epistominella exigua*. The main species related to Group II are *Trifarina angulosa*, *Globocassidulina subglobosa*, and *Discorbis vilardeboanus*. Group IV (middle – lower CANWN, 1000 to 1300 m) consists mainly of agglutinated species *Glomospira charoides*, *Rhabdammina abyssorum*, and *Psammosphaera fusca*. Our data suggest that the quantity (and quality) of food supply, hydrodynamic conditions, and sediment properties are the main drivers controlling the bathymetric distribution of benthic foraminiferal assemblages in both canyons. The CANWN and CAND host distinct benthic foraminiferal assemblages, especially from 1000 to 1300 m water depth, confirming that submarine canyons-related processes induce different ecological niches on the slope. The middle – lower CANNW revealed unstable trophic conditions, related to terrigenous sediment input due to turbidity currents. The increased abundance of opportunistic, shallow infaunal benthic foraminiferal species in CAND indicates that this submarine canyon trapped enough organic matter that favors species establishment and diversity, indicating a more productive and less unstable environment than in CANWN.

Factors controlling the benthic foraminiferal distribution on the Espírito Santo Basin slope, SW Atlantic

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In order to understand the main environmental factors driving the benthic foraminiferal distribution along continental slopes, and corroborate paleoenvironmental interpretations in the Holocene, we investigated recent benthic foraminiferal assemblages (total fauna >63 μm) and sedimentological data along six transects on the continental slope of the Espirito Santo Basin (ESB) between 18°20′ and 21°20′ S. The ESB is an important region for the oil and fishing industries. The ESB shelf-slope system is known due to a significant variation in the continental shelf width, changes in sedimentation regimes, variation of the shelf-break orientation, and the presence of complex morphological structures on the slope, built in response to relative sea-level fluctuations over geological time. Surface sediment samples (0–2 cm) were collected perpendicularly to the coast, from the upper (400 m) to the lower slope (3000 m) using a box-corer. The density, taxonomic diversity and assemblage composition change with depth and location. The genus *Globocassidulina* dominates the upper and lower slope, whereas *Bolivina* is the most abundant taxon in the deepest lower slope. The Q-mode cluster analysis allowed us to recognize five major groups, which reflect the distinct ecological preferences of the most abundant taxa. These groups are distributed in three main bathymetric sectors: upper, middle – lower, and lower slope. Group I (upper slope, 400 m) is characterized by the highest mean relative abundances of *Globocassidulina rossensis, Trifarina* spp. and *Trifarina angulosa*. Group II (middle – lower slope, 1000 to 1300 m) shows the highest mean relative abundances of *Globocassidulina subglobosa, Bolivina albatrossi, Bulimina aculeata* and *Uvigerina peregrina*. Group III (middle – lower slope, 1000 to 1300 m) is characterized by the highest mean relative abundances of *Globocassidulina crassa, Gavelinopsis versiformis, Epistominella exigua* and the unilocular group. Group IV (lower slope, 1900 m) shows the highest mean relative abundances of *Alabaminella weddellensis, Bolivina inflata* and *E. exigua*. Group V (lower slope, 2500 to 3000 m) is dominated by the genus *Bolivina* (*B. lowmani, B. pseudoplicata* and *Bolivina* spp). The most abundant taxa along the ESB slope are ecologically associated with the organic matter flux, bottom water oxygen concentration, and hydrodynamics conditions. Our data suggest that the quantity (and quality) of food supply is the primary factor controlling the distribution of recent benthic foraminiferal assemblages, which varies with depth. Group I (400 m) indicates that the organic flux is higher on the upper slope than on the middle and lower slope. The abundance of opportunistic benthic foraminiferal species of Groups II, III, IV and V (1000–3000 m), which feed on phytodetritus pulses, confirms the influence of the quasi-stationary Vitoria Eddy, as well as the seasonality of primary productivity in the ESB. Secondary factors include the physical-chemical properties of water masses (especially AAIW and NADW), and intermediate and deep boundary currents (IWBC and DWBC). The increased fragmentation of benthic and planktic foraminifera tests (>125 μm) on the upper and middle – lower slope is related to abrasion during transport from shallower regions to the slope. The distribution of recent benthic foraminifera assemblages found in this study reflects a more integrated picture of the population dynamics and the prevailing environmental conditions in the EBS during the Late Holocene (Biozone Z).

Benthic Foraminiferal Response to the BP Deepwater Horizon Oil Spill in the Northeastern Gulf of Mexico

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The largest known marine oil spill, in 2010, was the BP Deepwater Horizon Oil Spill at the Macondo well in the northeastern Gulf of Mexico. From April until July 2010, approximately 206 million gallons of unrefined oil were discharged at a depth of 1,544 m. Shortly after the initial blowout, both physical and chemical agents were applied to remediate and mitigate potential environmental and human health impacts. As a result of the combined effects of the spill, response efforts, and natural biological and physical processes, marine snow formed, and pulses of sediment led to the transport of weathered Macondo oil and other contaminants to the seafloor across the northern Gulf of Mexico. At the end of 2010, cores were collected in the vicinity of the Macondo wellhead for geochemical and benthic foraminiferal analysis.

In this study we analyze foraminifera from sediment core WB-1110-DSH10-ISO collected in the DeSoto Canyon, about 55 km northeast the Macondo well head. Previous geochemical studies of the core provide insight on the benthic environment at the time, including the accumulation of hydrocarbons and pulses of sediment associated with the Deepwater Horizon Spill. Benthic foraminiferal diversity and changes throughout the core were analyzed to investigate a response to the presence of the material transported to the seafloor during and immediately after the spill. Findings reveal a significant faunal shift in the presence of dark particulate matter in the top portion of the core. Notably, diversity increased with an increase in concentration of this material. Also, agglutinated foraminifera and tubular agglutinated foraminifera were more abundant in the layers in which dark particulate matter concentrations increased. Multivariate statistical analyses and assemblage turnover calculations show a distinct shift in faunal assemblages before and after the presence of the weathered dark sediments in the top portion. Ultimately, this study compares the observed pattern of foraminiferal changes associated with the BP Deepwater Horizon Oil Spill and the occurrence of the oiled sediments and marine snow to assess the potential of benthic foraminifera as indicators of oil spills.

Principles and applications of automated recognition and picking of microfossils using the Microfossil Sorter (MiSo) automaton

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Together with the development of genetics, high-throughput imaging is emerging as a powerful technique to explore the biodiversity, and within each species, explore morphological traits at a massive scale. Yet, high-throughput foraminifera imaging systems have been lagging compared to other biomineralizing organisms imaging systems, for several reasons such as the complex sedimentary matrix, their diverse types, their fragility, and their 3-dimensional complex structure. A pioneering system at the Scripps Institute of Oceanography was devised in the late 1970s to automate their imaging (System of Automated Micropaleontology), though it was never fully operational.

In this presentation, we will present the state-of-the-art microfossil picking machine developed at CEREGE, together with ATG-Technologies, named Microfossil Sorter (MiSo). This automaton handles sedimentary coarse fractions, singles out sedimentary particles including foraminifera (benthic and planktonic), images them through a motorized-Z camera stage, identifies them using Convolutional Neural Network (CNN) techniques, and depending on its classification sort them into different microtubes or vials for subsequent geochemical analyses. Typically, this automaton processes close to 10k particles per day, and its processing principle has been recently patented.

The identification of microparticles, based on z-stack images is based on a CNN classifier, and has been recently improved by the inclusion of image features, to improve both the accuracy and recall of the classification. We will show the most recent progresses of our Particle-Trieur software, which integrates the current workflow, from segmentation to annotation, classification to biometrical analyses, and discuss the limitations of current approaches.

Last, we will present and discuss a set of core-top and downcore applications for which this machine, and a cheaper exploratory system, have shown its usefulness, from foraminiferal sorting for isotopic analyses (see Y. Lichterfeld abstract); Nd geochemical analyses; foraminiferal imaging for trait-based analysis of planktonic foraminifera; benthic foraminifera identification in both recent sediments from coastal settings, but also in older Paleogene time intervals.

Pleistocene planktonic and benthic foraminifera assemblages from Fantangisña seamount in the NW Pacific Ocean (IODP Expedition 366)

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The Izu-Bonin-Mariana (IBM) trench-arc system, in the northwestern Pacific Ocean (12° N to 35° N) is, to date, the only known setting where active serpentinite mud volcanism takes place. The southern sector of the IBM (the Mariana forearc) comprises a large number of serpentinite mud volcanoes, situated between the trench and the Mariana volcanic arc. Among them, Fantangisña seamount was drilled during International Ocean Discovery Program (IODP) Expedition 366. Lithologies comprise serpentinite mud deposits with ultramafic clasts from the subducting Pacific Plate, forearc crust and mantle, blanketed by pelagic sediments containing few ultramafic clasts. Additionally, the base of the seamount includes nannofossil-bearing silty to sandy volcanic ash deposits.

Fantangisña seamount is situated at low latitudes (16° N) in the tropical Pacific sector, under the influence of the North Equatorial Current (NEC). The NEC is a warm, oligotrophic, wind-drifted current, which moves westward in the tropical Pacific Ocean.

In this study, we analysed benthic and planktonic foraminifera assemblages at Site U1498A, cored on the southern, more stable side of Fantangisña seamount edifice. The investigated interval mainly spans the Early to Late Pleistocene, as defined by our previous biostratigraphic analysis on this site.

Cluster analyses performed on planktonic foraminifera provided significant insights on the water column dynamics during the Pleistocene. Specifically, two major sample clusters were identified based on the ratio between thermocline-dwelling species (e.g., *Globorotalia* spp.) and mixed-layer dwellers (e.g., *G. ruber*, *G. rubescens*, *G. glutinata*, *Trilobatus* spp.), inferring variations in the depth of the thermocline. We considered these fluctuations of the thermocline as related to variations in the NEC intensity. Precisely, our results showed that during the Early-Middle Pleistocene Transition (EMPT), the intensity of the NEC increases, favouring the presence of a deep thermocline. In contrast, planktonic foraminifera assemblages recorded a weaker thermocline following the EMPT, which in turn can be related to a reduction in the strength of the NEC. We suggested that the strengthening/weakening of the NEC could be linked to ENSO climate phases (El Niño/La Niña).

Additionally, planktonic foraminifera diversity indices suggested that the serpentinite mud activity in the region does not affect the ecological distribution of the planktonic taxa. Interestingly, our data indicate that the production of serpentinite mud flows could enhance the preservation of the planktonic tests, allowing a fast burial after deposition.

Benthic foraminifera showed high diversity pre- and post-serpentinite mud volcanism and indicate oligotrophic and well oxygenated bottom-water conditions. Conversely, benthic forms are extremely rare within the serpentinite mud deposits as they severely suffered from the mud flows activity and gas outpouring.

Does the elemental composition of foraminiferal shells reflect their evolutionary history?

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Ongoing ocean acidification affects marine calcification, although the scope and magnitude of this impact is essentially unknown. Here, we investigate the evolutionary origin of shell building in foraminifera to understand the long-term interplay between ocean carbon chemistry and calcification. Our analysis of shell chemical composition reveals multiple, independent origins for foraminiferal calcification throughout the Phanerozoic. With the long timespan involved, variability in seawater chemistry provided contrasting environments for calcification to arise, resulting in the diverse calcification strategies that exist today. This, in turn, explains the opposite responses of shell building to carbon perturbations. Our results call for adopting an evolutionary perspective when predicting the impact of perturbations on marine calcification and thereby, on the global carbon cycle.

Holocene sea ice dynamics and paleoenvironments on the southwest Svalbard shelf reconstructed using a multiproxy approach

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Although the general patterns of Atlantic Water (AW) inflow into the Arctic during the Holocene are well known, the development of ocean currents and induced environmental changes following the previous deglaciation are still not fully understood. We present a multiproxy record from core OCE2019-HR7-GC from the southwestern Svalbard inner shelf, a highly dynamic frontal area influenced by various ocean currents and local water masses, in order to better understand past water mass dynamics and their effects on sea ice cover and the environment throughout the Holocene. We focus on the foraminifera assemblages along with sea ice (IP_{25}) and phytoplankton biomarkers, Alkenones, and Mg/Ca for reconstruct

surface and bottom water conditions, and the dominant water masses. We observe extensive sea ice cover before 10.2 kyr BP, which was likely linked to the Preboreal Oscillation. Based on our reconstructions, the period between 10 and 7 kyr BP was characterized by the warmest Holocene conditions on the SW Svalbard shelf. This interval is associated with high surface water productivity and an increased AW influx that drove strong erosive activity at the bottom. After 6.5 kyr BP, the SW Svalbard shelf was characterized by a dynamic environment with cold and unstable conditions that lasted until 3.5 kyr BP. After 3.5 kyr BP, we observe an increase in sea ice cover and iceberg rafting over our site, which likely indicates seasonally fluctuating ice margins, with low AW influx, which lasted until 2.2 kyr BP. A brief warm period accompanied by strong bottom currents occurred between 2.2 and 1.8 kyr BP, which may correspond to the Roman Warm Period. The environment returned to a colder state with the presence of sea ice until 1.5 kyr BP, which was followed by warmer conditions between 1.5 and 1 kyr BP, an interval that corresponds to the Medieval Warm Period.

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Foraminifera and tecamoebians from Oiapoque River Estuary, Brazil-French Guiana

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Tropical estuaries are important ecosystems that serve not only as critical habitats for a wide range of aquatic species (including fish, crustaceans, and molluscs), but also as breeding and nursery grounds for many commercially species. In addition, they provide a range of ecosystem services (e.g., nutrient cycling, sediment trapping, water purification, and others) and their mangrove vegetation plays a significant role in carbon sequestration and storage, which can help mitigate the impacts of climate changes. However, it is known that tropical regions have been highly impacted by climate change, mainly due to changes in precipitation, which reinforces the importance of studies to understand and monitoring these ecosystems. In this context, the foraminifera assemblages can play a great role in the environmental diagnosis and recognition of short-term changes in tropical ecosystems. Nevertheless, knowledge about the ecology of foraminifera in the Amazon Coast is scarce, which demands studies in this region. Thus, this work aimed to evaluate the living benthic foraminifera distribution during two distinct seasons through a combined approach using physical-chemical parameters and granulometric analysis along the Oiapoque River Estuary (2º - 4º N and 51º - 52º W). This estuary is located in a binational basin with ~32,000 km², being ~17,000 km² in French territory and ~15,000 km² belonging to Brazil with a long history of mercury pollution resulting from gold extraction. In the lower Oiapoque River is located the Cabo Orange National Park that is one of the oldest Brazilian conservation units for the integral protection of nature which present a rich biodiversity and several indigenous communities.

As a result, 22 foraminifera species (dominance of *Ammobaculites dilatatus, Miliammina fusca*, and *Ammotium morenoi*) and 07 thecamoebians species (dominance of *Difflugia globularis* and *Diffuglia oblonga*) were identified. In the wet season (December-May), the foraminifera assemblage showed a very restricted distribution, which includes only the estuary mouth. The analysis of physical-chemical and sedimentological parameters measured in both seasons pointed to significant changes in the lower estuary. The dry period (September-November) is characterized by low rainfall rates and a higher influx of oceanic waters (up to 21‰ salinity) into the estuary. By contrast, in the wet period, the oceanic water influx is extremely reduced due to the higher rainfall rates (300-400 mm/month, with some areas showing rates up to 500 mm/month) that promote an increase in the fresh waters contribution from Amazonian rivers, thus resulting in a salinity decreasing (2‰ salinity) and increase of suspended sediment in the environment. In both analyzed seasons, the occurrence of living calcareous foraminifera (*Elphidium excavatum* and *Ammonia tepida*) were restrict to the river mouth at the French Guiana margin that is recovered by red mangrove. The anthropic impact was identified by the high percentages of total organic carbon and sulfur that has a depocenter near Saint Georges l'Oyapock City.

The Detrended Correspondence Analysis showed that most foraminifera species had their distribution correlated to salinity, total dissolved solids, and dissolved oxygen corresponding to lower estuary region. On the other hand, thecamebians had their distribution correlated to less turbulent areas, with silty sedimentation and colder waters corresponding to the innermost region of the estuary. The results allowed distinguishing microenvironments inside the Oiapoque estuary with a strong interannual variation that must be considered for future management and monitoring plans. The foraminifera were important for recognizing the regions under coastal water influence in Oiapoque River and these methodologies can be applied to other Amazon estuaries. However, more studies must be carried out to understand the seasonal patterns in Oipaoque Estuary, especially in the mouth region.

The foraminiferal response to methane emissions in shallow water environments from the Scoglio d'Africa (Tuscan Archipelago, Northern Tyrrhenian Sea)

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In this research benthic foraminiferal response to shallow water methane (CH_4) emissions located in the area around Scoglio d'Africa (Tuscan Archipelago, Northern Tyrrhenian Sea) was investigated. Methane (CH_4) is an important greenhouse gas, with a global warming potential about 20 times as large as carbon dioxide (CO_2) on a 100-year horizon. In the marine environment, coastal areas represent methane hotspots highly exceeding emissions from the open ocean. In this view, Scoglio d'Africa may represent a much-promising study site for multidisciplinary marine research (carbon capture and storage, geochemistry of hydrothermal fluids and ocean acidification vs. benthic and pelagic organisms). The study area is located in the southernmost part of the Elba-Pianosa Ridge, a mainly submarine, north-south elongated morpho-structural high separating the Tuscany Shelf to the east from the Corsica Basin to the west. In the study area, submarine methane emissions have been studied since the 1960s and they are linked to the combined action of two processes: biogenic (microbial process called methanogenesis) and thermogenic origin. The gas emissions affect an area characterized by widespread *Posidonia oceanica* meadows occurring primarily between 10 and 40 m water depth. Two sampling surveys were conducted during 2021 and 2022: in the first (2021) thirteen sample grabs were collected while in the second, sediments and *Posidonia* samples were collected around two main mounds by scuba. The microfaunal analyses were carried out from samples coming from 11-16 m depth. The *Posidonia* were sampled 5-10 m from the emission points while sediment samples (grab and 50 ml syringe samples) were collected both at the *Posidonia* and no plant covering sites. The preliminary results of this research highlighted a very patch distribution and variability in density and biodiversity probably linked to the irregular distribution of the venting activity on the ground floor. The complexity of the interaction of the ecological factors characterizing extreme environments such as shallow hydrothermal vents did not allow us to carry out a real pattern of biota responses in situ. Around the muddy mounds, a strong loss of biodiversity and collapse in faunal density are recorded due to the combined effect by the CH_4 emissions and the mud flow setting. The rare living specimens are represented by agglutinated species like *Lepidodeuterammina ochracea* and *Ammodiscus* sp. Contrarily to sediment samples, the epiphytic foraminiferal assemblages (living on *Posidonia* leaves and rizhomes) are abundant, mainly dominated by rosalinids (*Neocorbina posidonicola* and *Rosalina* spp.). EDS microanalysis and isotopic analyses will be conducted both on the foraminiferal test and *Posidonia* leaves to highlight the isotopic signatures of living benthic foraminifera from methane rich environments. The aim of the research is to increase the knowledge on the of microfaunal response in this extreme environment as a proxy to improve reconstructions of methane release in the past and better predict the impact of future climate warming on methane seepage.

Exceptionally abundant Larger Benthic Foraminiferal fauna from the uppermost Eocene of Fanari (Thrace Basin, Greece)

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An uppermost Eocene site very rich in Larger Benthic Foraminifera (LBF) was discovered in the coastal zone of Fanari village, 30 km southwest of Komotini city (NE Greece). It consists of molassic-type deposits of the Trace basin. Its importance lies to three main reasons. Primarily, it represents one of the few sites in the Greek peninsula where isolated

micro- and macrofossils were recovered. Secondly, these fossils are well preserved and thirdly and most importantly this site constitutes one of the most abundant in LBF sequences in the Tethyan realm. Two stratigraphical sections (FAN A-lower part, FAN B-upper part), which consist of shallow marine deposits have been sampled. They comprise in general fossiliferous sandstones and siltstones that are rather continuous, and their displacement is related to a fault system. The objectives of this research are: (1) to determine the LBF assemblages of the latest stage of Eocene, in accordance with biometric analysis and morphological features (internal/external), (2) to provide a biostratigraphic framework and finally (3) to reconstruct the paleoenvironmental conditions.

A total of 21 samples from the sandstone and siltstone were collected. The macro- and microfaunal content was extracted after soaking in water and H_2O_2 (70%) and wet sieving. Subsequently, plethora of the recovered LBF specimens were submitted to the standard preparation techniques for their dichotomy. More than 1000 specimens have been elaborated (thin sections/bisected). Morphometrical measurements were performed on the bisected specimens to support and amplify the taxonomic identification of LBF.

Twenty-four taxa, among which six (chrono)subspecies, belonging to twelve genera were subsequently identified. FAN A section is characterized mainly by nummulitids, unlike FAN B, which is represented by a diverse and very rich micro-fauna. The most common species, present almost in the whole sequence, is *Nummulites fabianii*. However, the most abundant species are *Pellatispira madaraszi* and *Spiroclypeus carpaticus,* displaying their mass abundancies in the upper part of the sequence. It is worth mentioning that their accumulations show a quite opposite trend. Moreover, noteworthy is the increase of the proloculus size of *S. carpaticus,* detected also in the upper part of the sequence, leading to the distinction of two groups. Orthophragmines are abundant and occur only in the upper part of the sequence.

The whole sequence was placed within the stratigraphic framework based on the first occurrence of both *Heterostegina gracilis* and *Spiroclypeus carpaticus,* documented already from the lower layers of the sequence and occur through the top ones. This fact enabled us to assign both sections to the upper part of the Priabonian, to the SBZ 20 larger benthic foraminiferal zone.

Finally, the paleoenvironmental evolution and reconstruction of Fanari area took place, according to the composition and distribution of foraminiferal assemblages. Three main depositional marine shelf facies were distinguished that operated along the carbonate platform before its demise took place. In particular, a low-energy water, shelf environment limited to the shallowest parts of the upper slope shift to open marine settings is concluded.

Benthic foraminifera from the continental shelf of the Santos Basin (SE-S, Brazil) - traditional and Machine Learning, integrated approach

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The constant expansion in the exploitation of renewable and non-renewable resources in the coastal zones and deep sea generates a growing concern in the scientific community, which wants to correctly estimate the regional natural habitats and their biodiversity before human interventions. It is essential to avoid the loss of species or damages that might threaten them.

Currently, new and promising approaches are being incorporated into traditional ecological studies, with notable advances in processing large amounts of data to understand complex causal relationships, contributing to current diagnostic studies and future predictions. Foraminifers have a wide geographical and bathymetric distribution being abundant in all marine areas and are susceptible to environmental variations. The structure of benthic foraminiferal assemblages results from the interaction of multiple factors. Aiming to improve the application of foraminifera as proxies of climate and anthropogenic changes, their relationship with abiotic parameters has been intensely investigated. Among our objectives within the scope of the "Santos Project – Regional Environmental Characterization of the Santos Basin (PCR-BS)," coordinated by PETROBRAS, was the survey of foraminiferal species that live on the Santos Basin's (SB) continental shelf, gathering information about the structure of their associations and which are the most critical factors responsible for their distribution. The structure of their assemblages was analysed (density, richness, diversity, dominance, and uniformity), hierarchical clustering and Canonical Correspondence Analysis (CCA) were performed, and four main groups were identified, correlated to the following data: (i) the inner southern platform (25 m) has foraminifera positively correlated with a higher temperature, finer sediments, the influence of Mixture Water (MW) and Coastal Water (CW), and probable by the Plata Plume Water influence; (ii) the northern inner shelf has coarser sediments and many attached foraminifera; (iii) the middle shelf (50 to 100 m) is under the influence of South Atlantic Central Water (SACW), silt and clay sediments dominate

and retain nutrients (mainly chlorophyll-a and pheophytin-a), and is dominated by infaunal foraminifera with many opportunistic species; and (iv) the outer shelf (150 m) is dominated by gravel and high carbonate content, where epifaunal species less responsive to nutrient fluxes dominate.

Finally, we compared these results with Machine Learning (ML) approaches using self-organized maps (SOM), hierarchical dendrogram (CH), and random forest (RF) algorithms. The results of the SOM analysis, followed by the hierarchical clustering analysis with the WardD2 algorithm, separated the network into 28 neurons in four distinct groups of foraminifers. Furthermore, based on the results of the machine learning models, 21 environmental variables proved significant in explaining foraminifers' spatial distribution patterns giving precise predictions. Finally, RF analysis allowed for estimating the distribution of foraminifera associations with approximately 80% accuracy.

Both traditional statistics analyses and machine learning showed similar results in characterizing the SB continental shelf. The integration of new approaches proved promising, allowing the processing of large amounts of data and the production of environmental models. They may generate forecasts to predict the consequences of ecological changes and, perhaps, implement mitigation measures in advance.

The contribution of different sediment layers to foraminiferal assemblages' characterization in distinct habitats from Santos Basin (Southwestern Atlantic)

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The Santos Basin is Brazil's most significant offshore sedimentary basin, ranging for over 350,000 km^2, from Cabo Frio (Rio de Janeiro) to Florianopolis (Santa Catarina). The first investments in exploration and production studies for this basin date back to the 1970s. Today it is one of the largest pre-salt oil reservoirs in the world, with an estimated recoverable oil reserve of 21.6 billion barrels of oil, extending into water depths of around 3,000 m. Operations in the Santos Basin pre-salt area began on May 1, 2009, a milestone for the company and the country. A year later, the Definitive Production System went on stream at the Tupi Field, deployed about 280 km from the coast and in waters with a depth of 2200 meters.

Exploration activities must be carefully planned to ensure environmental quality and maximum longevity and safety of the infrastructure. Responsible management involves anticipating planning and continuous monitoring based on scientific knowledge. Research must go hand in hand with industry activities, trying to maximize efforts and best practices to increase production safely.

Small details in the sample design can provide the necessary information without spending unnecessary time. Aiming to optimize the working time in the analysis of samples from the studies of characterization and environmental monitoring, we analyzed two strata of different depths: 0-1 and 0-2 cm, to verify which one is sufficient for environmental characterization and what is the adequate minimum depth to be analyzed during the environmental monitoring works.

Benthic foraminifers are considered good indicators of environmental changes and are usually used to estimate marine ecosystems' health. They are single-celled organisms that live in direct contact with the sediment and its components at the water-sediment interface, up to several centimeters deep in marine and transitional sediments. The distribution of foraminifera in the sedimentary column depends on the chemical, physical, and biological conditions; they can move according to favorable or adverse conditions.

In Brazil, environmental characterization and monitoring studies usually use the first two centimeters due to the prevailing sedimentary characteristics of the Brazilian continental margin. International protocols suggest the first surficial centimeter of the sedimentary column be studied for environmental monitoring based on foraminifers; however, it is necessary to test how the foraminifera assemblages are distributed in different environments. Within the scope of the Santos Basin Environmental Characterization project, coordinated by PETROBRAS, we studied foraminiferal assemblages at four different habitats from the continental shelf, investigating the living benthic foraminiferal assemblages at the 0-1 cm and 1-2 cm depths, from different grain sizes and bathymetric zones. The assemblages' composition and parameters, especially the density, richness, and diversity indexes, were evaluated. In addition, a Student's T-test was performed to assess the density of living foraminifers among the two layers. The surficial layer (0-1 cm) has a higher density than the 1-2 cm layer ($p = 2{,}2\text{-}16$). The richness at the surficial layer was 319, while at the 1-2 cm layer, it was 281.

The most effective layer for studying foraminifera is discussed, aiming at the environmental characterization and monitoring activities.

"Biodiversidade Marinha da Bacia Potiguar – Foraminifera", an atlas of benthic Foraminifera from Rio Grande do Norte (NE, Brazil)

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The atlas "Biodiversidade Marinha da Bacia Potiguar – Foraminifera*"* is a volume from the series "Marine Biodiversity of the Potiguar Basin", a product of the Marine Environmental Characterization and Monitoring projects from Potiguar Basin, coordinated by Petrobras. It was elaborated by the "Laboratório Foraminifera e Micropaleontologia Ambiental*"* (LaFMA) from the Universidade Federal do Paraná (Curitiba-PR, Brazil) and two researchers from the Laboratorio de Foraminíferos of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" – CONICET (Buenos Aires, Argentine). We work together on a formal and productive partnership, and in the scope of the projects, 1,100 species of benthic foraminifera have been recorded in northern Rio Grande do Norte, in one or more of the following regions from the Brazilian northeastern continental margin: inner continental shelf, mid-outer continental shelf, and/or continental slope.

The atlas presents 132 living species of benthic foraminifera collected in different samplings: (i) 2nd Potiguar Basin Environmental Characterization Campaign, carried out in 2003; (ii) four Regional Environmental Monitoring Campaigns in the Potiguar Basin, carried out in 2009, 2010, and two in 2014; (iii) ten campaigns for Monitoring the Submarine Outfall of the Effluent Treatment Station of the Industrial Pole of Guamaré, carried out between 2008 and 2015, and (iv) two campaigns for Characterization of the Continental Slope of the Potiguar Basin, carried out between 2009 and 2011. Scanning electron and optical microscopy images show different aspects of the tests; in some cases observations on the direct comparison with type-specimens were included, and also images of the holotype or another type when available, and some observations on the regional occurrence of the species (bathymetry distribution, sedimentary data together with organic matter and carbonate content). A map with the distribution of the species in the study area and their registration in different world regions are presented to complement. Finally, at the end of the atlas, an illustrated glossary intended for non-specialists can help to understand the technical terminology.

This publication aims to awaken interest in foraminifera, making their study more accessible and attractive.

A new calcareous Globothalamea (Rhizaria, Foraminifera) from the northeastern Brazilian continental margin

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Studying living benthic foraminifers from the northeastern Brazilian continental margin for several years, we have recorded around 1,100 species with a tremendous foraminiferal richness. Many researchers were active in the last century on the Tropical Southwest Atlantic. The possibility of being involved in this research brings us a new understanding of the regional foraminiferal biodiversity and promotes the discovery of a new species presenting now. Searching publications for similar species we had no success. Another difficulty was placing this new form in an adequate genus due to certain distinctive features; therefore, we probably have a new genus, too; for now, we will call it *Discorbinella* (?) sp. nov.

The test was frequently attached to bioclasts or lithoclasts but also free; it presents a low trochospiral arrangement, subcircular to oval outline, slightly lobed with a rounded periphery. It has a calcareous wall semi-transparent with milky white color. The dorsal side is convex with 2.5 to 3 whorls, partially evolute. The sutures are gently curved and slightly depressed with a peculiar chamber overlapping due to how the proximal portion of the subsequent chambers lays over the distal portion of the anterior one. It has 6 to 8 falciform to subrectangular chambers per whorl, increasing in size as added. Another notable characteristic is the large pores distributed over most of the spiral side, not uniform in size but almost uniformly distributed, following the sutural direction on the dorsal side, giving a coarse appearance to the test. The umbilical side is involute and slightly concave; sutures are sinuous, visible but obscured by the extensive development of papillae almost even in size, though they cover most of the umbilical face except for the periphery, which shows a smooth stripe with pores, little ones. Umbilicus is covered by papillae from the chambers of the previous coil. The aperture is a small, simple opening on the periphery at the base of the last chamber, another one on the umbilical side, under the wide flap projected towards the umbilicus. The height (mean ± SD) is 50.46 µm ± 16.36, and the diameter is 166.20 µm ± 47.40. They live between 4 and 49 meters deep. Considering the narrow continental shelf, they are found from the inner to the outer shelf on variable sediments: lithobioclastics, lithoclastics, biolithoclastics, and bioclastics.

Attached and encrusting Foraminifera on mobile unconsolidated substrates in the Santos Basin (SE - S, Brazil): unexpected records

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Benthic foraminifers have an intimate connection with the substrate and different life habits. They can live free on the surface of the substrate (epifaunal) or bury themselves in the sediment (infaunal); they can move across the environment or be attached or incrusting with little or no mobility (sessile) fixed to rocks, lithoclast, bioclast, living plants or animals remaining temporary or permanently set. About 15.5% of 284 living agglutinated foraminiferal genera are sessile; most benthic are well-known and recorded worldwide. Still, studies on attached forams are rare or restricted to fossils and naturally consolidated substrates such as corals, areas with metallic nodules, or constructions such as oil platforms, artificial reefs, or distinct substrates offered in experiments. A literature search referring to attached or encrusting genera and species indicates that these foraminifers have been neglected or sparsely recorded in distributional and ecology studies. There is also a shortage of their images. Believing that the abundance and richness of adhered or encrusting foraminifers might be underestimated in the literature, we present unexpected data from these organisms from unconsolidated mobile sediments of the inner shelf of the Santos Basin (SE and S Brazil). Despite the lack of records in previous studies, samples collected from 3 to 25 m deep in surficial sediments presented high density and richness of attached forams. Unfortunately, many sessile species were either not recorded on the Brazilian coast or in few numbers. In mobile studied substrates, these "sessile" foraminifers compose up to 96% of the total fauna on the shallow inner shelf of the Paraná coast and up to 82% of the living forams collected at 25m depth; these areas are constantly disturbed by the wave action and currents, a striking feature of some parts of this coast. They have agglutinated or calcareous tests; most are permanently attached, but some may be temporarily attached. A free-living agglutinated foraminifera genus was also abundant, although it was not recorded in nearby regions. Some species were never mentioned, others were recorded, but their identity is controversial. This study provides information on attached and encrusting benthic foraminifera and agglutinated species poorly known. We believe that the images might help their recognition, and our data can subsidize regional paleoenvironmental interpretation, supporting the recognition of similar areas, especially those under intense wave action. Their record may also improve environmental characterization and monitoring studies. Future researchers should be sure that this group of foraminifera is really absent from the study area; otherwise, they will remain almost invisible, as they have been until now.

Surface drivers of deep-sea benthic foraminifera variability during the Mid-Pleistocene Transition in the subpolar North Atlantic

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Deep-sea benthic foraminiferal assemblages from the Mid-Pleistocene Transition (MPT) (1060-780 ka) have been investigated at high-resolution at IODP Site U1314, located in the subpolar North Atlantic (56.36°N, 27.88°W, 2820 m water depth) in the southern Gardar Drift. The downcore benthic foraminifera assemblages are compared to existing multiproxy data (sedimentological, isotopic, geochemical and surface ocean faunal census counts data) from the same core, and to modern distribution of benthic foraminifera assemblages in the subpolar North Atlantic, to understand the drivers of benthic faunal assemblage composition and diversity through the MPT.

The most common benthic foraminifera species at Site U1314 are *Epistominella exigua* (Brady), *Oridorsalis umbonatus* (Reuss), *Pullenia osloensis* Feyling-Hanssen, *Melonis pompilioides* (Fichtel & Moll) and *Astrononion echolsi* Kennett. Other, less abundant species, are *Gyroidina polia* (Phleger & Parker), *Gyroidina umbonata* (Silvestri), *Quadrimorphina laevigata* (Phleger & Parker), *Pullenia bulloides* (d´Orbigny) and a group of species indicative of low oxygen in pore waters (*Globobulimina* spp., *Chilostomella* spp. and *Stainforthia* spp.). High relative abundances of *E. exigua* (up to 60%) generally occurred during ice-rafted debris events. Therefore, we interpret peaks in *E. exigua* at U1314 as increases of seasonal primary productivity during iceberg discharges. *Astrononion echolsi* shows high fluctuations (10-25%) between 780-830 ka and 930-1060 ka being nearly absent in between those periods. This is the first time that *A. echolsi* is found in high abundances (up to 25%) at Site U1314 and in other North Atlantic Pleistocene and Holocene cores. The ecology of this species in the subpolar North Atlantic is not well known, and consequently its paleoenvironmental interpretation is still uncertain.

The Shannon diversity index of the benthic foraminifera assemblage at Site U1314 ranges from 1.8 to 3.4 and covaries at the millennial and orbital scale with sea surface temperatures (SST) reconstructed from planktonic foraminifera assemblages (high SST, high benthic diversity, and vice versa). The observed relationship suggests a strong benthic-pelagic coupling likely through increased/decreased organic carbon supply during latitudinal shifts in the position of the Arctic front, which marks the boundary between cold polar and warmer Atlantic surface waters in this region.

Anaerobic microbial metabolisms in particle microenvironments recorded by *Globorotaloides hexagonus*

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In the ocean, microenvironments inside organic particles can harbour lower oxygen conditions than ambient water. These microenvironments can host anaerobic microbes even outside of ocean anoxic zones. We present evidence that the planktic foraminifer *Globorotaloides hexagonus* inhabits a particle microenvironment and records the chemistry of anaerobic microbial metabolisms inside particles. Intrashell trends in Ba/Ca, Mn/Ca, and Zn/Ca ratios in *G. hexagonus* are interpreted as signatures of denitrification, Mn respiration, and sulphate reduction. We use *G. hexagonus* samples from discrete depth horizons in the Eastern Tropical North Pacific (ETNP) to examine vertical distributions of anaerobic metabolisms inside particle microenvironments through the ETNP oxygen minimum zone (OMZ). Geochemistry of individual specimens suggests that denitrification occurred inside particles throughout the water column, regardless of macroenvironmental oxygen concentrations, Mn respiration occurred in particles throughout the OMZ, and sulphate reduction occurred inside particles only in the core of the OMZ. We discuss the application of these intrashell trends to proxies for oxygen concentration as well as nitrogen, sulphur, and trace element cycling in OMZs.

Investigating the ecology of planktic foraminifera species with compound-specific stable isotope analysis of amino acids

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Foraminiferal proxies must be interpreted in the context of foraminifera ecology, including depth habitat, the presence/absence of symbionts, and diet. Stable isotope ratios and test morphology have traditionally been used to infer the ecological traits of both extant and extinct foraminifera species, but many uncertainties remain. Compound-specific stable isotope analysis of amino acids (CSIA-AA) has been used widely as a tool to untangle trophic ecology and carbon and nitrogen sources in organisms. CSIA-AA methodology is well established in many marine organisms but has only recently become feasible for small samples such as foraminifera tests. We present a new method for the application of CSIA-AA to foraminifera test-bound organic matter and present the results of CSIA-AA in three species of modern planktic foraminifera from Santa Barbara Basin sediment traps: *Globigerina bulloides, Turborotalita quinqueloba,* and *Neogloboquadrina incompta*. These results include the trophic position, or location in the food web, of each species, as well as dietary sources of carbon to each species. For example, CSIA-AA results from the spinose foraminifer *G. bulloides* indicate that this species was herbivorous (trophic position ~2) and feeding primarily on diatom aggregates in Santa Barbara Basin. We compare these data to observational evidence of ecological traits to expand upon current knowledge in modern foraminifera. Another goal of this work is to apply CSIA-AA to fossils; we discuss the application of methods to sediment-recovered and extinct species. Despite the potential, we also discuss the challenges of this method, such as the large sample size requirements.

The pre-onset excursion (POE) enigma of the U.S. Atlantic Coastal Plain: a prelude of the PETM environmental perturbation?

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The Paleocene-Eocene Thermal Maximum (PETM), is a short, transient global warming event, that took place ~56 Myr ago. It is the most pronounced of a series of hyperthermals that punctuated Earth's long-term warming trend spanning the late Paleocene to the early Eocene. The PETM was caused by a major injection of ^{13}C-depleted carbon into the ocean-atmosphere reservoirs, causing a greenhouse driven global temperature rise of 5–8°C. Associated with it are among others surface ocean acidification, shoaling of the carbonate compensation depth and regional changes in the hydrological cycle. The exact cause and trigger of the PETM is still under debate, ranging from influences from long-term mechanisms like orbital-variability based cycles and volcanic intrusions to instantaneous events like a bolide impact. Isotope data from the U.S. Atlantic Coastal Plain (site South Dover Bridge, Maryland) show additional small, but distinct, $\delta^{13}C$ and $\delta^{11}B$ excursions just below the base of the PETM, coined as the "pre-onset excursion" (POE). Their relationship with the PETM is still undetermined, but it may indicate that the latest Paleocene climate was not as stable as previously assumed and experienced a more gradual or stepwise change towards the PETM-onset in association with an enigmatic disturbance in the carbon cycle.

In this study we combine foraminiferal taxonomical data, grain size data and clay mineralogy with geochemical proxies ($\delta^{13}C$, $\delta^{18}O$, $\delta^{11}B$) to confine the POE at South Dover Bridge, investigate connected environmental changes and potential connections to the PETM. In this region, the PETM interval on the shelf is characterized by a distinct shift in grain size to a silty-clayey composition, with a high kaolinite content. The POE sediments also exhibit a fining trend, but to a lesser degree, and with no noticeable change in the clay mineralogy suite. The base of the POE coincides with a lowered pH at the seafloor, indicated by a $\delta^{11}B$-excursion recorded in benthic foraminifera tests, likely impacting the foraminiferal assemblages as a decrease of hyaline, thin-walled foraminifera is observed (*Bulimina virginiana, Paralabamina lunata*). While the thin-walled taxa increase in numbers throughout the POE again, other species fully disappear from the record (e.g., *Bolivinopsis emmendorferi*), or gradually diminish to eventually disappear at the onset of the PETM (e.g., *Cibicidoides alleni, Pseudouvigerina triangularis*). Taxa that would become the most dominant species during the PETM phase, appear during the POE (e.g., *Pulsiphonina prima, Anomalinoides acutus*), although the assemblage remains diverse. During the POE Atlantic coastal bottom water currents are reduced and riverine input may have increased, causing finer grained sediments to be transported wider into the basin and/or to settle at the seafloor. While the $\delta^{13}C$ excursion recovers between the POE and the onset of the PETM, environmental conditions show a slow and incomplete recovery, as reflected in the benthic foraminiferal assemblage, with noted changes persisting up to and throughout the PETM. Bottom-water temperatures ($\delta^{18}O$) start to increase by 2–4°C at the base of the POE, towards the PETM. The grain size record indicates that bottom water currents increased and/or riverine input decreased immediately after the POE.

We additionally report changes associated with the POE from two more sites in Maryland. While the $\delta^{13}C$-excursion is not as distinct, the biotic shifts, grain size and $\delta^{18}O$ suggest a potential stratigraphic correlation between those sites. The gradual changes after the POE, as well as the more transient changes, such as the POE, indicate that conditions on this late Paleocene Atlantic shelf were not as stable as commonly presumed, at least on this regional scale.

Paleoecological and biogeographical dynamics of the U.S. Atlantic Coastal Plain prior and during the Paleocene-Eocene Thermal Maximum

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The Paleocene-Eocene Thermal Maximum (PETM) is a short, transient global warming event, known as hyperthermal, that took place ~56 Myr ago. It is the most pronounced of a series of hyperthermals taking place in front of a long-term warming trend spanning the late Paleocene to the early Eocene. The PETM is characterized by a distinct carbon isotope

excursion (CIE) in marine and non-marine carbon-bearing sediments and fossils worldwide, caused by a major injection of ^{13}C-depleted carbon into the ocean-atmosphere reservoirs. This injection led to a greenhouse driven global warming of 5–8°C. Associated with it are, among others, surface ocean acidification, shoaling of the carbonate compensation depth, and regional changes in the hydrological cycle.

Here, we investigated the regional paleoenvironmental evolution of shallow shelf sites from the late Paleocene into the PETM, climate-triggered changes connected to the PETM and corresponding biotic responses of benthic foraminifera. Shelf environments are unique habitats, bridging terrestrial and coastal to deep-sea environments, and are influenced by both inland hydrological conditions and oceanographic processes. Sedimentation rates are potentially high, providing a high time resolution. Hence, shelf environments represent optimal settings to study extreme climate events, like the PETM, and adjunct background conditions.

We combine benthic foraminiferal assemblage and grain size data from multiple drill sites along the U.S. Atlantic Coastal Plain (New Jersey & Maryland) to reconstruct environmental conditions across a late Paleocene shelf transect. Assemblages were diverse and heterogeneous. The sites were prone to river-influence, decreasing from the south-western sites, where a typical opportunistic, lower diverse river outflow assemblage is present (dominated by *Epistominella* spp. and *Bulimina virginiana*), to the south-eastern sites, where a more open marine, stable setting allowed for a high diverse assemblage (*Cibicidoides* spp., *Alabamina midwayensis, Anomalinoides compressus, Bulimina* spp., *Paralabamina lunata*), to the northern, distal sites, which offer a deeper, more open marine environment (presence of *Bulimina hornerstownensis* and *Gavelinella beccariiformis*). The southern domain is strongly influenced by high food availability, indicated by high occurrences of *Bulimina virginiana*, which is relatively reduced in the northern domain. Bottom waters are oxic throughout the shelf, as shown by the constant occurrence of various *Cibicidoides* species and/or *Anomalinoides compressus*.

In contrast, the PETM shelf assemblage is poorly diverse and more homogeneous. During the PETM, the shelf becomes river-dominated with strongly reduced currents, resulting in the accumulation of fine-grained, silty-clayey sediments with high foraminiferal abundances in excellent preservation. Episodic low-oxygen conditions, caused by river-induced stratification allowed the less diverse, but opportunistic PETM fauna to thrive (*Pulsiphonina prima, Anomalinoides acutus, Pseudouvigerina wilcoxensis, Tappanina selmensis,* and *B. virginiana*), while the Paleocene assemblage nearly vanishes from the record. Some of the typical PETM taxa show environmental preferences of river influence and water depth for their habitat (*Spiroplectinella laevis, Tappanina selmensis, A. acutus*) in their distribution across the shelf transect. The food input remains high, but may evolve to a more pulsed input. During the recovery phase of the PETM, a renewal of bottom currents lead to better oxygenated bottom waters, with a more continuous food supply. Late Paleocene taxa (*Cibicidoides* spp., *Paralabamina lunata*) together with new taxa (*Bulimina callahani*) gradually reappear in the assemblage, while the dominant taxa of the PETM start to decrease in abundances. Despite the great environmental perturbation, no increased extinction rate is observed, hinting towards the presence of refugia along the shelf.

Surface water variations during MIS 44 to MIS 50 (1.36-1.5 Ma) on the Southern Portuguese Margin – evidence from planktonic foraminifera and biomarker data

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Planktonic foraminifera are commonly used as paleoclimatic tracers and have enabled millennial-scale reconstructions of climate variability, particularly in the Quaternary. So far little is known how climatic variations in the 41 kyr world, especially prior to the Mid-Pleistocene Transition, affected the planktonic foraminifera fauna. We are, therefore, generating early Pleistocene planktonic foraminiferal assemblage data for IODP Site U1387 (36°48.321´N 7°43.1321´W), drilled into the Faro Drift on the southern Portuguese margin (Gulf of Cadiz) at a water depth of 559 m during IODP Expedition 339 (Mediterranean Outflow Water). Besides the faunal data itself, changes in the coiling direction of *Globorotalia truncatulinoides* are recorded to infer subtropical gyre strength variations. The assemblage data is combined with *G. bulloides* and epibenthic foraminifera stable isotope data and sea-surface temperature (SST) data derived from alkenones to assess glacial/interglacial and millennial-scale climate and ecosystem changes. Here we present centennial-to-millennial-scale records for the interval from Marine Isotope Stage (MIS) 44 to MIS 50 (1.36-1.5 Ma).

The faunal data reveals the presence of subtropical to subpolar water masses at the southern Portuguese margin. Species related to subtropical surface waters are abundant throughout the record, conform with the observed alkenone SST that in general were warmer than today. During interglacial MIS 47, tropical species like *Pulleniatina obliquiloculata*, *Globorotalia crassaformis*, *Trilobatus trilobus*, and *Sphaeroidinella dehiscens* also contributed to the fauna indicating a stronger influence of tropical waters. On the other hand, the terminal stadial event of MIS 48 was marked by a high percentage (up to 60%) of *Neogloboquadrina pachyderma* accompanied by increases in the percentage of *Turborotalita quinqueloba*. This is evidence that subpolar surface water penetrated as far south as the Gulf of Cadiz and that the subtropical gyre contracted significantly

in the eastern North Atlantic. Ongoing analysis will reveal if the same pattern can be observed for the MIS 50 to MIS 49 and MIS 46 to MIS 45 transitions and how strong the cooling was during stadial events of glacial MIS 48, MIS 46, and MIS 44. The already available assemblage data also revealed the presence of extinct species *Neogloboquadrina atlantica* dextral and *Globigerinoides obliquus* and their extinction dates and ecological preferences will be further explored in the future.

Dysoxia in shallow bathyal marine deposits of the island of Rhodes (Greece) during the Plio-Pleistocene

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During the Plio-Pleistocene, the eastern Mediterranean Sea was influenced by orbital-driven climate changes, and sapropel formation occurred periodically during the minima in the precession cycle and associated shut-down of deep-water formation. The fossiliferous marine sediments of the Lindos Bay Formation, outcropping along the east coast of the island of Rhodes, provide an excellent fossil record to analyse to what extent the marine environments off the island of Rhodes were influenced by the oceanographic changes during the Plio- and Pleistocene.

Here, we present two new Late Pliocene to Early Pleistocene benthic foraminiferal records from the Plimiri section, located at the south-east coast of the island of Rhodes. Indicated by the recurrent dominance of eutrophic indicator species (genera *Brizalina*, *Rectuvigerina*, *Stainforthia*) and a decline in foraminiferal diversity, we found evidence of a periodic occurrence of dysoxic conditions at the seafloor, which can be linked to the sapropel events of the deep eastern Mediterranean basins. While the Late Pliocene record shows three dysoxic layers with up to one meter thickness each, the younger Early Pleistocene record shows only one event of a few centimetres thickness. Increased fresh-water and nutrient inputs from the island are likely responsible for enhanced primary productivity, resulting in the evolution of oxygen-deficient conditions in bottom-waters of the highly tectonically-structured island shelf. This onshore influence can be related to a river system fitted along NW-SE trend lineaments that are more prominent in the south-eastern part of the island. The deposition of the dysoxic Plimiri sediment layers likewise reflect periods of restricted water exchange with the open ocean due to the deposition in a bay or semi-enclosed basin, which further fostered the establishment of bottom water oxygen deficiency.

Methods for Classification of Epilithic Benthic Foraminifera of the Southeastern Clarion-Clipperton Zone

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The Clarion-Clipperton Zone (CCZ) in the equatorial Pacific Ocean is home to a diverse community of undescribed foraminifera and foraminifera-like lifeforms that rely on polymetallic nodules for habitat. Encrusting and attached foraminifera are dominant components of all biological size classes (meio-, macro-, mega-) in nodule fields. However, despite increased exploration and sampling efforts in the CCZ, the characterization of nodule associated foraminifera remains poor. It is necessary to characterize these epilithic communities to establish baseline taxonomic knowledge of the CCZ. Additionally, epilithic organisms, such as encrusting foraminifera, komokiaceans, and xenophyophores, are vulnerable to deep-sea mining (DSM) impacts, namely direct removal of hard substrate and burial from sediment plumes. Ecological baselines are necessary in understanding natural abundances and variabilities in foraminiferal assemblages, as well as impacts of DSM.

Nodule assemblages from multicore sites in the NORI-D lease area were analyzed using photography, microscopy, and morphological taxonomy. Whole nodules were photographed at sea using a DSLR camera, while individual foraminifera and quadrats of nodules were captured in the laboratory using a stereomicroscope equipped with a digital camera. Sets of photos were taken at varying depths of field by incrementally adjusting the camera or microscope focus. These photos were then fed into focus stacking software to create images with a greater depth of field and to ensure that the entire nodule/foraminifera was in focus. The resulting images were then incorporated into an interface that enables the user to select specific individuals within a whole nodule image bringing them to the microscope photo. This is particularly useful in determining life mode, size, and morphological characteristics. Using these photos, all foraminifera found on the nodule were identified and classi-

fied using a serialized open taxonomic description system that accounts for unidentified species while maintaining taxonomic consistency.

Xenophyophore specimens were sampled from box core and multicore sites. Specimens were photographed at sea using the aforementioned methods and preserved with Zymo DNA buffer at -80 C. Five distinct xenophyophores were morphologically analyzed and then sequenced for genetic confirmation/description.

Here we present a methodology that is useful for understanding an epilithic foraminiferal community in an area designated for DSM.

Biomineralization and proxies in foraminifera

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Biomineralization and proxy incorporation in hyaline (calcitic radial, perforated) foraminifera is of great scientific interest because they are major $CaCO_3$ producers in the ocean and play a significant role in determining the carbonate chemistry of the oceans and hence atmospheric CO_2. A substantial portion of the information we have on paleoceanographic and paleoclimatic changes for the Cenozoic (the last 65 Ma) is based on the sedimentary archive of planktic and benthic hyaline foraminifera in ocean drillings and in a few geological land sections. In addition to being important for stratigraphy and paleo-ecology the most crucial quantitative information is obtained from geochemical proxies in foraminifera shells (i.e. $\delta^{18}O$, $\delta^{13}C$, Δ^{47}, $\delta^{11}B$, Mg/Ca, and other trace and minor elements). The use of these proxies was, and still is, largely based on empirical field calibrations. Very few laboratory calibrations on live foraminifera were performed during the last 50 years and these were able to narrow more precisely the effects of specific environmental conditions (i.e. temperature, water chemistry etc.) on the shell chemistry and isotopes. Regardless of the methods used, it is clear that vital effects are observed in foraminifera and other biogenic archives such as coccolithophores and corals. Therefore, knowledge of the mechanisms of biomineralization is essential in order to extract more reliable environmental information from proxies in foraminiferal archives.

In the past 30 years, modern methods including electron microscopy, fluorescent confocal microscopy and microanalysis were developed and used to investigate the biomineralization of foraminifera using specific preparations (ameboids and recovering individuals) mainly of *Amphistegina lobifera* and several species of planktic foraminifera. The most important finding of these studies is that the main pathway for ions (Ca, CO_3, trace and minor elements) for calcification is seawater endocytosis, which is a key process in these large unicellular organisms. Seawater vacuoles (SWV), contain ~10 mM of Ca and ~2 mM DIC. To maximize the efficiency of calcite precipitation from seawater these organisms elevate the pH of the SWV and accumulate DIC from CO_2 diffusion into the SWV. This requires continuous alkalinity increase which is most probably achieved by proton/sodium exchangers. In some cases, $\Omega_{calcite}$ in the SWV is so high that amorphous $CaCO_3$ (ACC) is precipitated and the SWV shrinks (by a factor of 500-1000) to form numerous ACC vesicles. These ACC vesicles are rich in trace elements (particularly Mg), and the large benthic foraminifera (e.g. *Operculina ammonoides*) are using this pathway to make shells of high Mg calcite. Other species including the planktic and deep benthic species use similar SWV but remove the Mg to lower concentrations and elevate the pH and DIC, thus precipitating low Mg calcite. Some species (e.g. *Amphistegina spp*.) probably use both strategies. We will show microscopic and geochemical evidence to support the mechanisms described above for hyaline foraminifera.

In contrast, a completely different strategy is taken by coccolithophores that channel and pump the ions needed for their intracellular calcification through their membrane and into the coccolith vesicle. This was directly observed using TEM and geochemical information although the function of their shells remains unresolved. The difference between these two groups of calcareous plankton, which both emerged in the Mesozoic, highlights the diverse pathways that evolution has used to cope with past changes in seawater chemistry.

Determining the role of seawater vacuolisation in the biomineralisation process of the planktonic foraminifera using confocal microscopy

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The principal mode of delivery of the ions necessary for calcification to the biomineralisation site of foraminifera is poorly constrained, and may differ between different species. Specifically, much research in the last two decades has focused on determining whether the Ca^{2+} required for shell formation is delivered via trans-membrane ion transport or seawater vacuoles, with the importance of both processes having been argued for. In addition, amorphous and/or metastable precursor phases have been implicated in foraminifer biomineralisation, but their presence and role in calcification is yet to be conclusively shown. The vast majority of the direct observational evidence for these transport processes is derived from shallow-dwelling benthic foraminifera, yielding an enormous amount of valuable information, yet it is not clear whether these observations are applicable to the planktonic species widely used in palaeoceanography.

In order to address these knowledge gaps, we conducted a set of experiments designed to understand the importance of seawater vacuolisation in the planktonic foraminifera using confocal microscopy coupled with membrane-impermeable fluorescent probes (calcein, FITC, SNARF). We applied this technique to both intact specimens and recovering individuals that were decalcified using EDTA, the latter in order to more easily examine intra-cellular processes using confocal microscopy.

Our results demonstrate that at least two species of planktonic foraminifera, *Globigerinoides ruber* and *Globigerinella siphonifera*, vacoulise large quantities of seawater (tens of percent of the volume of the cell may consist of these vacuoles), and that the vacuoles have a residence time in the cell of a few hours. The quantity and residence time of these vacuoles is consistent with the hypothesis that seawater vacuolisation is the dominant or only source of Ca^{2+} for calcification. Over the course of ~1 day, these vacuoles are replaced by smaller, non-polarising, strongly fluorescent (calcein) vesicles, which may thus consist of amorphous calcium carbonate. In both recovering/decalcified individuals and intact specimens, we observe that the shell is calcein/FITC-labelled, demonstrating the presence of seawater and/or metastable/amorphous precursor phases precipitated from seawater at the biomineralisation site. These observations are the same, or very similar, to those of several species of benthic foraminifera, highlighting that diverse groups of foraminifera with contrasting shell chemistry (e.g. high/low-Mg calcite) are characterised by similar ion transport mechanisms.

Overall, our data demonstrate that seawater vacuolisation is very likely to be the dominant ion transport process in the planktonic foraminifera, and highlight that the shells of planktonic foraminifera are excellent recorders of their environment because seawater transport is a major component of the calcification process.

Bridging the gap: unravelling the fossil record of extant *Globigerina falconensis*

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The fossil record of planktonic foraminifera is full of numerous riddles, which need to be addressed to fully understand the evolution and phylogeny in this group of protists. We studied extant and fossil specimens of the planktonic foraminifera *Globigerina falconensis* plexus using an integrated approach combining biometry and genetic data. Morphological inconsistencies emerge between the fossil and extant populations which require taxonomical clarifications, since *Globigerina falconensis* is widely used in palaeoceanographic studies in conjunction with its sister taxon *Globigerina bulloides*.

Morphologically *G. falconensis* and *G. bulloides* are similar, with the main difference being the distinctive apertural lip present in *G. falconensis*, still making their classification challenging. Thus, we selected cores covering the entire stratigraphic range of *G. falconensis*, from the early Miocene to modern, from oceanic sites at high latitudes in the North Atlantic Ocean and the southern Indian Ocean to sites in equatorial regions. The inconsistent morphology of the modern populations distinguish them clearly from the Miocene holotype of *Globigerina falconensis* Blow described from lower Miocene sediments in Venezuela. The fossil types do not belong to the same taxon as the living species. A more lobate morphology evolved in the late Miocene, thus requiring a new name for the modern individuals. We thus suggest and describe a new morphospecies, which evolved in the late Miocene and still inhabiting the modern oceans. The morphological inconsistencies affect potentially the higher level of classification of these species, presenting a pseudocancellate wall texture. We used the molecular sequences from the PR2 database to reassess the generic attribution of the *G. falconensis* lineage, confirming its close relationship with *G. bulloides* and its retention in the genus *Globigerina*.

On the traces of the forgotten marker *Globigerina bollii*: an endemic species from the Mediterranean Langhian?

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Globigerina bollii Cita & Premoli Silva was described from middle Miocene sediments in the historical Langhian type section in Langhe, Piedmont (Italy). Due to its peculiar compact morphology it was set apart from all the other globigerinids typical of the coeval Mediterranean fauna, and it was only reported for a short and limited stratigraphic range. The taxon became a first order marker for the local biostratigraphy with its own *Globigerina bollii* Zone within the Langhian stage. However, the species was later synonymised with *Globigerina falconensis* ending its use in biostratigraphic schemes, and no longer utilised by authors working in the Mediterranean and Paratethys. We present here a reassessment of *Globigerina bollii*, showing for the first time a full collection of high quality SEM and optical images of the type series of specimens, and a comparative study with Mediterranean individuals from the Langhian of Cretaccio Section (Italy) and extra-Mediterranean individuals from ODP Site 747 in the Kerguelen Plateau (Indian Ocean). We document the stratigraphic range of all the occurrences cited in the scientific literature from 1960 to the present day, and all the references including images of the taxon.

We compare here *G. bollii* to other morphospecies inhabiting the oceans during the middle Miocene, providing a detailed discussion of their morphological differences, which allow us to retain *G. bollii* a valid taxon and to cancel its synonymy with *Globigerina falconensis*. Our taxonomical observations also allow us to conclude that *Globigerina bollii* should be reassigned to the genus *Globoturborotalita*, due to its strong affinities with other members of that genus such as *G. eolabiacrassata* Spezzaferri & Coxall, and *G. ouachitaensis* Wallace. We present a direct visual comparison with the other representatives of the potentially related plexus. An additional comparison is also discussed with *Globigerina bollii lentiana* Rogl, which was retained the ancestor of *G. bollii* and endemic of the Paratethys. We conclude that the presence of *G. bollii* in the Mediterranean during such a confined stratigraphic range (Mediterranean Zone MMi4c-MMi4d), coeval to other biostratigraphic events, such as *Paragloborotalia siakensis* acme, and the evolution of *Orbulina suturalis*, might be an indicator of the tropicalisation of the Mediterranean faunas during the Langhian. This time interval coincides with the Miocene Climatic Optimum (MCO) and the Monterrey Excursion, thus we suggest that *G. bollii* represents a regional occurrence of warmer globoturborotalids.

Phytodetritus-colonising living (Rose Bengal stained) benthic foraminifera during a spring phytoplankton bloom in the Arctic Ocean

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The Arctic Ocean represents a highly sensitive area subjected to ongoing drastic environmental shifts, for instance, atlantification, an increasing influence of advected Atlantic waters due to gradually rising temperatures and salinities. The change in physical properties of Atlantic waters is causal for a thinning sea-ice cover impacting the timing of spring phytoplankton blooms which develop progressively earlier and often as under-ice blooms. The occurrence of spring phytoplankton blooms leads to episodic export pulses of detrital organic material to the seafloor. Exported and cryogenic mineral ballasted algae aggregates are observed on the seafloor as a phytodetrital layer. The phytodetritus serves as a food source and habitat for marine benthos, especially benthic foraminifera (BF). They represent primary consumers of fresh phytodetritus, and certain species of BF are able to colonise the layer actively. Here we present results on the foraminiferal faunal composition in freshly accumulated phytodetritus and surface sediments during a spring phytoplankton bloom in the Arctic Ocean.

During the expedition PS92 of the research vessel POLARSTERN (19/05/2015-28/06/2015), surface sediments with associated phytodetritus samples were collected on the northern marginal shelf of Svalbard, Yermak Plateau, and Sophia Basin. Sampling water depths ranged from 219 m to 2175 m. For analysis of living (Rose Bengal stained) BF from the pure phytodetritus, a one-way pipette was used to take volume-defined phytodetritus samples of 1 to 2 ml. At the same site, a total volume of 84.8 ml of surface sediments was collected from 0-1 cm sediment depths. Living benthic foraminifera of both sample sets were investigated in the >63 µm size fraction; the sediments were separated into size fractions 63 µm-2 mm and >2 mm. The results from the phytodetritus are compared to the sediment.

Faunal composition, species dominance and abundance in the phytodetritus and sediments vary depending on the sampling location. The standing stock of BF in the phytodetritus was around 15 times higher than in the surface sediments, and the composition between both was very different. The phytodetritus was populated in total by 84 species belonging to 61 genera, and species richness ranged from 33 to 57. Well-known phytodetritus epifaunal species (e.g., *Alabaminella weddellensis*, *Epistominella arctica*), as well as shallow infaunal ones (e.g., *Cassidulina reniforme*) colonised and thrived in the phytodetritus. The number of living species in sediment samples was significantly less diverse than in the phytodetritus.

Thus, in total, the sediments yielded 58 species. The fine fraction (63 μm-2 mm) was mostly populated by deep-infaunal living species (e.g., *Melonis zaandami*), and epifaunal specimens (e.g., *Nonionella iridea*, *Ioanella tumidula*). The epizoic species with high numbers of presumably juvenile *Crithionina cushmani* were found in the coarse fraction (>2 mm). The presence of various fragments of "primitive" living BF (e.g., *Archimerismus*, *Aschemonella*, *Bathysiphon*, and others) was also documented in the sediments.

The comparative investigations showed that the phytodetritus accumulated on the Arctic Ocean seafloor was rapidly invaded by a large number of BF that are uncommon in the underlying sediment. In addition, the phytodetritus is populated by epibenthic and endobenthic specimens that nourish on it based on bright green protoplasm observations.

Taxonomic revision of some textulariinid benthic foraminifera of the Triassic-Jurassic boundary interval

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Textulariinid benthic foraminifera represent an important component of Mesozoic assemblages and are found in the marine realm from carbonate platform to deep-water settings. However, the taxonomic classification of several taxa and their phylogenetic relationship are uncertain, because several species are described in thin section and the diagnostic features of the wall texture (e.g., the presence of pores) and of the primary aperture (position, morphology) are often not visible. Vice versa, problems with the determination also arise when species are described from washed residues, and the isolated type specimens are compared with morphotypes encountered in thin section studies.

The species belonging to the *Duotaxis-Tetrataxis* morphogroup and to the genus *Trochammina* described from Triassic levels are among the taxa that require taxonomic revision. The type species of the genus *Tetrataxis* (i.e., *Tetrataxis conica* Ehrenberg) was described from Carboniferous strata and shows a calcareous microgranular double-layered wall typical of fusulinids, whereas Late Triassic *Tetrataxi*s species (*T. inflata* Kristan, *T. humilis* Kristan, *T. nanus* Kristan-Tollmann) are characterized by an agglutinated wall typical of the textulariinids. The range of Carboniferous and Triassic species is also separated by a significant stratigraphic gap. It has been suggested, but not yet supported by taxonomic studies, that these species should rather be placed in the genus *Duotaxis* Kristan, which currently comprises two species both described from the Triassic. Similar discrepancies exist for the genus *Trochammina*. Its type species, *Trochammina inflata* Montagu (type level: Recent) has a finely agglutinated and organic cemented imperforate wall and its primary aperture is an arch covered by a narrow lip in extraumbilical-umbilical position. In contrast, the holotype of the only Triassic species, *Trochammina alpina* Kristan (type level: Rhaetian) described from washed residues, has an agglutinated wall that is likely cemented by calcite, and the primary aperture is fully umbilical in position and has no arch. The other "*Trochammina*" species described from Triassic levels (e.g., *Trochammina almtalensis* Koehn-Zaninetti, *Trochammina tabasensis* Bronnimann, Zaninetti, Moshtaghian and Huber) were described from thin sections.

The aim of this study is to re-illustrate the type specimens of the Triassic species of *Duotaxis*, *Tetrataxis* and *Trochammina* previously known only from the original drawings or low-quality microphotographs, with high-resolution stereo-, optical, and Scanning Electron Microscope (SEM) images. Furthermore, we compare these images with specimens from thin sections and washed residue samples collected from several Tethyan localities (Valle Agricola and Mt. Sparagio in Southern Italy, Mt. Messapion in Greece, Western Black Sea Shelf in Romania, Fonsjoch in Austria) and from different depositional environments (carbonate platform to shelf) with the aim to evaluate their external and internal morphologic variability.

Results of this study will produce a taxonomic revision of several textulariinid lineages and will better constrain the species stratigraphic ranges across the Triassic-Jurassic boundary interval, with the ultimate goal of providing new information to more accurately estimate the biodiversity loss across the end-Triassic mass extinction and the evolution of new taxa during the following recovery phase.

A causal link between re-organization of ocean circulation patterns during Oceanic Anoxic Event 2 and extinction of Rotaliporids

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The Cenomanian–Turonian Oceanic Anoxic Event 2 (OAE 2) is a severe perturbation of the global carbon cycle induced by enhanced volcanic activity within one or more Large Igneous Provinces (LIPs) that injected huge amounts of volcanogenically derived greenhouse gases in the ocean-atmosphere system and likely coincided with the highest sea-surface temperatures of the Late Cretaceous. The greenhouse mode of OAE 2 was temporarily interrupted by a 5 to 11°C drop in sea-surface temperatures known as Plenus Cold Event (PCE) recognized in several European epicontinental basins, in the Western Interior Seaway (WIS) and in the Atlantic Ocean. Broadly coeval to the PCE, a repopulation event of benthic foraminifera (Benthonic Zone) in the WIS and a geochemical fingerprint for oxidation in several European epicontinental basins suggest a re-oxygenation phase of bottom waters that temporarily interrupted dysoxia/anoxia at the sea floor.

Planktonic foraminifera extinctions during OAE 2 involved the large-sized, deep-dwelling rotaliporids, which were common in late Cenomanian, oligotrophic tropical-subtropical assemblages. The cause(s) for this extinction is still poorly constrained. Candidates include expansion of the oxygen minimum zone (OMZ), ocean acidification, collapse of the thermocline under global warming during OAE 2, or cooling and water-mass reorganization in northern Europe during the PCE combined with expansion of the OMZ at lower latitudes.

This study documents quantitative changes in planktonic and benthic foraminiferal from two European key-localities, Eastbourne (Anglo-Paris Basin, SE England) and Clot Chevalier (Vocontian Basin, SE France). Results are combined with published micropaleontological (planktonic and benthic foraminifera) and geochemical data (e.g., TEX_{86}, $\delta^{18}O$, ε_{Nd}) resulting in a highly-resolved reconstruction of biotic and oceanographic changes in sea-surface and at the water-sediment interface at upper bathyal depth within OAE 2. The data demonstrate synchronicity between sea-surface cooling (PCE), oxygenation of bottom waters (Benthonic Zone), changes in sea-surface and intermediate circulation patterns (ε_{Nd} shifts) and extinction of rotaliporid planktonic foraminifera throughout the European epicontinental seas, Tethyan, Atlantic Ocean, and Western Interior Seaway. We suggest that the southward expansion of cool, relatively low saline and mesotrophic Boreal waters in the Northern Hemisphere during the PCE disrupted sea-surface thermal stratification at tropical latitudes and critically contracted the ecological niche occupied by rotaliporids playing a fundamental role in their extinction.

Diet controls foraminiferal nitrogen isotopes: a feeding experiment on *T. sacculifer*

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The isotopes of organic nitrogen (N) preserved in foraminiferal shells have been developed as a proxy for past ocean nutrient conditions. This proxy is based on the assumption that the N isotopes ($\delta^{15}N$) incorporated into the tests of heterotrophic foraminifera track the N isotopic composition of their diet. This is supported by modern seasonal covariations of $\delta^{15}N$ between foraminifera and particulate organic matter. However, little is known about the underlying mechanisms that translocate N from diet into foraminiferal soft tissue, and finally embedded into their mineralised shells.

We investigated the mechanism of N incorporation into foraminiferal tests by feeding living planktic, dinoflagellate-bearing *Trilobatus sacculifer* with two strains of brine shrimp (*Artemia*) with different naturally ^{15}N-enriched isotopic compositions. The evolution of $\delta^{15}N$ through the feeding experiment was examined by dissecting individual chambers and grouping them by the order of their growth sequence. The $\delta^{15}N$ of the dissected chambers and remaining soft tissue were measured. Both feeding groups show that the shell $\delta^{15}N$ and the soft tissue $\delta^{15}N$ are elevated, representing a mixing of original biomass N and new N from the food intake. However, the shell-bound and the soft tissue N show different mixing behaviours: shell $\delta^{15}N$ rapidly approaches diet $\delta^{15}N$, while soft-tissue $\delta^{15}N$ represents a mixed signal between the original

biomass and total diet intake. This observation suggests that the N-rich biomineralising organics incorporated into the shell are sourced from N in recently metabolised food particles, rather than the average soft-tissue N pool in the foraminifera.

These results will be presented and discussed in context of foraminiferal N metabolism, and the use of $\delta^{15}N$ as a tracer for past nutrient conditions.

A new species of *Eoparafusulina* (Fusulinacea, Monodoexodininae) from the Lower Permian of the Northwest Peninsular Malaysia: Its significance to Sibumasu Block (Eastern Cimmerian Continent) palaeobiogeography and palaeoclimatology

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A new species of *Eoparafusulina*, i. e., *Eoparafusulina perlisensis* sp. nov. is described from the Lower Permian sandy limestone in the Kubang Pasu Formation in Perlis of the Northwest Peninsular Malaysia. Previous Malaysian authors reported the occurrence of *Monodiexodina shiptoni* and *Monodiexodina sutschanica* from the same area. The findings of this study, nevertheless, enabled us to have a better overview on the Early Permian fusulinoidean fauna found in this region. The described new species has an almost symmetrical, and elongated subcylindrical shell somewhat similar to *Monodiexodina* described by Sosnina, 1956. Owing to its proloculus, juvenarium, and septal folding, however, this species corresponds to an advanced species of *Eoparafusulina* (sensu lato). These lines of evidence suggest that the specimens reported before in the Kubang Pasu Formation are morphologically transitional forms to *Monodiexodin*a, and they are not really a *Monodiexodina* (sensu stricto). Therefore, they should be included in the genus *Eoparafusulina*, too.

The late Sakmarian–early Yakhtashian (Late Cisuralian; late Early Permian) age of the investigated biozone is clearly indicated by the presence of fusulinid-markers like *Alaskanella, Eoparafusulina,* and *Pseudofusulina*. The genus *Eoparafusulina* is generally the characteristic element to determine the early Asselian–early Yakhtashian (= Artinskian) age in many sections world-wide. However, owing to the presence of *Alaskanella* which its age is considered to be late Early Permian close to the Sakmarian/Yakhtashian boundary, the age of the Kubang Pasu Formation is defined as the late Sakmarian–early Yakhtashian, not the late Yakhtashian–Bolorian that was previously suggested by the Malaysian workers.

The impoverished genera diversity in the Kubang Pasu Formation reveals that during the Asselian (early Early Permian), the Northwest Peninsular Malaysia was still part of the Gondwana continental shelf. It probably rifted from the Gondwana margin and started to drift towards equatorial regions during the late Asselian or early Sakmarian. The northward movement of Sibumasu Block during the late Early Permian is especially evident in the development of the found fusulinids in this work. During the late Early Permian, besides, the Northwest Peninsular Malaysia was located not far from the East Malaya (the Central and Eastern belts), but in the higher palaeolatitudes subtropical region.

The microfacies analysis of the Kubang Pasu Formation suggests a very high-energy shallow marine warm environment, more likely of the sand shoal.

Long-Term Evolutionary Trends within Benthic Foraminifera

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Foraminifera are important archives of paleo-oceanographic information that have evolved and diversified throughout the Phanerozoic. Their tests' mineralogy may reflect significant changes in global climate and ocean conditions. These organisms originated as organic walled and agglutinated forms before evolving calcareous tests in the early Silurian. It is logical to expect test wall type to vary through time as a result of global environmental and evolutionary changes. In this project, genus-level information was aggregated from *Foraminifera Genera and their Classification,* published by Loeblich and Tappan in 1988, the most recent and commonly used reference literature for foraminiferal genera. Our dataset includes the accepted name, wall type, first occurrence, and last occurrence information for 3,114 taxa. Using this data, we specified

2,442 genera, binned by Epoch level, tracked wall-type diversity, compared the ratios of calcareous versus agglutinated foraminifera, and contextualized foraminiferal responses to geologically significant events. Major findings include a high relative proportion of organic foraminifera from the Cambrian to the Ordovician Period. Calcareous foraminifera evolved in the Early Silurian and increased in relative proportions from the Silurian to the Devonian. There are notable decreases in relative abundance of calcareous foraminifera during the mid-Carboniferous warming, the Early Triassic Epoch, and the Triassic/Jurassic mass extinction event. Despite documented climatic fluctuations throughout the Cenozoic, calcareous foraminifera remain stable around 80% diversity from the Eocene through the Pleistocene. Comprehensive datasets such as this are essential for research about faunal diversity and paleoclimate records, ocean chemistry, and conservation. This data has the potential to inform global trends of benthic foraminifera and ocean chemistry throughout the Phanerozoic.

The geochemistry of non-spinose foraminifera: What is it good for?

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Over the last decade, culture experiments with non-spinose planktonic foraminifera have been performed to understand controls on trace element incorporation into shell calcite. When grown in culture, non-spinose planktonic foraminifera have relatively homogenous intrashell trace-element geochemistry for elements such as Mn, Ba and Sr. Yet, plankton tow, sediment trap, and fossil specimens from seafloor sediments have more heterogeneous trace element compositions, both intrashell and between individuals, including highly variable Zn, Mg, Mn, Ba, Sr, and likely others. Apart from Zn and Mg, this type of intrashell variability is generally absent in the spinose planktonic species.

Here, we present results from the foraminifera culture experiments and specimens that completed their lifecycle in the ocean and discuss potential mechanisms responsible for the intrashell TE variability. Elevated Ba and Mn suggest many non-spinose species calcify within organic marine snow microhabitats, and thus may be useful for tracking changes in the production of particulate organic matter in the past. If non-spinose species do occupy this unique niche, it raises the question: Does the particulate microhabitat complicate the utility of other trace element proxies? We will share intrashell trace element data collected by laser ablation ICP-MS, discuss potential mechanisms related to their incorporation, and consider complications related to microhabitat environments.

Deep-sea response to interglacial-glacial variability on the South Australian margin over the last 94 ka

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The continuous record offered by deep-sea sediments has been extensively used to constrain shifting continental and oceanographic conditions. Yet, past fluctuations in deep-sea benthic conditions and bottom-currents are in numerous parts of the globe scarcely documented, one such example being the South Australian margin. Indeed, though variations in surface water and terrestrial conditions in this area are well documented, little is known about benthic environments and their dynamics over the last interglacial-glacial cycle. We focus here on benthic foraminiferal assemblages sampled from a sediment core recovered at 2420 m depth from a small plateau south of Kangaroo Island within the underwater Murray Canyons Group (South Australian margin). Benthic foraminiferal assemblages show a distinct separation between interglacial and glacial periods over the last 94 ka, which can be linked to water-mass variations, shifting surface and benthic currents, together with variations in the River Murray's input and relative position across the Lacepede Shelf. Our results show that the lowest sea-levels, markedly during the Last Glacial Maximum, coincide with the highest oxygen content at the seafloor and with the transport of allochthonous benthic foraminifera from shallow-water areas due to the relative proximity

of the River Murray's mouth. Good seafloor oxygenation inferred from high abundances of miliolids possibly results from a greater influence of oxygen-rich Antarctic Bottom Water during the last glacial period. In contrast, fewer miliolids and greater numbers of epibenthic and phytodetritus-feeding benthic foraminiferal species during warm interglacial periods suggest a shift in benthic conditions in the area. We propose that the Deep Boundary Current, which transports low-oxygen, carbon-rich Indian Deep Water, strengthened during interglacials and favoured the proliferation of the observed assemblage. This significant change in the deep-sea domain mirrors the intensified circulation of Leeuwin Current at the surface.

Fossil benthic foraminifera from the Danakil Depression (northern Ethiopia): avian transport within an active rift valley

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The Danakil Depression, a rift valley reaching elevations of 125 m below sea level situated between the Ethiopian Plateau and the Danakil Alps, is one the hottest places on Earth. Evaporites precipitate within the rift basin and have done so at least since the late Pleistocene. Artisanal mining of the evaporites of the salt plain has been known since centuries. In contrast and unsurprisingly, much less knowledge has been gathered about foraminiferal faunas during past times. During the mid- to late Pleistocene, marine incursions flooded the depression at least four times, leading to the formation of fringing coral-algal reefs topped by gypsum. The two most recent marine incursions date back to MIS 5e (approximately 129 ka ago) and MIS 7 (approximately 200 ka ago). The study of a 625 m long commercial core (DAN003D) drilled by BHP Billiton in the centre of the basin allowed for a palaeoenvironmental reconstruction of the area. The core is believed to cover approximately the last 100 ka and is essentially made up of thick halite deposits, testimony of a warm and dry climate. However, two clastic-rich and clayey intervals are found within the top and bottom parts of the core, corresponding respectively to the late Pleistocene and late MIS 5e. Benthic foraminifera, essentially *Ammonia* spp. and *Elphidium* spp., and ostracods, were retrieved from these intervals and illustrated by Scanning Electron Microscopy. This microfaunal assemblage is typical of modern-day coastal shallow water environments and would suggest that the Danakil Depression was wetter than nowadays and subject to marine incursions. Yet, as evidenced by various proxies, no marine incursions took place during the deposition of Pleistocene foraminiferal-bearing sediments. We hence propose that during the late Pleistocene, benthic foraminifera and/or their propagules were carried by avian transport from the neighbouring Red Sea within the saline lakes of the Danakil Depression, in turn pointing to a possible important ecological role of the area for migratory birds.

Polyphyletism and parallel evolution in Foraminifera and their implications in biostratigraphy. Two new examples from the Priabonian of the Helvetic Alps

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Recurrent evolution of similar or equivalent forms through geologic time is common in Foraminifera. We show two examples from the Priabonian Sanetsch Fm in the Helvetic Nappes of the Swiss Alps: one dealing with polyphyletism and the other with parallel evolution.

1-*Rotorbinella*, a polyphyletic genus

Rotorbinella is a small hyaline foraminiferal genus with the simplest rotalid architecture: a simple umbilical plate delimiting a spiral canal around an umbilical plug. It appears in the Cenomanian and has a discontinuous stratigraphical range with species known from the Cenomanian, Coniacian-Santonian, Paleocene-Ilerdian and Miocene-Recent time intervals.

We identified a new species from the Sanetsch Fm, *Rotorbinella* sp. 1. The differences with other *Rotorbinella* species are subtle and refer to quantitative characters. These differences, together with the hiatuses in the stratigraphical record of *Rotorbinella,* point to a polyphyletic origin of *Rotorbinella*. This simplest rotalid architectural model would have originated

recurrently, first in the Cenomanian, and latter during the upper Turonian, the Paleocene and also in the lower Priabonian. Most Miocene to Recent species are known only from external characters and need a revision including structural studies.

2-Diachronous parallel evolution in Caribbean and Tethyan *Asterocyclina*

Orthophragminids are a group of orbitoidiform larger foraminifera that thrived during the Eocene. They consist of several genera of two different families, Discocyclinidae and Orbitoclypeidae, both originated in the Caribbean. In the Thanetian (late Paleocene) the discocyclinid *Discocyclina* and the orbitoclypeid *Orbitoclypeus* reached the Tethys. During the Eocene both groups evolved separately in the two bioprovinces. *Orbitoclypeus* gave rise to equivalent stellar ribbed forms, assigned to the genus *Asterocyclina*, which has the same stratigraphical range in the two bioprovinces. However, from the data available, it is not possible to ascertain if *Asterocyclina* evolved in parallel in the two bioprovinces or migrated from one to the other.

In the Caribbean, some species of *Asterocyclina* developed a new character, which we have named *rods*: radial thickenings of imperforate calcite along the ribs. This was a feature known only in middle-upper Eocene Caribbean species. Now we have found this character in a late Eocene Tethyan species, *A. ferrandezi*. Furthermore, rods are found in two new subspecies (=phylogenetic chronospecies), which occur in Shallow Benthic Zones 19 and 20 respectively. A revision of own samples and of the literature showed that they occur in different basins of the western Tethys.

Apart of their interest as new biostratigraphical markers for the Priabonian, these two new subspecies are relevant because they demonstrate the occurrence of parallel evolution in larger foraminifera. While in the Caribbean species of *Asterocyclina* with rods appeared yet at the early middle Eocene, in the Tethyan realm they originated during the late Eocene. In this case, parallel evolution is made evident because it is diachronous, but this is rather the exception. Biochronostratigraphical correlation based on equivalent species from different bioprovinces should have to be considered with the utmost caution. It can easily lead to either erroneous biostratigraphical correlations between different bioprovinces or to misinterpretations of the timing or direction of migration.

Disentangling implications of changes in morozovellids coiling direction at the Eocene Climatic Optimum (EECO, ca 53-49 Ma) (Pacific, Atlantic and Indian Oceans)

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A major change in planktic foraminiferal populations occurred at the start of the Early Eocene Climatic Optimum (EECO), the interval of peak Cenozoic warmth from between ~53–49 million years ago (Ma). The symbiont-bearing genus *Morozovella* suffered an abrupt and permanent decline in abundance and taxonomic diversity after dominating tropical-subtropical early Paleogene assemblages. Conversely, the genus *Acarinina* markedly increased in abundance and diversity.

Moreover, at ocean drilling sites in the tropical Pacific (1209-1210), and the Indian Ocean (762) morozovellids display a switch from dominantly dextral coiling preceding the EECO, to sinistral coiling within the EECO, as previously recorded in Atlantic Ocean sites (1051, 1258, 1263). This happens close to the carbon isotope excursion known as K/X or ETM-3 (~52.8 Ma), which also provides a new biostratigraphic tool for correlation.

To interpret the observed changes, we measured the $\delta^{13}C$ composition of dextral and sinistral morozovellid and acarininid morphotypes spanning the start of EECO. Carbon isotope data reveal that sinistral morphotypes belonging to the same morphospecies typically have lower $\delta^{13}C$ values. The dominance of sinistral morphotypes, at the expense of dextral forms within the EECO, coupled with the lower $\delta^{13}C$ signatures of the former, suggests that the sinistral forms were less dependent on their photosymbiotic partnerships, possibly moving slightly down in the mixed-layer, and thus able to adapt more readily to paleoceanographic change at the EECO. Remarkably, the genus *Acarinina* does not display coiling preferences throughout and its $\delta^{13}C$ data suggest greater flexibility giving evidence of major resilience to the EECO perturbance. Whether sinistral and dextral morozovellids were the result of cryptic speciation, our record implies an evolutionary selection favouring sinistral forms. Alternatively, whether the coiling changes were exclusively environmentally controlled, the different species were able to preferentially adopt sinistral coiling as a result of changed conditions in the mixed-layer during the EECO.

Planktic foraminiferal abundance and test-size record across the Early Eocene Climatic Optimum (EECO, ~53-49 Ma) at Shatsky Rise (Pacific Ocean)

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The dynamic early Paleogene climate presents the crucial opportunity to detect relationships among calcareous plankton productivity, past carbon cycle perturbations and climate. We focus on the Early Eocene Climatic Optimum (EECO, ~53-49 Ma) as it is associated with peak temperature and pCO_2 of the Cenozoic and therefore offers a long-term perspective of global warming impacts on marine biota. We investigate the Pacific sites 1209-1210, complementing evidence that the EECO markedly impacted planktic foraminiferal assemblages at the Atlantic Oceans. The selected sites have an excellent age model and stable isotope constraints that document the carbon isotope excursions that are the expression of the several hyperthermals events superimposed on the long-term warming. We record an abrupt and permanent abundance decline of more than one-third for the symbiont-bearing genus, *Morozovella,* from the beginning of the EECO (J event, ~53 Ma) at sites 1209-1210, whereas *Acarinina* concomitantly increased in agreement with Atlantic sites. One possible cause of the morozovellid abundance decline is a negative impact on their photosymbiotic relationships with algae, as suggested by the lower $\delta^{13}C$ values exhibited by survivors. Symbiosis is advantageous in the oligotrophic mixed-layer habitat and increases growth and final size. Therefore, we hypothesise that the morozovellid decline may have reduced planktic foraminiferal productivity and test-size. We evaluated the Coarse Accumulation Rate (CFAR) as an approximation of the planktic foraminiferal accumulation rate. The >38 μm dominantly consists of planktic foraminifera in pelagic sediments and here is not significantly affected by dissolution which would reduce CFAR. In addition, we perform a test-size analysis on planktic foraminiferal assemblages across the EECO. Changes in the size of marine calcifiers can be caused by evolutionary mechanisms or environmental perturbance, both of which represent potential consequences of extreme warmth. Earlier work has shown that morozovellids are generally larger than acarininids, hence suggesting that size should decrease when morozovellid abundance drops. Samples were split into aliquots of 1000–1500 specimens and imaged at 160x magnification. The morphological parameters were analysed in Olympus Stream Motion, and the 95th percentile of the maximum diameter was calculated. Unexpectedly, our results show that the planktic foraminiferal assemblages do not display test-size reduction. Overimposed to a long-term general test size increase trend, we recorded test-size fluctuations across the short-term hyperthermals. The increase of planktic foraminiferal sizes across the hyperthermals may be linked to increases in the abundance of acarininids and decreases of morozovellids, which is the common pattern across these events. CFAR decreases across the EECO during the morozovellid abundance reduction, suggesting that this decline impacted overall planktic foraminiferal productivity and was seemingly not balanced by the acarininids. Future test-size analysis of the two groups involved will help to unravel a more exhaustive response to the EECO perturbance of planktic foraminiferal assemblages.

A new high resolution stable isotope record from the North Atlantic Ocean: a detailed insight into the mid-Maastrichtian event

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The long-term global cooling trend during the latest Cretaceous was interrupted by an intense global warming episode at ~69 Ma known as the mid Maastrichtian event (MME). The MME is characterized by two positive $\delta^{13}C$ excursions with an overall magnitude of 0.6‰ to 1.5‰ separated by a negative inflection. The $\delta^{13}C$ excursions are accompanied by the extinction of inoceramid bivalves, an abrupt increase in deep-sea and sea-surface temperatures as well as terrestrial mean annual temperatures between 21 and 23 °C at a paleolatitude of ~35° N. Changes in oceanic circulation, particularly a change in thermohaline circulation patterns, have been identified to be one of the main drivers of the MME. Nevertheless, the driving mechanisms, timing, character, and consequences of the circulation change are still up for debate. In this study, a 2 Myr-long time interval of the Mid to Late Maastrichtian has been analyzed at a ~2.5 to 5 kyr-resolution with the aim to improve the understanding of the climatic patterns leading to the MME. For IODP Core U1403 in the North Atlantic (J-Anomaly Ridge), XRF core scanning, wt% $CaCO_3$ analyses, and stable oxygen and carbon isotope records of benthic foraminifera were generated. Bottom-water temperatures were reconstructed through Mg/Ca measurements of the same

foraminiferal tests. Preliminary data reveal a warming of North Atlantic deep-sea temperatures by ~2–3°C between ~68.5 and 69 Ma, accompanied by several $CaCO_3$ dissolution events as well as $\delta^{13}C$ excursions of up to 0.8 ‰. These findings point towards a major perturbation in the global carbon cycle accompanying the overall change in ocean circulation whose causes appear to be more complex than previously thought.

Test volume response to bottom water oxygen changes in *Cibicidoides wuellerstorfi*

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Benthic foraminiferal test morphologies and morphometrics have been used as proxies for paleoceanographic reconstructions based on the observation that variations in test formation record changes and stresses affecting the organisms. Test volumes have been thought to be sensitive to variations in available oxygen with some evidence showing an inverse correlation between foraminifera test size and aqueous oxygen availability. However, there is still a large amount of uncertainty in this relationship and its broad applicability to reconstruction efforts.

In an effort to further elucidate the relationship between test volume and bottom water oxygen in epibenthic foraminifera, volumetric analysis will be performed on a set of *Cibicidoides wuellerstorfi* specimens from different bottom water oxygen environments. These samples will be imaged via micro-computed tomography (micro-CT). Three-dimensional models derived from the micro-CT reconstructions will then be used to assess whole test volume of each specimen in the data set.

This work will be done in conjunction with pore surface area and I/Ca ratio analysis. Both pore surface area and I/Ca ratios have shown a strong correlation with bottom water oxygen levels and will be correlated with whole test volumes to assess the idea that reduced volume, and consequently surface area, is beneficial to the foraminifera inhabiting low oxygen environments, and is thus indicative of such environments.

If validated, this relationship would make for an attractive proxy when using foraminifera from the fossil record as it would be less susceptible to diagenetic factors that could potentially limit the quality of other proxy methods. This would be especially beneficial in observing changes in oxygenation through paleoceanographic events such as the Paleocene-Eocene Thermal Maximum (PETM) or the Cretaceous-Paleogene (K-Pg) boundary when combined with other proxies such as BFOI (Benthic Foraminifera Oxygen Index), I/Ca ratios, or pore surface area.

Tappan & Loeblich's phylogeny of Foraminifera families: dusting it off for a closer look

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A digital version of the tree of foram families by Helen Tappan Loeblich and Alfred Loeblich, Jr. published in 1988 has provided a platform by which to better access and newly assess the Loeblichs' last word on foram origins, of ancestor–descendant relationships. Their phylogeny has been calibrated stratigraphically (against GTS2020) and this can now be maintained into future time scales. Reported stratigraphic occurrences and the conjectured intervals implied by their phylogenetic proposals are made graphically distinct. Pop-ups of ancillary information, such as basic taxonomy and stratigraphic distribution, higher and included taxa, and representative images, has allowed an alternative and, in some ways more easily accessible, means by which to tap the rich knowledge contained in the Loeblichs' *Treatise* and *Genera* tomes. Thumbnail images for each family on the tree have been carefully size-transformed to reflect actual size, despite the several orders of size represented across all forams. All of this information has been encapsulated in a back-end relational database, which can provide transparent documentation and be available for scrutiny and sharing by the specialist community.

At the suborder level the Loeblichs were able to almost fully implement their vision of 12 monophyletic groups (in the context of evolutionary taxonomy) recognised by wall composition and microstructure. Their more diverse choice of features applied to define 98 superfamilies proved more challenging for their phylogenic thinking and so, despite their wish to express evolutionary relationships through classification, they implied that around 20% of these superfamilies were probably polyphyletic in terms of family origins, some with 3 or even 4 different ancestral families. Then, at the level of family, a quarter of the phylogenetic relationships they proposed were not supported by the stratigraphic distributions that they themselves had compiled. They clearly, as they had often stated, were juggling a number of aspects when considering phylogeny, not only stratigraphic order.

It would, therefore, be misguided to consider the interplay between the Loeblichs' classifying and their phylogenetic thinking, made from the benefit of multidecadal hindsight, as a criticism of their work. Their attempts were surely heroic in the context of a massive life-long program to provide a coherent account of all forams, living and fossil, down to genus. What emerges rather is a rich and sophisticated approach taken by the Loeblichs to forams, albeit one that we would these days expect to be more explicitly documented, but which cannot be dismissed as in any way simplistic. This would of course, for example, argue against any suggestion that they, as representatives of so-called evolutionary paleontologists, applied stratigraphic order as some straightforward connecting framework for stitching together phylogenic trees.

How do morphological and eDNA data compare for biomonitoring? An example with the distribution of three *Ammonia* (Foraminifera, Rhizaria) species in estuaries of the French Atlantic coast

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Assessing the distribution of species in a given environment is essential to understand their ecology and disentangle natural and anthropic influences. In this study, we investigate three pseudocryptic species formerly mixed in the morphospecies *Ammonia tepida*: *Ammonia veneta* (phylotype T1), *A. aberdoveyensis* (phylotype T2) and *A. confertitesta* (phylotype T6). These pseudocryptic species are major constituent of foraminiferal assemblages in intertidal and shallow waters environments along the European coasts, with *A. confertitesta* usually being considered as an exotic species originating from eastern Asia. Their morphological discrimination has only become possible recently, allowing us to assess potential differences in their ecological characteristics. To understand the distribution of these species, we used a combined morphological and molecular approaches at 64 sites in seven estuaries along the French Atlantic coast.

While the combination of morphological and molecular methods confirmed the presence of the three species in all seven estuaries, the two methods showed discrepancies in their distribution. *Ammonia confertitesta* was present in all estuaries in the eDNA data set but was rare or absent in the morphological inventory of the northern estuaries (Elorn, Aulne, Odet, Crac'h and Auray) dominant in the southern Vilaine estuary and common in the Vie estuary further south. The large variability in absolute and relative densities (morphological data) of the supposedly invasive *A. confertitesta* suggests an opportunistic behaviour for this species. It appears that despite the widespread presence of genetic material (including adults, juveniles and propagules), the *A. confertitesta* population has not yet fully developed everywhere. The seven investigated estuaries represent different stages of replacement of the autochthonous species *A. veneta* and *A. aberdoveyensis* by *A. confertitesta*. Favourable conditions for such a replacement could be created by major river floods, creating temporarily vacant ecosystems. These would be preferentially recolonised by *A. confertitesta*, because of its more opportunistic behaviour and perhaps a higher tolerance to low salinity. Our study demonstrates that the combination of morphological and eDNA approaches is optimal to reveal the current and potential spreading of possible invasive species in estuaries and allows a better understanding of the natural distribution of species in the different estuaries.

Temporal changes in intertidal benthic foraminifera: a seasonal survey from the English Channel (France)

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Intertidal ecosystems are fragile environments that are naturally stressed by high spatial and temporal variability of physico-chemical parameters. In addition, these environments have been increasingly affected by the consequences of global

warming and the associated rise in mean sea level, heatwaves. The intertidal areas of the Hauts-de-France (English Channel, France) stand out for the occurrence of vulnerable ecosystems that have experienced natural and human–induced stresses. Over the last two centuries, the northern part of this region has been exposed to a strong human pressure, with the development of numerous activities (i.e., metallurgic factories, fisheries, embankments). On the contrary, its southern part includes less impacted areas. The objectives of this study are: 1) to characterise the seasonal variations in abundance (i.e., foraminiferal density, FD) and diversity of benthic foraminifera and 2) to identify which species are the most frequent and their temporal variations in this region based on a one-year survey. Sixteen sampling stations were selected from five sampling areas along the intertidal zones of Hauts-de-France with different levels of humanisation. At each of the four seasons (spring 2014; summer 2014; autumn 2014; and winter 2015), four replicated sediment samples were collected at each station. Three replicates were used for the foraminiferal analysis and the fourth was used to measure abiotic parameters (i.e., grain-size, total organic carbon, C/N ratio), collecting 256 samples (192 for foraminifera and 64 for sediment properties). Statistical analyses (i.e., Krustal-Wallis test and PERMANOVA) were carried out to reveal any significant influence of seasonality on foraminiferal assemblages. Significant seasonal variations were observed for FD although it did not show a clear temporally trend across the region. The diversity showed a significant seasonal influence with the highest values commonly found during spring and summer. For both FD and diversity, different patterns were exhibited in natural and human–altered stations. *Haynesina germanica* and *Elphidium selseyense* were the most frequent species differently distributed across the region. They both showed significant seasonal variations. The overall outcomes of this survey shed light on complex seasonal patterns in benthic communities of intertidal environments. Furthermore, this study evidences the importance of baseline and temporal investigations to plan further environmental monitoring of ongoing climate and human-related changes in the intertidal settings.

Proton pumping influences element incorporation in hyaline foraminifera

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Despite sharing similar calcification pathways, the amount of Mg incorporated by hyaline foraminiferal species varies significantly (from ~100 to as low as 1-5 mmol/mol). Such variability is determined by biological factors, for which the underlying mechanisms remain only partly known. In this study, we show that the functioning of cellular V-type H^+ ATPases, interpreted by external H^+ fluxes outwards, are stronger in species with low Mg/Ca ratios. In order to maintain charge neutrality, increased activity of H^+ transporters correlates with inward Ca^{2+} fluxes and thereby decreases Mg/Ca values in the fluid from which foraminifera calcify. This confirms the importance of transmembrane transporters on calcium accumulation and thereby their role in element to calcium ratios in foraminiferal shells. We furthermore show strong modulation of mitochondrial distribution during biomineralization, helping to clarify where enzyme-mediated H^+ transport occurs. As they are densely distributed at the calcification site, mitochondria may also serve as a (temporary) storage site for the Mg^{2+} extracted from the site of calcification as well as providing the energy for H^+/Ca^{2+} ion exchange.

Short-term waxing and waning of Antarctic ice sheets during the late Oligocene – evidence from benthic foraminiferal geochemistry

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Sandwiched between the early Paleogene greenhouse and Neogene icehouse climates, the Oligocene epoch (33.9–23.03 Ma) represents what is arguably the most important transitional phase of Cenozoic climate evolution, with the first major expansion of Antarctic ice sheets (AIS). Temporally highly resolved paleoclimatic and paleoceanographic proxy records for the Oligocene therefore are a prerequisite for obtaining deeper insight into the fundamental mechanisms and processes involved in the waxing and waning of continental ice sheets. Whereas the long-term evolution of Oligocene glaciations is rather well known, current knowledge about short-term (i.e., orbital to suborbital scale) ice-sheet dynamics is still very limited and a matter of ongoing debate. Therefore, the focus of this project is to elucidate short-term ice-sheet dynamics

during the Oligocene based on proxy data from IODP Site U1406 (Newfoundland Ridge, North Atlantic). Stable oxygen isotope measurements of benthic foraminifera have been used to establish a high-resolution age model for the studied interval of Site U1406. Mg/Ca-based bottom-water temperature (BWT) reconstructions have been established on the same samples to allow the $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$; a proxy for sea-level/ice-volume) to be calculated.

Our records indicate four glacial-interglacial obliquity-paced cycles with ice-volume changes of up to ~70% of the modern AIS. The amplitude of ice-volume change during these late Oligocene glacial-interglacial cycles is comparable to that of the late Pliocene and early Pleistocene. Ice-volume estimates for interglacials are small enough to be accommodated by a land-based AIS but, for three of the four glacials studied, our calculations imply that ice sheets likely advanced beyond the Antarctic coastline onto the shelves. Our findings suggest an AIS vulnerable to melting driven by both bottom-up (ocean) and top-down (atmospheric) warming under late Oligocene warmer-than-present climate conditions.

Evaluation of the effects of decabromodiphenyl ether BDE-209, a persistent organic pollutant, on benthic foraminiferal community using morphological and eDNA metabarcoding approaches

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Persistent Organic Pollutants (POPs) are organic compounds that are resistant to environmental degradation. Among them, the polybrominated diphenyl ethers (PBDEs) are known for their toxicity, lipophilicity, persistence, and resistance to degradation and bioaccumulation potential. Many studies have recently reported that BDE-209 (decabromodiphenyl ether) could be accumulated in the environment and has been found to exhibit toxic effects on organisms. The BDE-209 is among the most common and the widest occurring POPs in some coastal-industrial areas of Kuwait posing serious threats to human health and the environment. A mesocosm experiment was conducted to evaluate the impact of BDE-209 on benthic foraminiferal (protozoan) communities. Sediments bearing such communities were incubated in mesocosms, exposed to varying levels of BDE-209 and monitored for up to 12 weeks. Relatively high concentrations of BDE-209 affected benthic foraminiferal communities (i.e., molecular and morphological ones) by reducing their diversity and changing their composition. No CTG-labelled (i.e., living) foraminiferal specimens were identified at high concentrations, namely 10 and 20 mg/L after 8 weeks of treatment, whereas ASVs were found at the highest concentrations even at the end of the experiment. Despite the significant difference in the composition of the two communities, the response of the foraminiferal molecular community well mirrored that of the morphological one. The present investigation evidences that BDE-209 pollution has detrimental effects on benthic foraminifera. This spiked-sediment toxicity approach may represent a valid complementary tool by which the effect on the biota of a single pollutant or a set of mixed organic or inorganic pollutants can be studied over time under controlled environmental conditions (i.e., micro- and mesocosms). These findings emphasize the importance of using foraminiferal communities in laboratory experiments to assess cause-and-effect relationships to allow for the validation of field study outcomes and test the sediment quality guidelines and thresholds.

Benthic foraminiferal changes in hydrothermal areas around Ischia Island: the evaluation of the effects of ocean acidification through morphological and molecular ecology

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Since the beginning of the Industrial Revolution, the use of fossil fuel has resulted in an atmospheric increase in carbon dioxide (pCO_2) and a concurrent alteration of ocean chemistry with a decrease in ocean pH and of the carbonate saturation state. These changes in water chemistry, referred to as Ocean Acidification (OA), are also leading to biodiversity loss and an impact on key marine organisms that rely on calcium carbonate for building their skeletons or shells. Future OA scenarios can be studied and modelled in hydrothermal areas, particularly in correspondence of vents such as in Ischia Island (NW sector of the Gulf of Naples, Southern Italy) that represents one of these natural laboratories. In this research, the variations of benthic foraminiferal (i.e., morphological and molecular) communities were investigated in fourteen samples collected along two transects at North and South of the Castello Aragonese bridge, where clear pH gradients were reported. The sites with the lowest pH values are dominated by agglutinated specimens that are less to not prone to dissolution. On the other hand, calcareous specimens, both hyaline and porcelaneous, are mostly found at sites with normal marine pH values. Variations of benthic foraminiferal parameters like density or living/dead specimens are not only driven by pH values but also by the occurrence of the *Posidonia oceanica*, a seagrass, and the sediment grain-size (i.e., mud). The wall-type changes of the morphological community along the pH gradients correspond well to those identified in the molecular community. These observations suggest that OA negatively affects the benthic foraminiferal communities and support the application of the foraminiferal metabarcoding even in the assessment of the effects of climate changes.

Response of large benthic foraminiferal assemblages to sea-level changes over the past 40,000 years in the Great Barrier Reef: IODP Expedition 325

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To understand sea-level changes since the Last Glacial Maximum (LGM) and their effects on coral reef systems, shelf-edge slopes of the Great Barrier Reef (GBR) were cored during the Integrated Ocean Drilling Program (IODP) Expedition 325. Recovered unconsolidated sediments beneath the submerged shelf edge reefs contain abundant foraminiferal tests, which record changes in depositional environments and paleo-water depth. Here we present a record of these changes obtained by foraminiferal analyses. A total of 177 sediment samples were collected from 17 drill holes along three transects located within two geographical areas (Noggins Pass and Hydrographers Passage), and were analysed to determine stratigraphic changes in benthic foraminiferal assemblages (2–0.5mm size fraction). Results show that four foraminiferal assemblages (A, B, C and D) are delineated by multivariate analyses (Q-mode cluster analysis and non-metric multidimensional scaling: NMDS), and these assemblages correspond to a back-reef to reef margin zone (0–10 m deep; Assemblage A), an upper photic zone (10–30 m deep) associated with hard substrates (Assemblage B), an intermediate to lower photic zone (30–90 m deep) characterized by soft substrates (Assemblage C), and a lower photic zone (90–130 m deep) only found in modern shelf slopes (Assemblage D). Gradual shifts in these four foraminiferal assemblages mainly reflect a water-depth gradient and the relative dominance of substrate types (hard and soft substrates). The lack of Assemblage D in pre-LGM deposits from all transects could be related to lowering temperature and/or increasing terrestrial sediment flux (i.e. more light attenuation).

Sedimentological and foraminiferal analyses of unconsolidated reef sediments recovered in cores 111–140 m below sea level at Hydrographers Passage revealed the occurrence of a benthic foraminiferal assemblage dominated by the genera *Calcarina* and *Baculogypsina*, which is common in modern reef-flat and back-reef environments in the Great Barrier Reef and elsewhere. This assemblage is associated with higher foraminiferal proportions in reef sediments and higher proportions of well-preserved *Baculogypsina* tests in the same intervals, which also characterize reef-flat environments. Radiocarbon (^{14}C–accelerator mass spectrometry) ages of reef-flat dwelling foraminifers, which indicate the time when these foraminifers were alive, are consistent with the timing of two-step sea-level falls into the LGM. This foraminiferal evidence suggests the development of geomorphologically mature fringing reefs with shallow back-reef lagoons during the LGM.

The lower part of cores drilled on the shelf edge slopes of Hydrographers Passage, consisting of lime (carbonate) sand with bioclastic grains, cover periods from late Marine Isotope Stage 3 (MIS 3) to the LGM. During a period from 35 to 29 ka, the proportion of soft bottom-dwelling *Operculina* spp. decreased, whereas that of fore-reef-dwelling *Amphistegina lessonii* increased. Shallow-reef-dwelling *Baculogypsina sphaerulata* and *Calcarina* spp. also increased at a shallower site, indicating the gradual proximity of reef-flat habitats. Decreased planktonic foraminiferal ratio in a fine sand fraction

indicates a gradual decrease in open-water influence. These foraminiferal trends indicate a shallowing upward pattern from 35 to 29 ka, recording rapid sea-level fall and full glaciation into the LGM.

Foraminiferal view on Toarcian environmental perturbations on the northern part of the Adriatic Carbonate Platform, Slovenia

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The Toarcian (late Early Jurassic) is marked by environmental perturbations caused by volcanism. Most notable is the spreading of marine anoxia and deposition of organic-rich facies in epicontinental seas, known as the Toarcian oceanic anoxic event (T-OAE, ~183 Ma). The effects of climate changes, increased weathering and primary marine productivity, and a decrease in bottom oxygen levels are poorly understood in the case of carbonate platforms.

The Lower Jurassic succession from the Adriatic Carbonate Platform (AdCP) of the western Tethys comprises Hettangian peritidal carbonates, Sinemurian subtidal facies, upper Sinemurian–Pliensbachian lagoonal, oolite shoal and lithiotid "buildups" facies, and Toarcian middle/outer ramp facies. The latter is represented by nodular and mottled carbonate mudstone and wackestone, known as Spotted limestone, vertically and laterally alternating with crinoid and/or oolite grainstone facies. The Pliensbachian-Toarcian succession indicates relative deepening caused by tectonics. Due to their dependence on oxygen levels and supply of organic matter, benthic foraminifera might offer important insight into palaeoenvironmental conditions on the AdCP during the Toarcian. Transition from the Pliensbachian to Toarcian was recorded in the Radensko Polje section (northern Dinarides, central Slovenia). Thin sections were used for investigation of facies changes and foraminiferal assemblage. Besides taxonomic determination, diversity, the proportion of opportunistic species, and the proportion of epifaunal, shallow infaunal, and potentially deep infaunal morphotypes were determined.

The lower 7 m of the Radensko Polje section consists of packstone and grainstone with intraclasts, peloids and bioclasts, presumably late Pliensbachian in age. Skeletal grains are common, comprising fragments of molluscs, corals, crinoids, calcimicrobes, and foraminifera. The latter comprise 16 determined and 4 undetermined species. Foraminifera are relatively common, with often more than 24 specimens in an area of 4.5 cm^2. Shannon-Wiener diversity index in a single sample is up to 1.5. Epifaunal forms represent 55–70% of the specimens, shallow infaunal 25%, and potentially deep infaunal 5–20%. Opportunists and ecological specialists are equally represented. The succession continues with 7 m of mudstone and bioclastic wackestone, subordinately peloid-bioclastic grainstone. *Chondrites* burrows are common in mudstones, and parallel lamination and hardground surfaces are present in bioclastic-peloid wackestone to grainstone. Bioclasts are rare in this part, comprising undetermined skeletal fragments and sponge spicules. Foraminifera are rare or absent. Opportunist *Meandrovoluta* and small nodosariids represent epifauna and shallow infauna. The diversity index is 0.10. The Spotted limestone is overlain by oolite wackestone–grainstone, subordinately bioclastic wackestone. Grading, lenses of bioclastic packstone/grainstone, amalgamation, and vertical burrows are present. Radial ooids and crinoids are characteristic, as well as foraminifera attached to ooids. Bioclasts locally represent 85% of grains. The number of foraminifera per thin section is up to 51 per 4.5 cm^2. Ten determined and eight undetermined species were recognized, of both specialists and opportunists. Epifaunal forms represent 45–85% of the specimens, shallow infauna 15–45%, and potentially deep infauna 0–15%.

The presence of foraminifera throughout the succession, including the entire Spotted limestone unit, testifies against a long-term anoxia in the Toarcian in relatively shallow, supposedly photic-zone depositional environments of the northern AdCP. The drop in diversity and the large proportion of opportunistic taxa is consistent with the idea of environmental perturbations during the Toarcian. Possible explanations are lower stability of the environment, food availability diminution and depleted oxygenation.

Eocene to Oligocene high paleolatitude neritic record of Oi-1 glaciation in the Otway Basin southeast Australia

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Multiple foraminiferal stable isotope investigations from upper Eocene to lower Oligocene deep-water marine sequences record the transition from global greenhouse to the icehouse conditions (Oi-1 glacial). While Southern Ocean high latitude deep sea records of this transition are well known, their shallow marine equivalents are rare and have the potential to record the eustatic and oceanic consequences of Paleogene glacial variability. The well-known high paleolatitude (~55°S) neritic carbonate sequence at Browns Creek and Castle Cove in the Otway Basin in southeast Australia spans the Eocene-Oligocene boundary. During this time the area lay on the northeastern margin of the Australo-Antarctic Gulf facing the evolving Southern Ocean. The importance of this record has been hampered by a lack of a consistent stratigraphy and contradictory foraminiferal interpretations. To reconcile these issues we combine new foraminiferal and nannofossil bio-, chemo- and lithostratigraphic analyses of the outcrops and a new core (Colac-2) with pre-existing data to revise the stratigraphy. This confirms the middle/upper Eocene boundary is near the base of the section. The overlying upper Eocene siliciclastic strata are truncated by an unconformity (of ~0.8 Ma in duration) and overlain by glauconitic sand (the *Notrostrea* greensand) deposited after ~35.9 Ma. Subsequently deepening to middle to outer neritic depths deposited cyclic carbonates. Shallowing after ~35 Ma deposited laterally variable calcareous siliciclastic facies. These strata were tilted and eroded prior to 34 Ma leading to shallow water facies that may have been subaerially exposed during uplift. Brachiopod strontium isotope dates and an 0.5‰ carbon isotope excursion above this unconformity suggests the top of the Browns Creek and the base of the Castle Cove section correlate to Eocene-Oligocene transition (EOT-1) at ~34 Ma. The subsequent persistence of positive C/O isotope values above this level records the transition to the Oi-1 glaciation at ~33.7 Ma. Strong cyclicity in the inner shelf Castle Cove limestone is interpreted to record the commencement of obliquity dominated glacio-eustacy during the Oi-1 glacial phase. The shallowing from outer to inner shelf palaeodepths from the late Eocene to the early Oligocene is likely related to the onset of cryosphere expansion, however, palaeodepth estimates are complicated by the onset of regional compressional tectonism at the Eocene/Oligocene boundary that caused localized tilting and an unconformity with possible antisiphoning effects in this near-field site.

Resilience of microbenthic and planktic foraminiferal across the Middle Eocene Climatic Optimum (MECO) along the shallow-water Sealza succession (Liguria, NW Italy)

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This study focuses on the Middle Eocene Climatic Optimum (MECO, centered at ~40 Ma) which is one of the major Eocene global warming events, characterized by ~4–6°C warming, shifts in the global carbon cycle and rise in atmospheric pCO_2. Even though the MECO is a still enigmatic event, studies on its paleobiotic effects are yet rather limited, and exclusively focused on deep water settings.

We present here new quantitative analyses of planktic and benthic foraminifera to assess the effect of the MECO on the biotic groups studied along the shallow-water section of Sealza in Liguria (NW Italy). This succession is interpreted as the product of a drowning ramp influenced by continuous tectonic activity and provides an exceptional chance to compare biotic variations in shallow-water assemblages with deep-water communities across the MECO. At Sealza section, the MECO interval is constrained by stable isotope oxygen data and the presence of the species *Orbulinoides beckmanni*, defining the Total Range Zone E12 which range largely corresponds to the MECO event.

The succession is over 200 meters thick, and we subsampled almost 15 meters (SE25-SE41) for foraminifera and nannofossil extractions. In addition, over 50 bulk samples as well as selected isolated planktic and benthic foraminifera were analyzed for stable isotopic composition.

Around 300 foraminiferal shells were picked from each sample to evaluate the resilience of different planktic and benthic species. The abundance of planktic foraminifera is generally scarce, as expected from a shallow-water succession. The most abundant genus is the cold index *Subbotina*, which however records its lowest abundance within MECO interval.

The most abundant genera among benthic foraminifera that are well-preserved and easily recognizable, are the epifaunal *Cibicidoides* and *Anomalinoides,* but the genera *Uvigerina* and *Bolivina* were also observed.

The results different from the majority of published materials that deal with deep water settings, as most of the taxa retrieved are shallow water dwellers. The data obtained clearly separate those taxa that are more resilient from those that are heavily affected by the MECO. We assume that MECO enhanced the runoff from the onshore riverine system and that produced more material deposited into the shallow offshore, thus modifying the substrate and reducing the irradiation on the seafloor.

Planktic and benthic foraminifera across the Middle Eocene Climatic Optimum (MECO): the case study of the shallow-water Capo Mortola succession (Liguria, NW Italy)

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The early Paleogene is characterized by several warming episodes that are evaluated as analogues to the ongoing climate change. Herein, we focus on the Middle Eocene Climatic Optimum (MECO, centered at ~40 Ma), which is one of the major Eocene global warming events, characterized by a ~4–6°C warming, shifts in the global carbon cycle and rise in atmospheric pCO_2. Even though the MECO is still an enigmatic event, studies on biotic effects across this interval are yet rather limited. Herein, we present new data on planktic and benthic foraminifera of the carbonate terrigenous section of Capo Mortola (Liguria, NW Italy). This historical succession is very rich in larger foraminifera, such as nummulitids and orthophragmines, and offers the exceptional opportunity to compare biotic variations across the MECO in shallow-water assemblages with the record of planktic foraminifera. The section shows conspicuous paleoecological variations, brought on by the variance in neritic input because of tectonic and climatic instability.

The first purpose of our work is to refine the biostratigraphic framework of the section by correlating the Shallow Benthic Zones with the calcareous plankton zonal schemes. In addition, we provide a quantitative analysis to evaluate the impact of the MECO on the investigated biotic groups. Preliminary data on the Capo Mortola section, despite the evident dominance of benthic over planktic forms, allow us to recognize *Orbulinoides beckmanni*, and thus the E12 total range Zone, broadly corresponding to the MECO interval. The MECO constraint is substantiated by the negative shift in bulk oxygen stable isotopes.

It is very interesting to observe that lithological variations along the Capo Mortola succession do not show similarities with analogue successions investigated in the region also spanning the MECO. At Capo Mortola, deposits that register the MECO event are characterized by an elevated dominance of Larger Benthic Foraminifera (LBF), and the environment is not at all affected by enhanced riverine or deltaic activity, as instead expected during a major warming event that has been generally connected with enhanced precipitation. Increased dominance of oligophotic LBF (i.e., discocyclinids) may be related to a strong irradiation of the seafloor coupled with very limited sedimentary rates and very reduced neritic input from nearby deltas.

Modern environmental conditions on an agriculture-impacted estuary (Mondego, N Portugal): a foraminiferal approach

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The Mondego estuary is an Atlantic, mesotidal and relatively small coastal water-body (21 km in length, 8.6 km^2), located in the central coast of Portugal, that is divided into two arms both separated by the island of Morraceira. This estuary has historically been impacted by agricultural activities upstream (maize, potatoes and rice production), receiving a significant volume of effluents with high loads of total nitrogen and phosphorus. Moreover, its water and surface sediments are characterized by the presence of diverse and abundant pesticides, some of them exceeding the maximum values established by European legislation. Therefore, it is an excellent example of an eutrophic coastal environment that can be considered a natural-laboratory to analyse the possible agricultural impact on benthic microfaunal communities from western Iberia. The aim of this work is twofold: i) To characterize, for the first time, the topographic and longitudinal zonation of benthic foraminifera in its modern sediments and ii) To determine the possible ecological response of benthic foraminifera to agricultural pollution.

Twenty-two surface samples were collected in May 2022 across four transects in salt marsh and tidal flat settings from the southern arm of the Mondego estuary, the only arm that still preserves its original subenvironments, since the northern arm is continuously dredged. Samples were stained with Rose Bengal to distinguish the biocoenosis (living individuals) from the thanatocoenosis (dead tests). Standing crop values are total number of individuals/80cm^3.

Lower and upper estuary salt marshes are made up of the typical agglutinated species *Trochammina inflata* and *Entzia macrescens* both in the living and dead assemblages, whereas *Miliammina fusca*, *Tiphotrocha comprimata*, *Haplophragmoides wilberti*, *Scherochorella moniliformis* and *Siphotrochammina lobata* appear as secondary and accessory taxa. The hyaline taxon *Elphidium williamsoni* presents high abundances only in salt marshes from the lower estuary. Upper estuary salt marshes exhibit elevated frequencies of brackish hyaline taxa, involving *Ammonia tepida*, *Haynesina germanica* and *Elphidium oceanense*, possibly in response to a lower slope that facilitates tidal inundation. In general terms, salt marsh living and dead assemblages are similar, although slightly higher to higher abundances of living hyaline species are recorded. Alternatively, tidal flats are dominated by the autochthonous brackish species *H. germanica*, *A. tepida*, *E. oceanense* and *Quinqueloculina seminula* in the living assemblage, with clear increasing abundances of dead marine tests (e.g., *Quinqueloculina bicornis*, *Lobatula lobatula*, *Bolivina* spp. and *Elphidium* spp.) towards the main channel of the estuary and seaward. These compositional changes in benthic foraminiferal assemblages across topographic and longitudinal gradients are the response to tidal inundation and marine influence. The foraminiferal diversity is consistent with similar coastal areas from the northern and western Atlantic Iberian margin (Shannon index: 0.33-1.2, Alpha index: 0.83-13.67).

The observed standing crop values range from high to very high in all sampling stations, with an average of 6250 individuals/80cm^3 (650-33,120 individuals/80cm^3). Contrary to what is observed in polluted coastal areas, none of the sampling stations presented low abundance or "azoic spots", suggesting current good environmental conditions.

Therefore, we can preliminarily conclude that, at present, there is no apparent ecological stressor derived from agricultural pollution inhibiting stable and diverse populations of benthic foraminifera in the Mondego estuary. However, future multidisciplinary studies, involving geochemical-compositional proxies in core and surface samples may help achieve geographic and historical perspectives of the possible impact of agriculture-related activities that led to the recent environmental transformation of this coastal area.

Pore patterns of epifaunal benthic Foraminifera as a palaeoxygenation proxy in the South-East Pacific

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Benthic Foraminifera (BF) have developed structures through the test wall for gas exchange between the living cell and the surrounding seawater. These structures are tubular holes (pores) perpendicular to the wall surface, and their patterns can

be explained by adaptations to environmental parameters such as temperature, oxygen, or nitrate concentrations. The pore density and/or pore surface in some infaunal and epifaunal BF taxa relates inversely to bottom water oxygen concentration (BWO_2), where total porosity increases to enhance oxygen uptake. Hence, it has been proposed that pore patterns could serve as a proxy for past BWO_2 and redox conditions.

To validate the use of the pore pattern proxy for reconstructing palaeoceanographic conditions in the South-East Pacific (Peru-Chile; 12-44°S), we analysed epifaunal BF taxa (*Cibicidoides wuellerstorfi*, *C. lobatulus*, *Cibicides aknerianus*, *Planulina limbata*, *P. ariminensis*) from surface marine sediment samples collected at 24-3,190 m water depth. The sediments are dated early Holocene to recent times (^{14}C age). We measured the pore number, area, radius, density, and porosity on the penultimate and antepenultimate chambers and the whole test area of both ventral and dorsal sides. These are compared to BWO_2 and other bottom water hydrological variables such as temperature, salinity, and nutrients.

We verify an inverse correlation between BWO_2 and pore density only on the ventral side for penultimate and antepenultimate chambers and the whole test area for *C. wuellerstorfi*. Still, BWO_2 correlates inversely with porosity instead of pore density on the dorsal side. In the case of *C. lobatulus*, the BWO_2 varies inversely and more strongly with pore density for all measurements on both sides. For *C. aknerianus*, the correlation between pore density and BWO_2 is still present on both sides but not as strong as for *C. lobatulus* or *C. wuellerstorfi*. Our results indicate a negative correlation between BWO_2 and pore density on both sides but only for the whole test area in *P. ariminensis*. Pore patterns of *P. limbata*, however, are not related to BWO_2.

The relationships between epifaunal pore patterns and BWO_2 established in this study support using epifaunal BF pore patterns as a locally calibrated proxy in the South-East Pacific to reconstruct regional changes in subsurface ocean oxygenation throughout the geological record.

Regional imprint and global signature of the Late Miocene-Early Pliocene Biogenic Bloom in the Tasman Sea (IODP Site U1506)

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The Late Miocene-Early Pliocene Biogenic Bloom was a major paleoceanographic event marked by increased marine biological productivity. At multiple ocean sites, especially beneath upwelling regions in the Indian and Pacific oceans, increased mass accumulation of biogenic deposits (i.e. opal and $CaCO_3$) has been documented between 9 and 3.5 Ma. Two hypotheses have been proposed to explain the anomalously high primary productivity during the Biogenic Bloom that is further supported by diatom-based proxies and benthic foraminiferal assemblages. This event has been related to either increased nutrient availability in the oceans (triggered by enhanced continental weathering and increased input of sediment through rivers), or to a major redistribution of nutrients due to the reorganization of ocean circulation. The widespread signal and common patterns of the Biogenic Bloom point to global forcing, however palaeoceanographic studies provide evidence for regional differences in its expression and timing. These findings underline the importance of studying regional scale processes to fully understand this event.

We investigated the expression of the Biogenic Bloom at Integrated Ocean Drilling Program (IODP) Site U1506 in the Tasman Sea, combining paleontological and geochemical data. The new age model based on orbital tuning of the Natural Gamma Radiation (NGR), benthic foraminiferal oxygen isotopes, and calcareous nannofossil biostratigraphy, was integrated with quantitative analyses of benthic foraminiferal assemblages and other independent proxies (benthic and planktonic carbon stable isotopes, mass accumulation rates of $CaCO_3$, and seismic data) to understand and possibly disentangle the regional signal from global imprint of the Biogenic Bloom at Site U1506.

Benthic foraminifera indicate two different productivity regimes within the study interval, which spans from the Tortonian (Late Miocene) to the Zanclean (Early Pliocene), and covers the middle part of the Biogenic Bloom, from 7.4 to 4.5 Ma. A high seasonal food supply to the seafloor, well-oxygenated bottom waters and strong current activity have been

inferred between 7.4 and 6.7 Ma. In contrast, benthic foraminiferal assemblages between 6.7 and 4.5 Ma are dominated by dysoxic taxa, indicating lower oxygen conditions and a continuous food supply to the seafloor. This change in productivity regime at 6.7 Ma coincides with a major stratigraphic change visible on the seismic profiles, which has been related to a weakening of the bottom current strength.

Our results point to a diverse expression of the Biogenic Bloom event at Site U1506, related to a regional change in oceanography during the Late Miocene. This study highlights the value of high-resolution studies in identifying the regional and global imprint of this event.

The potential of changing coiling directions of the planktic foraminifer *Globorotalia bykovae* (Aisenstat) for stratigraphic correlation in the Central Paratethys

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Changing coiling trends of certain species can be used to distinguish time intervals on various scales. However, this attempt has been largely neglected in the last decades. Triggered by the need of alternatives for frequently missing index species in the marginal seas of the Paratethys with its instable environmental conditions, we tested the potential of changing coiling directions in *Globorotalia bykovae* (Aisenstat) for the correlation of strata. We chose *G. bykovae* because it is planktic and therefore widely distributed, easy to identify in the foraminiferal assemblages of the Central Paratethys, and occurs rather regular in late Karpatian to Badenian (late early to middle Miocene) samples. Furthermore, it is the morphologically most similar species to those used by Bolli in his 1971-paper to demonstrate the shift from the 50/50-ratio to the dominance (90% or more) of sinistrally coiled planktic foraminifera at the early to middle Miocene transition.

In order to test the potential of this method, we counted coiling directions in three well dated drill cores in Austria (Krems Embayment of Alpine Foreland Basin, Lower Austria) and three cores in the Slovak Republic (Danube Basin). Our preliminary results show not only the general shift towards sinistrally coiled specimens at the Karpatian-Badenian boundary, but show the possibility of much more detailed subdivisions. During the early to middle Badenian, several short lasting changes in the prevailing coiling direction opens the possibility to use the causing (probably) paleoecological events as stratigraphic tool for the correlation of sections. Distinct trends in coiling directions can be correlated within biostratigraphic zones (e.g., M5b, M6) and paralleled lithologic marker beds.

Therefore we propose the application of this method in section (or drill core) correlation at least as additional evidence or if index species are missing or just occur sporadically. Intra-basinal correlation appears possible if *G. bykovae* is present in the samples in sufficiently high amounts. This is probably the case during phases with normal marine conditions and environmental changes do not let to the (local) disappearance of this species.

Comparing flow-through culturing systems to investigate elemental uptake in the calcite tests of benthic foraminifera

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Elemental seawater concentrations of many trace elements have been collected through the analyses of benthic foraminiferal calcite. In addition, laboratory experiments have been conducted to determine the effect of various concentrations of these elements. Furthermore, analyses of foraminiferal calcite for many redox-sensitive transition metals, used to historically study the redox state of oceans, remain under constrained. Due to their low concentrations in seawater and the potential biological impact on the calcifying organisms studied, attention should be given to adsorption, contamination, and other interfering effects in such experimental studies using flow-through devices. Here, we examine the benefits and drawbacks of three such systems used to study the incorporation of trace elements into benthic foraminiferal calcite.

Three flow-through culturing systems are discussed: system 1) an apparatus using a plastic culture tray, system 2) a modified scheme utilizing a customized block of polytetrafluoroethylene (PTFE) instead of the plastic culture tray, and system 3) a serial system of synthetic perfluoroalkoxy alkane (PFA) vials connected using PTFE tubing. Elements have variable affinities to adsorb onto surfaces and seawater trace metal concentrations are very low. Accordingly, particular

attention should be given to materials incorporated by devices utilized to examine trace metal effects. Notwithstanding, adjustments and compromises are often considered, depending on limitations and experimental objectives. The experimental designs presented can be adapted to a range of disciplines that study calcifying organisms, possibly for ocean acidification research and especially for tracking oceanic concentrations of trace metals.

New morphotypes of *Balkhania balkhanica* Mamontova, 1966 from the upper Valanginian - lower Aptian of the northern Tethyan margin

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Balkhania balkhanica is one of the valuable species that has been used for the biostratigraphy of the Barremian-Aptian interval along the Tethyan carbonate platforms. This species is recorded from the Tethyan margins such as Russia, Lebanon, Iran, Afghanistan and Turkmenistan. *B. balkhanica* type species in Turkmenistan includes discoidal and evolved test, less than 5 mm to more than 15 mm in diameter, and megalospheric and microspheric forms. This species presents a choffatellid-like and calcite microgranular-agglutinated test. *Pseudochoffatella gigantica* also introduced as a synonymy of *B. balkhanica*.

Here, two Lower Cretaceous formations deposited on a carbonate platform along the Iranian Tethyan margin (Kopet-Dagh Basin, NE Iran and Yazd Block, Central Iran) have been studied. We found the first appearance of *Balkhania balkhanica* in the upper Valanginian beds of the Tirgan formation in the Kopet-Dagh Basin. They show small-size specimens of microspheric forms, very similar to those described for *B. balkhanica* type specimens described from Turkmenistan. The main difference is a much smaller test size, which ranges from 0.7 to 1.5 mm. They are therefore considered as a small-size morphotype of *B. balkhanica* species, which range from the upper Valanginian to the upper Hauterivian. The megalospheric forms were probably too small and thus difficult to observe and/or to preserve in the sedimentary record. *B. balkhanica* specimens have also been found in the upper Barremian-lower Aptian deposits of the Tirgan formation and upper Barremian of the Taft formation in the Yazd Block. Morphometric measurements show similarity to the type species, but most of them have a different wall composition, namely an agglutinated wall characterised by the presence of large quartz grains. Hence, we name them *Balkhania balkhanica* arenaceous morphotype. We also call *Balkhania balkhanica sensu stricto* for specimens of both of the forms that show nature and size-range of the tests identical to typical specimens in Turkmenistan, and have been recorded in this study and previously.

First appearance of the small-size morphotype of *Balkhania balkhanica* may be interpreted as basal morphotype of an evolutionary trend of this species from smaller to larger sized morphotypes at the Barremian-Aptian interval. This trend of increasing size has also been shown in other foraminifera. The nature of the grains in the composition of the wall is not always a taxonomic criterion for distinguishing agglutinated foraminifera at species level. The arenaceous morphotype could be an ecomorphotype adapted to peculiar ecological conditions and using quartz for building its wall according to its availability in the environment.

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Response of morozovellid and acaraninid planktic foraminifera to early Eocene global warmth in a southern high-latitude site in the Indian Ocean

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Foraminiferal assemblages from Ocean Drilling Program (ODP) Hole 738C are analysed to assess the response of photosymbiont-bearing planktic foraminifera (morozovellids and acarininids) during the early Eocene, a time of extreme and sustained warming associated with high pCO_2. This site is located on southeast Kerguelen Plateau at southern high-latitudes (62°42.54'S, 82°47.25'E), which makes it ideal for the study of past climatic fluctuations in the circum-Antarctic surface waters.

We studied the diversity, abundance and test size of planktic foraminifera based on quantitative analysis of 300 specimen counts. In addition, morphometric analyses were performed on three species, including *Subbotina velascoensis*, *Acarinina*

soldadoensis and *Morozovella subbotinae*, from ten horizons spanning 244.80 to 283.40 meters below seafloor (mbsf). Following published interpretations, we consider *S. velascoensis* as an asymbiotic species and *A. soldaensis* and *M. subbotinae* as a symbiotic species. Published oxygen isotope data on *Acarinina* from the lower Eocene of Hole 738C indicate decreasing values in the studied interval, suggesting increased warming of surface waters. The lowest $\delta^{18}O$ values have been observed around 277 mbsf. Our data reveal an important planktic foraminiferal morphologic shift during this early Eocene surface seawater warming involving the symbiotic *Morozovella* and *Acarinina* foraminifera, as has been observed in several other oceanic sites (e.g., ODP Sites 1258, 1051 and 1263).

From 277.80 mbsf on, the abundance of *Morozovella* begins to decrease and finally *M. subbotinae* disappears at 264.36 mbsf, whereas *Acarinina* remains relatively abundant and diverse throughout the interval from 264.36 to 277.80 mbsf. *Subbotina* abundance increases beginning at 277.80 mbsf. In addition, the maximum size of both target symbiotic species, *Acarinina soldadoensis* and *Morozovella subbotinae*, begins to reduce (from 300 µm to 224 µm and from 250 µm to 200 µm, respectively) and after a depth of 255.32 mbsf, *A. soldadoensis* recovers its maximum size. Interestingly, despite the fact that the asymbiotic species *Subbotina velascoensis* shows a major decline in abundance from 264.6 to 244.8, it exhibits a mostly constant maximum size (~ 224 µm) throughout the studied interval.

The relationship between size increase of planktic foraminifera and photosymbiotic activity has been already demonstrated using test size relative to $\delta^{13}C$ gradients. We propose that during the increased warming of the early Eocene the reduction in size of *Morozovella* and *Acarinina* in the southern Indian Ocean was due to a reduction in symbiotic activity ('bleaching events') driven by extreme environmental stress, as suggested for other oceanic sites. Morphometric and carbon isotope analyses are underway to test this hypothesis.

Correlation of the early Eocene biostratigraphy, stable isotope analyses and relative abundance of morozovellids at Site 738 with the observations from Sites 1258, 1051 and 1263 of the Atlantic Ocean suggests that the first permanent decline in abundance of morozovellids was probably earlier in the southern Indian Ocean relative to the south Atlantic and then western Equatorial Atlantic Ocean. Moreover, at Site 738, the maximum test sizes of *M. subbotina* and *M. gracilis* were small (~ 250 µm) before their decline in abundance compared to other oceanic sites (e.g., Site 1051) where the maximum test sizes were much larger (~ 470 µm). An even more drastic reduction in size for these species is then observed at Site 738 in the course of the early Eocene increasing warming, coinciding with the decrease in their abundance just prior to their last occurrence, suggesting that the southern Indian Ocean ecosystem may have been more vulnerable to the warming event.

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Applying faunal indices to understand paleoenvironmental changes with benthic foraminifera: a case study from Chilika Lagoon, East coast of India

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Coastal areas have suffered environmental changes over the past few centuries, and floral and faunal assemblages have also changed. As foraminifera have the advantage of possessing mineralized tests preserved in the sediment compared to other organisms, they are a powerful tool for assessing (palaeo-) environmental changes. Chilika Lagoon (19˚28'–19˚54' N: 85˚06'–85˚35'E), the largest brackish lagoon in Asia, has been studied in detail for the last few decades by using different environmental proxies such as physical and chemical parameters. In this work, we interpret the paleoenvironmental history of the lagoon in response to the artificial opening of the sand bar with diversity indices, bivariate plots, and Murray's Ternary plot and try to find out the potentials of these tools in reconstructing paleoenvironments.

In the present study, cores were collected from two sites in the outer channel of the lagoon. The cores were sliced into 1 cm and divided into half ~ one for chronological and geochemical analysis and another for microfossil analysis. For micropaleontological analysis, the samples were wet sieved through a 63 µm sieve and dried at 50°C. The sediment samples were split with the help of a micro splitter, and benthic foraminifera from 1 gram of each split sediment sample was counted. A total of 3323 benthic foraminifera, including 15 species of Textulariida and seven species of Rotaliida, have been identified from both cores. The species of Rotaliida include *Ammonia sobrina, Ammonia parkinsoniana, Ammonia tepida, Ammonia* sp. 1, *Ammonia* sp. 2, *Cribroelphidium hispidulum* and *Cribroelphidium* sp. and Textulariida includes *Ammobaculites exiguus, Ammobaclulites agglutinans, Ammobaculites dilatatus, Ammotium directum, Ammotium fragile, Ammotium salsum, Ammotium* sp.*, Miliammina fusca, Miliammina petila, Textularia agglutinans, Textularia earlandi, Trochammina advena, Trochammina hadai, Trochammina* sp. and *Haplophragmoides* sp.

With the Pb-210 dating method, four different intervals of environmental changes have been recognized. Very low foraminiferal abundance, including calcareous and agglutinated foraminifera ones, was noticed during the early 1900s, when

salinity fluctuations may have led to the survival problems of these species. With the opening of the artificially dredged mouth in 2000, the foraminiferal abundance and diversity value increased due to a rapid increase in salinity level. Further opening of new mouths in 2008 and widening of this mouth in 2010 and 2012, opportunistic uniserial agglutinated foraminiferal assemblages appeared and dominated, indicating the development of high salinity and low oxygenic condition in the outer channel over the last few decades. The reconstruction of the history of the environmental changes in the coastal marine ecosystem is essential to learn how the present environment formed and anthropogenically stressed ecosystems originated and to evaluate how they might evolve soon.

Deccan volcanism, Chicxulub impact, orbital forcing, and changes in planktic foraminiferal assemblages across the Cretaceous/Paleogene boundary

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The 1 Myr interval (66.4-65.4 Ma) across the Cretaceous/Paleogene boundary (KPB) is a brief period of Earth's history during which remarkable two events took place: the Chicxulub impact (~66 Ma) and the massive volcanism of the Deccan Traps (~66.3–65.6 Ma). Determining the contribution of either asteroid impact or massive volcanism to the KPB mass extinction event (~66 Ma) has fuelled and continues to fuel an intense scientific debate. In addition to the global climate disturbance that occurred just after the Chicxulub impact, others global and regional paleoclimatic events, such as the Late Maastrichtian Warming Event (LMWE; 66.25-66.10 Ma), the Dan-C2 (65.8-65.7 Ma), and the Lower-C29n event (LC29n; 65.48-65.41 Ma), have been recognized across the KPB in different localities. These events have been linked to climate changes induced by both Deccan volcanism and/or orbital forcing.

We carried out high-resolution planktic foraminiferal studies (including quantitative analyses, aberrant index, fragmentation index, and test morphometries) and carbonate geochemical analyses (bulk $\delta^{13}C$, bulk $\delta^{18}O$‰, $CaCO_3$%) from well-known KPB sections, such as Caravaca and Zumaia (Spain), El Kef (Tunisia), and ODP Site 1262 (South Atlantic). Integrating all these proxies together with both major and trace elements (e.g., Hg, Ir, Zr, Ba, and Te, among others), may help to unravel the causes of the climatic, environmental, and biological changes across the studied interval and their relationship with the Deccan volcanism, the Chicxulub impact, and the orbital cycles. All proxies have been calibrated with an orbitally tuned age model and compared with the latest eruptive models proposed for the Deccan Traps.

No extinctions but small paleobiological changes have been recognized during the LMWE at Caravaca, such as moderate but transient changes in planktic foraminiferal assemblages, an increase in the fragmentation index tentatively related to ocean acidification, and dwarfism in *Contusotruncana contusa* tests. At Zumaia, the LMWE is synchronous with the last 405 kyr eccentricity maximum of the Maastrichtian, and we hypothesize that raised CO_2 levels through Deccan outgassing during the late Maastrichtian may have amplified climate sensitivity to the orbital forcing, resulting in the enhanced global climatic response of the LMWE. No relevant changes have been recorded in all the studied sections during the last 100 kyr of the Maastrichtian. This suggests latest Maastrichtian environmental, climatic, and evolutionary stability was disrupted by the sudden mass extinction of > 95% of the planktic foraminiferal species at the KPB. During the Dan-C2 event, planktic foraminiferal assemblages show a rapid recovery. However, changes in planktic foraminiferal assemblages were virtually non-existent during the LC29n. Both early Danian events are robustly linked to extreme orbital configurations. Conversely, in all the studied localities, we have identified a bloom of opportunistic triserial guembelitriid *Chiloguembelitria* in the early Danian (~65.9 Ma), which covariates with an increase in aberrant planktic foraminifera. These increase in aberrant tests only was outnumbered for that recorded at the KPB, suggesting a resurgence of environmental stress in the sea surface. According to our first results in major elements, this environmental stress episode is temporally well-correlated with an anomaly in the Hg/TOC ratio (~65.9 Ma) at ODP Site 1262, supporting a cause-effect relationship with the Deccan Traps mega-eruptions that occurred during the emplacement of the Ambenali Fm. in the early Danian.

Aberrant planktic foraminifera as biomarkers of environmental stress and/or chemical contamination across the Cretaceous/Paleogene boundary

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The foraminiferal abnormality index (FAI = % in aberrant foraminifera) with benthic foraminifera has been proven useful in recognizing stressed and/or polluted environments in recent sediments. However, using this proxy with planktonic foraminifera is becoming more common, being used as a biomarker to identify events and episodes of greater environmental stress or chemical contamination from the distant past as well. A good example are the high values in FAI recorded across the Cretaceous/Paleogene boundary (KPB) that are tentatively linked to the environmental effects of the Chicxulub impact and/or Deccan massive volcanism. Various types of abnormalities in the test morphology have been described during this time interval, including protuberances near the proloculus, abnormal chambers, double or twinned ultimate chambers, multiple ultimate chambers, abnormal apertures, distortion in test coiling, morphologically abnormal tests, attached twins or double tests, and general monstrosities.

The first high-resolution study on the planktic FAI evolution across the KPB was carried out at El Kef and Aïn Settara sections (Tunisia; Tethys). At these two localities, a FAI peak (~18-20%) was recognized within the dark clay bed immediately above the KPB. It contrasts with the low values of FAI (usually <2%) across the uppermost Maastrichtian, suggesting relatively stable environmental conditions during the last ~50–100 ka of the Cretaceous. The dark clay bed of the KPB is well-known for registering high values in heavy metals (e.g., Cr, Ni, Cu, P), and thus the increase in aberrant tests was linked to increased environmental stress and heavy metal pollution from the Chichxulub impact. A second peak in FAI was recognized in the early Danian, which was initially related to both the Dan-C2 and Deccan volcanism.

In this study, we carried out a quantitative study of the FAI from several well-known KPB sections, such as Caravaca (Spain; Tethys), Zumaia (Spain; North Atlantic), and ODP Site 1262 (South Atlantic), integrating it in a robust age model. The objective is to evaluate how the FAI behaves in different environments and establish cause-effect relationships with some of the environmental events reported across the KPB. The values reached by the FAI vary between sections, with the lowest values recorded at ODP Site 1262 and the highest at Aïn Settara. However, all the sections display similar FAI trends. The highest values within the KPB dark clay bed (i.e., the first ~10 ka of the early Danian) are related to the immediate environmental aftermath of the Chicxulub impact (i.e., ocean acidification, heavy metal pollution, toxic phytoplankton blooms). A decrease in FAI characterizes the following 70 kyr, although average values remain relatively high, suggesting that environments are still stressed but trending towards recovery. The environmental stabilization was abruptly interrupted ~100 kyr after the KPB, coinciding with the onset of the second FAI peak. According to geochemical and taphonomic proxies, this second peak does not correlate with changes in sea-surface temperature and/or ocean acidification. The second FAI peak occurred ~100 ka before the onset of the Dan-C2 climatic event (~65.8 Ma), but it correlates well with the Ambenali Formation emplacement (~65.9 Ma) of the Deccan Traps. The coetaneous bloom in opportunistic planktic foraminifera (triserial guembelitriids) and the high Hg values reinforce the hypothesis of the high input of volcanogenic nutrients and a higher concentration in heavy metals (e.g., Hg) during this interval. The weak biological pump conditions in the early Danian oceans may have enlengthened the residence time of the volcanogenic nutrients and elements on the sea surface, causing the FAI to remain high. More studies in other localities on the FAI evolution across the KPB are required to decipher whether it was linked to Deccan chemical contamination and/or other environmental stressors.

Mesophotic benthic foraminifera assemblages record the drowning of a carbonate platform in the northern Red Sea, Saudi Arabia

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Mesophotic coral ecosystems (MCEs) are peculiar ecosystems characterized by low-light levels and typically occur between 30 and 150 m water depth in tropical and subtropical regions. They can develop on top of drowned carbonate platforms, since these provide high rugosity and three-dimensional structural complexity that result in great niche diversification. Benthic foraminifera are an important component of the mesophotic community and since they are optimal environmental indicators, they can be used to characterize and further understand this relatively understudied ecosystem. Through the analysis of benthic foraminifera assemblages, this study aims to describe a MCE developed on an isolated, partially drowned carbonate platform located to the south of Al Wajh lagoon (northern Red Sea, Saudi Arabia). Ultimately, constraining biological assemblages *vs* depth will help to develop criteria to recognize and quantify accommodation space increase caused by rapid sea level rise and/or salt tectonic-related drowning.

Al Wajh is a rift-basin land-attached carbonate platform characterized by an arid climatic setting. Its geological evolution has been influenced by tectonics, delta-top deposits, and salt tectonics. The southern margin is undergoing a fragmenting process related to the plasticity of the thick evaporitic layer deposited during mid-Miocene restricted conditions, which underlies the Plio-Pleistocene shallow-marine carbonates. The platform blocks are rafting towards the center of the basin and some of them have slid down partially or completely below the euphotic zone, including the one selected for this study. This platform rises to a height of 650 m above the seafloor, and it has been investigated during a joint research cruise between KAUST and JAMSTEC in February 2022, where hydroacoustic data, CTD profiles, seafloor images, and water and sediment samples were acquired. A total of 11 sediment samples have been collected between 40 and 130 m water depth for benthic foraminifera assemblages' analysis.

The current depth profile of the platform is reflected in the taxonomic composition of the foraminiferal assemblages. Shallower samples are characterized by abundant epiphytic taxa such as *Cibicides* and shallow *Amphistegina* species such as *A. lessonii*, with rounded and thick tests. Deeper samples are dominated by infaunal, mud-dwelling taxa such as *Bolivina*, *Bulimina*, *Heterolepa*, and the deep, flat-shaped *A. papillosa*, *A.radiata* and *A. bicirculata*. *Operculina ammonoides* is a major component of all the assemblages and can occur both in its microspheric and megalospheric form. Small miliolids are present in shallower samples, while at deeper locations this group is only represented by reworked specimens. Reworked and broken tests of rotaliids are abundant in all samples.

This study establishes a clear depth-dependent trend in benthic foraminifera assemblages on a drowning carbonate platform. The way the platform drowning affects the benthic foraminifera assemblages is comparable with the changes expected in the biota community caused by a relative sea-level rise during deglacial phases. Moreover, in this mesophotic environment, a considerable proportion of reworked specimens indicates a mechanism of sediment transport by relatively strong currents. Hence, correlation of benthic foraminifera assemblages with water depth has to consider only *in situ* specimens, while excluding reworked ones. Future investigations on the paleoenvironmental evolution of this platform through the study of benthic foraminifera assemblages along sediment cores will provide further details on the combined effect of drowning/accommodation space increase related to subsidence due to salt tectonic movement and eustatic sea-level rise.

The taxonomy and taphonomy of modern Foraminifera in the Blue Hole of Faanu Madugau (Ari Atoll, Maldives)

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The Blue Hole of Faanu Madugau (Ari Atoll, Maldives) has a depth of about 80 m, and according to physical and chemical data measured along a depth profile from the surface to the bottom, suggests the complete absence of any water circulation below a depth of 50 m. Acidic pH, high concentration of H_2S, and anaerobic conditions point to a very limited biotic window. To check for the historical record of the sedimentary succession deposited at the bottom of the Blue Hole, a shallow core was sampled by hand from the seafloor at 80 m ca. depth. The sediment observed at the bottom was extremely porous and oversaturated several centimetres beneath the surface, thus making core penetration relatively easy. The sampled core was around 1 m thick, but during the long ascensions, most of the sediment settled at the base of the core, thus producing only an 18 cm thick sediment interval. The core was immediately sliced into 2-cm intervals on the support vessel. Samples were dried and picked for biotic remains among the sediment particles.

The fauna retrieved is almost exclusively composed of foraminifera shells; a few molluscs and ostracods are also present, along with rare sponge spicules. The foraminiferal distribution is dominated by benthic taxa, while planktonic taxa are scarce. Among the benthic foraminiferal assemblages, the genus *Amphistegina* is the most abundant in all samples, with the species *A. bicirculata*, *A. lessonii*, and *A. radiata*. Other common taxa identified are *Neoassilina ammonoides*, *Operculina complanata*, *Elphidium* cf. *gunteri*, *Heterostegina depressa*, *Palaeonummulites venosus*, *Borelis pulchra*, *B. schlumbergeri*,

and *Neorotalia calcar*. *Quinqueloculina* spp., *Spiroloculina* sp., and some agglutinated tests such as *Textularia* sp. are sporadically observed.

Since most of the retrieved assemblages are solely limited to the photic zone and inhabit mostly shallow reefs and lagoons, this study showed that all the retrieved foraminifera are transported from the surrounding environments to the greatest depths.

This interpretation leaves several questions to be answered in the future with more focused studies. One of the major questions should address how it is possible that the Blue Hole of Faanu Madugau has never been filled like the rest of the surrounding lagoon. Our data points to the interpretation that, since the entire material retrieved is the product of transportation from the nearby lagoon and reefs, only a diminished production rate can result in a reduced sedimentation rate, but that seems unplausible given the extent of the reefs in the region. This issue leads to the need to extrapolate the sedimentation rate of the deposit retrieved, which will be done in the future by measuring the C^{14} data from the foraminiferal fauna.

Bottom water conditions during the Ocean Anoxic Event 1a in the southern Tethys and central Pacific Ocean: the benthic foraminiferal response

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The environmental impact of the Ocean Anoxic Event 1a (OAE 1a) has been intensively studied in the Cismon core (Tethys, Italy) and DSDP Site 463 (central Pacific Ocean) by using different geochemical and micropaleontological proxies, but the benthic foraminiferal response reflected in the bottom waters had not been documented until now. Here we present new benthic foraminiferal assemblage data across the upper Barremian-Upper Aptian from the Cismon core (Tethys Ocean) and DSDP Site 463 (central Pacific Ocean). Based on changing taxa distribution through different benthic foraminiferal intervals (BFI), a reconstruction of bottom water conditions was addressed to distinguish the paleoenvironmental changes across the OAE 1a. In the pre-OAE 1a interval, a shift from relatively stable oxygenated conditions (upper Barremian) to more depleted oxygen conditions (lowermost Aptian) on the seafloor at the Cismon core has been observed. As a prelude to OAE1a, a considerable decrease in benthic foraminifera (crisis phase) suggests a marked deterioration of the bottom waters under a dysoxic regime in both stratigraphic sections. Within the OAE 1a interval, benthic foraminifera, especially in the Cismon core, evidence two distinctive short-term changes in the bottom waters. A lack of benthic foraminifera (barren phase), indicative of anoxic water conditions, is followed by a slight and scarce occurrence of benthic foraminifera (repopulation phase), suggesting the presence of at least very low concentrations of oxygen at the seafloor under a dysoxic-anoxic setting. In turn, at DSDP Site 463, there was a deprivation of benthic foraminifera (barren phase), indicating the depleted-oxygen conditions characteristic of an anoxic environment. Benthic foraminiferal taxa in the post-OAE 1a interval coincide with a transition phase as the seafloor experienced a slight improvement in the oxygen concentration in the bottom waters. Finally, the benthic foraminifera at Cismon and DSDP Site 463 reflect extreme paleoenvironmental and climatic conditions during the Barremian-early Aptian associated with the oceanic perturbations resulting from the activity of the Ontong Java Plateau, including increased volcanogenic CO_2 emissions and enhanced greenhouse climatic conditions.

Towards estimating community composition from metabarcoding output in large benthic Foraminifera

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Describing living community compositions is essential to answer basic ecological questions; however, it is a challenging task. Continuous progress is being made in foraminiferal research to improve taxonomy, species identification and

community composition based on genetic information. Metabarcoding is a recent tool that could be used instead of traditional specimen counting under the microscope, which is time consuming and can lead to species misidentification. Quantitative metabarcoding has the potential to allow for more informative environmental monitoring, by rapidly producing outputs similar to specimen counting with higher taxonomic accuracy, in presence of a good reference database.

However, estimating molecularly foraminiferal community composition is challenging. Metabarcoding results provide relative abundance, which can be biased from a technical level (e.g., DNA extraction, amplification) or from a biological level (e.g., number of gene copies differing between species). Our work focuses on advancing metabarcoding methods to better understand these biases and correct for them, using a recently developed mitochondrial marcher (COI). This marker has decreased genetic variability compared to the well-known nuclear marker (SSU 18S). Correcting these biases will provide a more accurate assessment of the species community composition and therefore permits the use of this data to answer ecological questions.

We are interested in monitoring large benthic foraminifera (LBF) assemblage composition in coral reefs, because they are good bioindicators of environmental conditions associated with coral growth. To achieve this, we used single specimens of LBF in combination with bulk sediment samples. We compared chamber volume, surface area and the number of COI gene copies in seven LBF species. First results show a positive correlation between surface area and number of COI gene copies was found in six of the seven species, but especially strong for *Amphisorus*, *Heterostegina depressa*, *Neorotalia gaimardi* and *Operculina ammonoides*. Most calculations of gene copy density lay between 0.1 and 0.5 million copies/mm^2, but for *H. depressa* reaching up to 15 million copies/mm^2.

Based on these preliminary results, we expect that species composition can be extracted from the number of reads, proportional to the number of specimens and the space taken in a sample. Quantitative metabarcoding of species composition still needs to be demonstrated and validated by comparing our results with mock communities and sediment samples, both analysed morphologically and molecularly.

Foraminiferal pore densities reveal that the Peruvian oxygen minimum zone was similar in extent but weaker during the Last Glacial Maximum

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Quantifying past oxygen concentrations in oceans is crucial to improve understanding of currently ongoing global ocean deoxygenation. The use of porosity and pore density of aerobic epifaunal foraminifera as proxies for quantitative O_2 reconstructions is evolving. In this study, we tested four different methods to determine the pore density of epifaunal *Planulina limbata* in core top samples from the Peruvian Oxygen Minimum Zone (OMZ) between 7 and 12°S. The strongest correlation between pore density and near-bottom water O_2 concentrations ($[O_2]_{BW}$) has been found when the pore density was determined on a size-normalized area of the spiral side. Subsequently, we used the novel calibration and a record of pore density of the epibenthic foraminifer *P. limbata* from the Peruvian OMZ to reconstruct oxygen concentrations in near-bottom waters from the Last Glacial Maximum to the Late Holocene at 17.5°S about 500 meters water depth. We found that $[O_2]_{BW}$ levels were 40% lower during the Last Glacial Maximum than during the Late Holocene (about 6.7 versus 11.1 µmol/kg, respectively). A comparison with other reconstructions of oxygen concentrations in the region reveals a shallow OMZ during the Last Glacial Maximum that was similar in water depth and extent but weaker than during the Late Holocene. Increased glacial oxygen concentrations are probably related to lower temperatures (higher oxygen solubility), decreased nutrient and increased oxygen supply by source waters, and a decrease in coastal upwelling.

Ubiquitous occurrence of phosphate storage in foraminifera – Another adaptation to anaerobic environments?

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Benthic foraminifers are ubiquitous marine protists that possess specific adaptations to the partly extreme environments in their ecological niche. Ocean deoxygenation due to climate warming and anthropogenic eutrophication is an ongoing threat for marine organisms that are not well adapted to O_2 depletion. Nevertheless, several benthic foraminifera species might benefit from ocean deoxygenation, since they are well adapted to O_2 depletion due to their capacities to denitrify or the ability to stay dormant during periodic hypoxia. In addition, their high abundances in O_2 depleted environments make them key players in marine nutrient cycling.

Recently, we found that foraminifera can accumulate large amounts of phosphate in their cells. New data show that this is a widespread phenomenon and occurs in diverse environments such as tidal flats, hypoxic fjord basins, oxygen minimum zones and the Mid-Atlantic Ridge. 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 might facilitate phosphogenesis in some environments. Foraminifera encode the genes required for both a polyphosphate, as well as a creatine phosphate metabolism. Both creatine phosphate and polyphosphates are good energy carriers that can rapidly regenerate ADP to ATP, when electron acceptors are depleted. Coupled TEM-EDS and cryo-SEM-EDS reveal intracellular phosphorous accumulations that are associated with vesicles of ~2-5 µm in diameter. These vesicles are possibly acidocalcisomes that are typically used to store polyphosphates in eukaryotic cells and are similar in size and shape. These results indicate, that the high intracellular phosphate storage is likely another adaptation to O_2 depletion and used to stay mobile, when their preferred electron acceptors are depleted in the environment.

Trends in the record of foraminiferal organic linings

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Foraminiferal organic linings still present nearly unexplored potential for learning evolutionary trends within the phylum Foraminifera. We recognize that the fossil record of organic linings is highly scattered and limited. Therefore, we decided to create a catalogue of all foraminiferal linings available in the scientific literature so far. The first version of Global Database of Foraminiferal Organic Linings (*ForamL* Version 1.2) has been based on 155 scientific publications that illustrated 614 linings (see *ForamL Version 1.2*, doi: 10.17632/xw7w5ns649.3). All foraminiferal organic linings have been grouped following the supraordinal classification that divides Foraminifera into 3 large groups: (1) a paraphyletic monothalamids, as well as two classes (2) Globothalamea and (3) Tubothalamea, while phylogenetic position of an order Lagenida is still uncertain. These taxonomic groups of foraminifera are distinguished based on morphology and arrangement of chambers analyzed within the database. The database covers the whole Phanerozoic, divided into the Cenozoic, Mesozoic, Paleozoic, and then to systems/periods. The purpose of gathering the data is to extend scientific knowledge on the origin, taphonomy, and phylogenetic patterns of these fossilizable organic foraminiferal structures. The *ForamL* database is also linked to the most recent review of the knowledge on foraminiferal organic linings published by the authors. It will be further supplemented by available records of foraminiferal organic linings.

Our quantitative analysis of the database, shows a chronostratigraphic upward trend revealing an increase in the amount of linings from the lower to upper units (systems and erathems). The highest amount of foraminiferal organic linings calculated per time unit is found in the Cenozoic, then lower in the Mesozoic and the lowest in the Palaeozoic. This phenomenon seems to be associated with accessibility of the data due to better access to younger sediments and greater interest in studying sediments representing younger geological periods that results in a larger number of published studies from younger strata. Another, partly complementary, explanation comes from the Triassic vs Jurassic and Cretaceous record. A high increase in the number fossil linings since the Jurassic may indicate the evolutionary proliferation of new globathalamean taxa that belong to Rotaliida and Textulariida. In this case, we can argue that we are dealing with the evolutionary trend. The analysis of the overall morphotypes of multilocular linings indicate a domination of spiral tests that include low trochospiral and planispiral chamber arrangements. This trend might reflect absolute dominance of spiral tests in the fossil record. Furthermore, we should note a consistent occurrence of biserial foraminiferal organic linings that appeared in the Jurassic and exist in the fossil record in all higher stratigraphic units. This pattern also appears to be related to the evolutionary trends known from the biserial globothalemean foraminifera.

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Diversity and distribution of the benthic foraminifera on the Brunei shelf (Palawan/North Borneo ecoregion): effect of seawater depth

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The marine benthic diversity of Palawan/North Borneo ecoregion is relatively poorly known despite its implied unique high species richness within the Coral Triangle. The present study aimed to better understand the diversity and distribution of the benthic foraminifera on the Brunei continental shelf of this region. We documented the species collected in sediment samples from 11 sites extending 75 kms from the coastline along a depth gradient ranging between 10 and 200 m. To understand how distribution is related to environmental factors, we undertook preliminary carbon and oxygen stable isotope analyses of selected species from three families (Rotaliina, Miliolina, Lagenina). In view of anticipated widely-varying, depth-related environmental conditions, we assessed foraminifera assemblage patterns and the existence of different biotopes. We found a total of 99 species belonging to 31 families and 56 genera, of which 52 species represented new records for Brunei and probably the ecoregion. The oxygen isotope data reflected strong positive correlations with depth that links to anticipated colder temperature at greater depths. The carbon isotope data showed some species-specific separation among the different taxa, especially for some rotaliid and miliolid, that may link to different habitat, food-source, and/or biomineralization effects. Three assemblages were distinguished relating to specific depths of ~10-40 m, 70-100 m and 200 m (shelf edge), indicating the presence of two benthic marine biotopes on the Brunei shelf. Overall, this study adds significant understanding to the local and regional patterns of benthic foraminiferan diversity and distribution.

Porosity in *Ammonia* sp. as an indicator of hypoxia in Long Island Sound, USA

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Long Island Sound (LIS), between Connecticut and Long Island, NY, called 'The Urban Sea', is a relatively small body of water with sharply declining water quality from East to West, due to varying levels of population density and industrialization, and dominant water exchange with the Atlantic Ocean at its eastern end. Western LIS, closest to New York City, is characterized by overall high levels of pollution, including, heavy metal contamination and eutrophication due to input of nutrients from wastewater treatment plants.

Coincident with increasing eutrophication, there has been a turnover in the composition of benthic foraminiferal assemblages in western LIS. These had been dominated by the diatom-using *Elphidium excavatum* since the establishment of LIS as an estuary during the Younger Dryas, but became dominated by the omnivorous *Ammonia* sp. in the 1980s-1990s. The cause of this replacement is not clear: it may have been hypoxia, though *E. excavatum* as well as *Ammonia* sp. are hypoxia-resilient in cultivation, and/or caused by changes in phytoplankton communities due to increased N/Si. However, abundant *Ammonia* sp. could also be an invasive species, which outcompeted native *Elphidium* species in the most polluted regions.

We collected *Ammonia* sp. from Black Rock Harbor (Bridgeport, CT), next to a sewage outfall pipe, and from the Richard's Property (Branford, CT), a site with better water quality. Cells were picked and imaged on a Keyence light microscope to measure porosity before extracting and sequencing SSU. We use ImageJ to measure 2-dimensional area and maximum diameter of the test on the spiral side, and average pore size and porosity.

Ammonia spp. been shown to have inter- and intraspecies variability in pore size, with intraspecies variability corresponding to oxygen levels: larger pores may aid in gas exchange and/or house ectobionts for survival under hypoxia. Genetically, *Ammonia* is one of the best-studied genera of benthic foraminifera, but there is little sequence data from LIS, with specimens limited to two phylotypes (T1, T9). In our phylogeny, new data on LIS *Ammonia* grouped with clade T6 (*Ammonia confertitesta*) with 100% bootstrap support, a phylotype until now found only in Europe and Asia. We will sequence more specimens from both locations to determine what phylotypes are present and compare phylotypes and morphology.

Growing Deformed Benthic Foraminifera from Propagules with Exposure to Zinc

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Deformed tests in benthic foraminifera have been widely reported in both calcareous and agglutinated, multi-chambered taxa. These abnormalities have been attributed to a broad range of stressors, both naturally occurring (e.g., fluctuating salinities or temperatures, shell repair, infestations) and human induced (heavy-metal or organic pollution, and related conditions). Identifying the underlying causes and mechanisms of morphological abnormalities in field-based studies alone is difficult because a specific site may experience multiple contaminants as well as brief temporal changes in environmental conditions. Controlled laboratory experiments are therefore invaluable in assessing the effects of environmental conditions and contaminants on foraminiferal assemblages and the responses of individual taxa.

Previous work has shown that growth from propagules in the presence of zinc produces high proportions of calcareous foraminifera with abnormal morphologies. The levels of zinc used in these experiments exceeded the U.S. Environmental Protection Agency's maximum safe concentration for saltwater, but were below the threshold that prohibited foraminiferal growth and/or killed propagules. By growing deformed foraminifera in the lab, we can better examine biological responses to individual contaminants and how they perturb calcification and growth.

To determine conditions that repeatedly produce foraminifera with deformed tests, assemblages were grown from propagules using different sets of conditions. Those that produced the most consistent results for our study site include: constant temperature (between 18 and 23°C), ambient salinity at the collection site (between 30 and 32‰ artificial seawater), and exposure to a total initial concentration of 50 mg/L Zn (using $ZnCl_2$). The concentration of zinc in the artificial seawater typically declines over the course of the experiment as it adheres to sediment particles, organics and perhaps the container walls. The propagules used for this experiment were sourced from an extensive mudflat or the adjacent saltmarsh surface located on the southern end of Sapelo Island, Georgia, U.S.A. Overall, monothalamid foraminifera (*Psammophaga sapela, Ovammina opaca*) grew abundantly over the initial few weeks with no evidence of morphological abnormalities or other deleterious effects. Over the weeks that followed, populations of the calcareous perforate foraminifera, *Haynesina germanica* and *Ammonia "tepida"* grew, both with high abundances of deformed tests (5 – 48%). In addition, the agglutinated miliolid, *Miliammina fusca*, grew from sediments from the marsh surface with abundant deformed tests.

Living deformed *Haynesina germanica* and *Ammonia "tepida"* were able to extend pseudopodial nets. *H. germanica* however lacked the deep olive coloration that is characteristic of healthy individuals with abundant sequestered chloroplasts. *A. "tepida"* likewise lacked the characteristic golden color but were able to feed on *Dunaliella.* Abnormal morphologies range from slightly to grossly malformed, and the types of abnormalities are comparable to many of those reported in field-based studies. Here, abnormalities in calcareous species include: fragility, abnormal chamber arrangement, enlarged or diminutive chambers, abnormal openings in the test, crenulations in the test, exfoliation of the test surface, abnormal pores, abnormal surface textures, and enlarged or out-of-place apertures. The primary deformity in *Miliammina fusca* is an abnormal chamber arrangement where new chambers become loosely coiled and appear nearly planispiral.

Ectoplasmic control of calcium ion transport during chamber biomineralization in rotaliid Foraminifera: novel results from live fluorescent labelling of frothy pseudopodia

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Our aim is to present the results of new actualistic studies on microstructure and biomineralization in calcareous Foraminifera. We explored the organization of the ectoplasmic structures and the process of seawater vacuolisation during chamber formation in rotaliid Foraminifera represented by *Amphistegina lessonii* d'Orbigny and *Ammonia confertitesta* Zheng. We employed live fluorescence staining and confocal microscope observations. Two distinctly different fluorescent dyes were used, i.e. (1) Calcein Red-Orange AM, a cell-permeable dye, to visualise the ectoplasm, and (2) Calcein, a calcium-binding, cell-impermeable, green dye, to observe seawater vacuolisation. Our results show that during the biomineralisation stage of chamber formation, Calcein Red-Orange AM stains the outer and inner lamellipodia, but also

demonstrate specific sponge like structures called frothy pseudopodia that fill in the interior of the new chamber. Frothy pseudopodia are formed by interconnected cytoplasmic sheets that separate numerous cytoplasmic voids from each other. In contrast, the cytoplasm within older shell remains unstained by Calcein Red-Orange AM. At the same time the green Calcein stains only the calcification site and the cytoplasmic voids within the newly build chamber. These voids lack the Calcein Red-Orange AM signal. We observed variety of the sizes and shapes of these voids, however they largely fall into two major groups: (1) irregular and large (up to several dozens of µm in diameter) ones, and (2) distinctly smaller (typically 2-3 µm in diameter), oval ones. The larger ones are called vacuoles and the smaller ones are called vesicles. Our observation demonstrates that these vesicles and vacuoles together make up 50-90% of the new chamber volume during the biomineralization of the wall. Thanks to employing live staining, we demonstrated that vacuoles are relatively stationery, i.e. do not move or change shape in the timespan of about 10 minutes. On the contrary the vesicles are highly mobile. The differences between them are also expressed in fluorescence intensity. Using time-lapse imaging, we observed the fading of the green Calcein fluorescence within the vacuoles, the fluorescence signal disappears from vacuoles within c. 10 minutes from the beginning of observations. In contrast, the intensity of the fluorescence in vesicles is usually stable in the same period, with exception of the vesicles that emptied their contents into the seawater surrounding the observed individual. The fading of the green Calcein signal in vacuoles indicates formation of temporary connections between vacuoles and the ambient environment resulting in the dilution of the Calcein solution with the unstained seawater. These connections allow diffusion of the calcium ions into the vacuoles, hence they play a vital role in the transport of calcium ions for calcification. The enclosure of the vacuoles within the frothy pseudopodia makes the opening and closing of the connections controlled by the cell, as well as for modification of the properties of the fluid inside vacuoles, e.g., by changing the pH.

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Assessment of ecological quality status of Arctic salt marshes and adjacent tidal flats using foraminifera

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Over past decades, diversity- and sensitivity-based foraminiferal indices have been widely applied on shelves and in shallow subtidal waters to assess ecological quality status (EcoQS). However, the application of these indices in the intertidal zone still poses a challenge, and only a few attempts have been made. Here, we present a modified approach to assess EcoQS in intertidal environments based on bias-corrected Shannon diversity of foraminifera. We characterized the distribution of polycyclic aromatic hydrocarbons (PAHs) in the intertidal sediments at seven study sites along the northern coast of Fennoscandia. We described diversity and distribution of intertidal foraminifera in relation to several abiotic factors and PAH concentrations. In addition, we also examined whether foraminiferal shell growth abnormalities correlated with these factors (and did not find out any obvious relationship). The EcoQS based on the effective number of foraminiferal species matched the PAH-based EcoQS. This opens new perspectives of using foraminifera as a biomonitoring tool in naturally stressed intertidal environments. Supported by RFBR grant 18-54-20001 (St-Petersburg University Pure ID: 62876031).

Seasonal dynamics of intertidal foraminifera of the subarctic White Sea

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Seasonality in intertidal assemblages of foraminifera have been documented from low- and temperate- latitudes but remains underexplored in high latitudes. We aimed to track seasonal changes in foraminiferal populations inhabiting tidal flats in the subarctic White Sea. The study was designed for two tidal flats different in their sediment facies – one dominated by silt, the other by sand. Each tidal flat was transected by four stations from mid to lower intertidal elevations. Each station was sampled in triplicate (10 cm apart) in March (fast ice sawed), May, August, and November 2015. The sediment samples (20 cm^3, 0-1 cm) were preserved in 80% ethanol with Rose Bengal stain (2 g/L). The 0.125–0.5 mm size fraction was used for foraminiferal analysis. Thirteen species of foraminifera were found in all samples with living (stained) individuals

representing six species. Living foraminifera were present at all stations on both flats in all seasons. The abundance of living individuals was consistently higher on the silty flat (100 ind. in average, max ~400 ind./10 cm^3) as compared to the sandy flat (15 ind. in average, max ~45 ind./10 cm^3). Three species, the calcareous *Elphidium williamsoni*, the soft-walled *Ovammina opaca*, and the arenaceous *Miliammina fusca,* dominated both flats. The abundance of *E. williamsoni* did not show a clear seasonal pattern. The maximum abundance of *O. opaca* occurred in May at all stations on both flats. By contrast, the abundance of *M. fusca* peaked in November on both flats. The observed increase in abundance of these species may be related to their diet. *Ovammina opaca* has been reported to feed on diatoms. In the White Sea, the first and most pronounced phytoplankton bloom occurs in late April or early May. This bloom is dominated by diatoms and is associated with the melting of fast ice and high concentration of mineral nutrients near-shore. On the contrary, in late autumn, when photosynthesis wanes but the remineralization of organic matter accumulated during the vegetation season still continues, the conditions seem favorable for deposit feeders (bacterial feeders) such as *M. fusca*.

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A down core analysis of foraminifera from Patrick Bayou (Galveston Texas) before and after hurricane disturbances

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Foraminifera have been used as proxies for pollution for decades due to their sensitivity to potentially toxic elements or PTEs. This study sampled foraminifera from a core taken from Patrick Bayou, a location known to suffer from severe mercury pollution. This core was taken in early 2018 after Hurricane Harvey, visibly indicated by the sudden shift in sediment regime of the core slightly above 50 cm in depth. Above the 50 cm discontinuity, sediments consist mostly of silt-sized particles while below this point the core is comprised mainly of fine sand. The density and diversity of the foraminiferal assemblage was analyzed at different levels of the Patrick Bayou core. Large shifts in density and diversity on either side of the Harvey divide in the core could potentially be linked to an increase in PTEs in Galveston Bay. Mercury in particular is a common trace metal that can have a large impact when taken in by biota as methyl-mercury. Mercury has been shown to negatively affect both the relative abundance and the biodiversity of benthic foraminifera. When Hurricane Harvey remobilized the sediment in Patrick Bayou, PTEs that had been bound and sequestered were released, making them bioavailable again. The foraminifera sampled from the top of the Patrick Bayou core, from the post Harvey deposit, are dominated by very few species. Meanwhile, the foraminifera sampled from sediments undisturbed by Harvey are much more diverse. This observable shift in foraminiferal assemblage is presumably due to an increase in pollutants in the sediments following Hurricane Harvey. This demonstrates the ability of foraminifera to be a reliable proxy for pollution levels in Patrick Bayou.

A glimpse into the past of planktonic foraminifera: Aalenian (Middle Jurassic) forms and their phylogenetic relationships

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The planktonic foraminifers most probably already appeared in the Late Triassic, nearly the same time or shortly after we know the fossil of other calcareous shell-bearing planktonic microorganisms as dinoflagellates, nannoliths and coccolithophores. In contrast to these forms, early planktonic foraminifera – also known as protoglobigerinids – only became widespread in the late Bajocian (Middle Jurassic). At this time, they often appeared en masse (ooze) in the neritic and pelagic environments of the Neotethys with different taxon compositions, in which 2–8 taxa could be identified. The number of described species reached 15, and all 8 morphotypes of the protoglobigerinds appeared.

Until this time, the knowledge about the early period of their evolution is very poor due to the extremely rare and incomplete fossil records. We only know internal moulds from the Triassic, and they were mentioned from a total of 7 areas from the Lower Jurassic, but isolated specimens are known from only two sites. Additionally, the only proved Aalenian (most probably lower Aalenian, Opalinum Zone) protoglobigerinids were documented from Domuz Dag, Turkey. The large (up to 320 µm) specimens, often with a thick outer wall known only from thin sections. For this reason, these forms could only be classified tentatively into species or even genera. Therefore, the recent discovery of these forms in well-dated Aalenian successions of the Transdanubian Central Range, Hungary, is of great importance for understanding their evolution.

The studied protoglobigerinids came from condensed successions built up of red and grey nodular flaser-bedded, Ammonitico Rosso-type limestones. More precisely, they were yielded from the Nagy-Pisznice section (Opalinum and Comptum subzones of the Opalinum zone, lower Aalenian, and Concavum Zone, upper Aalenian) and the Tölgyhát B section (Comptum Zone, lower Aalenian) of Gerecse Mts., and the Bakonycsernye section (Murchisonae Zone, middle Aalenian and Concavum Zone, upper Aalenian) of Bakony Mts. During the Aalenian, this area was situated in the Mediterranean Biome of the Boreal-Atlantic-Caucasian Province.

The planktonic foraminifers were studied in thin-section and isolated specimens, extracted with pure acetic acid. The associated microfauna contained fragmented thin bivalve shells, foraminifera, ostracods, radiolarians, echinoderms, globochaetes, and juvenile ammonites. The foraminiferal fauna were dominated by spirillinids (60–80%), lagenids (mostly smooth-walled nodosarids and lenticulinids (up to 10%), and conical forms (trocholinids and paalzowellids), besides these epistominids and a few agglutinated forms, also occurred.

The protoglobigerinids were poorly to moderately preserved and gave the 1–2 % of the foraminifera fauna with 2–3 taxa, except the oldest sample, where their proportion reached nearly 30 % and 7 taxa could be identified. All forms were thin-walled and relatively small, less than 250 µm. The tests have a low to medium-high trochospire with 2.5–3 whorls and 3 or 4 chambers on the last whorl. All of them have an umbilical aperture, sometimes bordered by a lip. The morphology and the wall structure of the tests are more similar to the Toarcian association from Domuz Dag, Turkey than to the Aalenian one from the same area. This could also mean that the deep-dweller forms with cortex appeared earlier in the eastern part of Neotethys. Based on the isolated specimens the following taxa could be identified: *Globuligerina oxfordiana, G. bathoniana, G. glinskikhae, G.*? *hungarica, G. dagestanica, G.* aff. *dagestanica*, and *Conoglobigerina*? *avariformis* forma sphaerica. These forms were previously only known from the upper Bajocian or younger layers.

Our results filled an entire stage gap in the knowledge about the evolution of the protoglobigerinids. Contrary to the previous perceptions, these forms showed great diversity (7 out of 8 morphotypes already occurred) and frequency already in the lowermost Aalenian.

Pore detection of the denitrifying benthic foraminifer *Bolivina spissa* through automated image analysis technique

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Global warming driven by human activities accelerate ongoing ocean deoxygenation and the expansion of oxygen minimum zones. This is amplified by large-scale use of chemical nitrogenous fertilizers, which alter the marine nitrogen cycle. Nitrate (NO_3^-) is the main reactive nitrogen compound in the ocean and an important macronutrient that can be limiting in some environments. The shallow infaunal foraminiferal species *Bolivina spissa* is abundant in oxygen depleted environments all around the Pacific. This species can denitrify and most likely takes up NO_3^- as an electron acceptor through the pores, making its pore density an empirical proxy for NO_3^- concentrations. In our study, we tested the application of a newly developed automated image analysis technique to detect pores in the tests of *B. spissa* using a deep learning algorithm. For our study, we utilized downcore samples taken from the Gulf of Guayaquil (M77/2-059-1), Mexican Margin (MAZ-1E-04), Sea of Okhotsk (MDO1-2415), and modern core top samples from Central Sagami Bay (Japan), and Costa Rica (SO206-43-MUC). We investigated the interdependence between pore parameters such as the pore density (number of pores per unit area), porosity (% of area of the tests occupied by the pores) and the average pore size on specimens of *B. spissa*. Our study showed that the fully automated technique allows an efficient measurement of pore parameters producing statistically robust results. We found a significant difference in porosity among the studied locations. The porosity in samples from the Gulf of Guayaquil was mainly controlled by the size of the pores, while the porosity at other locations showed a stronger correlation to the pore density. We compared the pore density and porosity of four different closely related *Bolivina* species as a potential NO_3^- proxy. *Bolivina spissa* and *Bolivina subadvena* showed the same correlation between pore density and bottom water NO_3^- concentrations ($[NO_3^-]_{BW}$), while the pore density of *Bolivina argentea* and *Bolivina subadvena acuminata* was much higher and did not fit into this correlation. In addition, preliminary results indicate that there is a stronger correlation of $[NO_3^-]_{BW}$ to pore density than to porosity. We speculate that this could be related to the electron acceptor uptake mechanism of denitrifying foraminifera, since NO_3^- is a charged ion and can be actively taken up through the pores, using ion channels. This is different compared to oxygen, a neutral molecule whose uptake is completely limited to passive diffusion, which makes the total porosity a more important factor for the exchange of neutral gases.

Reconstructing the Oxygen Minimum Zone in the Arabian Sea using Mn/Ca in planktonic foraminifera

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The Arabian Sea contains one of the most intense Oxygen Minimum Zones (OMZ) worldwide that may have been present for millions of years, triggered by lower oxygen water masses and high productivity along its edges. Understanding and reconstructing the OMZ is an essential part for predicting how future changes in its intensity may be, not only in the Arabian Sea but also worldwide. Although many reconstructions have been done, most are giving indirect estimates, i.e. reconstructing absolute dissolved oxygen concentrations in the past is not very accurate yet.

Foraminifera may provide a solution to this using the incorporation of redox-sensitive elements like manganese (Mn) into their calcite shells. It has already been shown that Mn/Ca in benthic foraminifera is sensitive to the dissolved oxygen concentration in the micro-environment they calcify in. When dissolved oxygen concentrations decrease, the amount of Mn available in the pore/bottom water to be incorporated into the calcite shells increases when Mn-(oxy)hydroxides are reduced. Similarly, the shells of those species of planktonic foraminifera that (partly) live in the OMZ may have higher shell Mn/Ca than those that stay in well-oxygenated water masses.

Here we present the first results to explore how Mn/Ca in the shells of different species of planktonic foraminifera varies related to different dissolved oxygen concentrations from a series of 68 core tops from the Arabian Sea taken during research expeditions SO-90 and SO-130 with RV Sonne. We selected species that occur under different circumstances that are also characterized by different dissolved oxygen concentrations. *Globigerinoides ruber* is a mixed layer species that continually occurs under well-oxygenated conditions. *Globigerina bulloides* also occurs in the mixed layer but prefers those periods when productivity increases. *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata* live deeper in the water column, likely (partly) well within the OMZ. And *Uvigerina peregrina* is an endo-benthic foraminifera that has already been studied previously in the Arabian Sea showing increased Mn/Ca when the overlying OMZ is intense.

Traditionally, Mn/Ca in foraminifera is used as an indicator for the presence of diagenetic coatings that are formed in the sediment. Our results suggest that these coatings are not present in our samples as 1) Mn/Ca is generally very low for all species with average values of 0.034-0.11 mmol/mol; 2) different species show significantly different average Mn/Ca. Specifically *P. obliquiloculata* shows up to three times higher Mn/Ca than the other species. In a next step seasonal variations in the occurrence of the different species will be compared with dissolved oxygen concentrations at their respective locations and habitat depth to determine possible relationships with Mn/Ca. This will identify the species that are most suitable to reconstruct past variations of dissolved oxygen concentrations within the water column.

Assessing freshwater foraminifera diversity in New England (USA)

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Despite traditional textbook definitions of foraminifera as marine protists, foraminifera also occur in freshwater habitats, with first reports roughly 150 years ago. Yet, to date, very few freshwater foraminifera have been described in part because these fragile organisms are currently uncultivable. There are fewer than 15 freshwater foraminifera species described both morphologically and molecularly, and only one species has had its whole genome sequenced (*Reticulomyxa filosa)*. In this study, we use foraminifera-specific primers designed to amplify a portion of the 18S rRNA gene as a means of characterizing freshwater foraminifera community diversity in different settings. Our focus is on exploring trends in the species composition of freshwater foraminifera in low-pH bogs, carnivorous pitcher plants, and a freshwater tank, with all sites sampled in Massachusetts and Maine (USA). Our preliminary results indicate the existence of a low-diversity of freshwater foraminifera in these environments, which is in striking contrast to the tremendous diversity found among marine lineages. We also find lineages (i.e. OTUs) that are widespread and others that are site-specific, and we identify several clades of "unknown" freshwater foraminifera that may be specific to the locations we sampled. Together, these data help to

expand our understanding of freshwater foraminifera biogeography through analyses of extreme habitats such as low-pH peatlands.

A phylogenomic approach to understanding population level processes in benthic foraminifera

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The widespread distribution of foraminifera morphospecies coupled with the observation of numerous cryptic species makes these lineages ideal candidates for population genomics studies. Open questions in this field include the nature of species boundaries, patterns of gene flow, and estimates of effective population size. Molecular work on population biology in Foraminifera is hampered by the fact that most are uncultivable and most come with complex associated microbiomes; however, we are building a pipeline to analyze the nucleotide polymorphisms that mark species boundaries and provide signals on gene flow. Primarily targeting benthic lineages in mudflats and tide pools sampled along the eastern coast of the United States, we are using single-cell transcriptomics to ask population level questions about patterns within and between sites. Starting with an initial dataset of single-cell transcriptome data from 107 marine and 8 freshwater cells, we are: extracting rDNAs as preliminary 'identification' and assessing foraminiferal genes (as opposed to contaminants and symbionts) using a taxon-rich phylogenomic approach. From here, we will use standard 'omics tools to evaluate single nucleotide polymorphisms (SNPs) and calculate population statistics (e.g. Tajima's D, dN/dS ratios). Together these data will address genomic and evolutionary features that allow foraminifera to proliferate and explore the nature of cryptic species in these diverse lineages.

Difficult life under a tidal glacier terminus: Interseasonal responses of benthic foraminifera close to the Kronebreen glacier front (Kongsfjorden, Svalbard)

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Arctic fjords are transitional areas between glacier-covered land and the ocean, characterised by strong environmental gradients. In addition to global changes affecting Arctic coastal environments, spatial and seasonal variabilities of physical and geochemical conditions in fjords affect benthic ecosystem, particularly living foraminiferal microhabitats. It is urgent to understand the functioning of these complex environments, to better monitor their modifications under the current global warming conditions.

Kongsfjorden (Svalbard) has entered in an intense phase of warming and ice melting, which have prevented the formation of extensive sea-ice since 2009 in winter. Therefore, the present evolution of this fjord now represents a first phase of transition from subpolar to future temperate conditions. In summer, it is characterised by high glacier melting water production resulting in freshwater spreading at the surface, associated with high turbidity close to tidewater glacier fronts, and bottom waters influenced by Atlantic water intrusions. Therefore, close to the glacier terminus, high detrital sedimentation and limited organic matter exported towards the seabed are supposed to affect both lateral and vertical foraminiferal distribution on a seasonal scale.

Two sampling campaigns were carried out in May and August 2021 to characterize seasonal environmental changes along a longitudinal transect from the Kronebreen glacier front to around 10 km far from it. Our research focused on the seasonal effect of physico-chemical gradients on foraminiferal communities, their spatial distribution, and microhabitats. Organic matter quantity and quality, sediment grain size, and physical parameters of the water masses were investigated as possible driving parameters for benthic ecosystem responses.

In May, the water column was well mixed throughout the fjord, and the environmental gradient was mainly driven by the organic matter content in the sediment, with a strong increase of biopolymeric carbon (BPC) and phytopigments from the glacier front to distal locations. In August, the water column stratification with surface turbidity induced a lowering of organic matter content in the sediment near the glacier front. In the proximal area, foraminiferal assemblages were

characterised by the dominance of the pioneer species *Capsammina bowmanni* in the top sediment layers in August, and very low abundances to total absence of foraminifera in May. Food limitation and substrate instability induced by the turbid plume seem to be the major factors driving the summer foraminiferal distribution. In the distal area, foraminiferal assemblages were mainly represented by *Nonionellina labradorica* and *Adercotryma glomeratum* associated with a higher diversity in both seasons. However, in May, foraminiferal abundances were generally lower, due to food limitation. Interestingly, despite the occurrence of different bottom water masses at the two seasons, similar species compositions were observed, suggesting that the water masses do not directly influence the presence or absence of a species. However, a change in main microhabitat distribution was observed for both species, with a peak in superficial layers in summer and more infaunal behaviour in May. This change could be the response to different feeding regimes in the two seasons and/or possibly to enhanced downward transport of foraminifera by macrofaunal bioturbation in spring.

Our results clearly show that physical and geochemical gradients induced by melting waters and sediment discharges originating from the tidewater glacier during summer are the main factors that drive foraminiferal distribution at the local (10 km) scale. This finding induces that foraminifera can be used to monitor the effects of ongoing climate change on the benthic ecosystems of Arctic fjords and have the potential to be proxies for reconstructing glacier front positions in the recent past.

Microfossil events and planktic foraminifera response to Cretaceous Oceanic Anoxic Events in the Sabinas Basin, Northern Mexico

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During the Late Cretaceous, Oceanic Anoxic events represent major global perturbations in the carbon cycle, characterized by extensive deposits of organic-rich sediments distinguished by pronounced carbon isotopes excursions (CIE), reflecting an enhanced organic carbon burial during a time of global greenhouse climate and improved volcanic activity that promoted changes in the water chemistry, marine productivity, and structure of planktic communities. In Mexico, few studies incorporate geochemical proxies and microfossil data to interpret palaeoenvironmental evolution throughout the Cretaceous, a time in which the paleogeographic position of Mexican basins represented a linking area between the Western Interior Sea and the equatorial Atlantic water mass.

Here, we analyze a 193 m-thick interval of the IRME-2 core from the Sabinas Basin in northern Mexico to reconstruct paleoenvironmental conditions using geochemical proxies, planktic foraminifera events, and abundance fluctuations of microfossils (foraminifers, calcispherullids, radiolarians, echinoderms, and bivalves).

The succession, mainly represented by micritic limestone interbedded with shaly limestone and bentonites, encloses the transition between the Buda Limestone, the Eagle Ford and the Austin formations deposited under open marine conditions below the storm wave base. According to first and last occurrences of planktic foraminifera markers, this interval can be assigned to the upper Cenomanian to Santonian, encompassing the *Rotalipora cushmani* to the *Dicarinella asymetrica* zones. The carbon isotope curve ($d^{13}Corg$) shows two levels with pronounced positive excursions. The first one, between *Rotalipora cushmani* and *Whiteinella archaeocretacea* zones, correlating with the OAE-2 in the Cenomanian/Turonian transition, and the second within the *Dicarinella asymetrica* Zone related to the OAE-3 in the Coniacian-Santonian interval. Before the emplacement of the OAE-2, the IRME-2 core records levels of filaments and infaunal benthic foraminifera increment. Then, accompanying the rise of $d^{13}Corg$ (~4.1‰), productivity-sensitive trace elements (PSTE) such as Ni and Cu showed enrichment levels, followed by an increment of 30% in biserial planktic foraminifera abundance probably related to the "*Heterohelix* shift." Moreover, mixed layer and intermediate dwellers represent the most abundant forms of planktic foraminifera assemblages, while thermocline dwellers are almost absent. In contrast, the interval recording the positive CIE in *D. asymetrica* Zone did not present significant enrichment of PSTE, and thermocline dwellers planktic foraminifera increased slightly.

Fluctuations observed in the enrichment factor of redox and productivity-sensitive trace elements, along with the prevalence of mixed layer and intermediate dwellers in the upper *R. cushmani* Zone of the Sabinas Basin, points to variable oxygen levels and mesotrophic-eutrophic conditions in the water column during the emplacement of OAE-2. Whereas the presence of thermocline dwellers and low values in enrichment factors of trace elements indicate a well-oxygenated water column and mesotrophic-oligotrophic conditions throughout the OAE-3.

Permian–Early Jurassic Nodosarians: Punctuated diversification but no mass extinction

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Thick basinal mud successions in Permian to Early Jurassic basins of the East Gondwana interior rift system in Australia and Timor provide an excellent record of Nodosarian evolution ranging from the Early Permian (Sakmarian) to the Early Jurassic (at least, Pliensbachian). The foraminifera belong to assemblages extracted from friable mudstone and, unlike in thin-sections, full morphological features can be observed in the tests. The Australian successions are relatively undeformed with stage correlations based on rare ammonoids and conodonts and with local palynomorph zonations linking sections. Additional age control is provided by some isotopic dating of zircons from volcanic ash beds. Because the sections in the Timor orogenic belt, at the edge of the present-day Australian continent, are structurally deformed, the reconstructed basinal mud succession is based mainly on conodont (Permian-Triassic) and palynomorph biostratigraphy with some additional control from ammonoids and zircon dating.

This presentation outlines preliminary observations on the Nodosarians in the basinal mud facies. Although a continuous reconstructed section through the mud facies is not yet available, sufficient stratigraphic details exist to outline the broad evolution of the subclass in this depositional setting. Modifications to the "family" classification are suggested based on progressive stratigraphic appearances of genera, mode of chamber addition (e.g., rectilinear, arcuate curved backward, arcuate curved forward, planispiral, polymorphine, and combined modes), chamber shape, and the inception of new morphological features (e.g., apertural types, ornament). Fine details of wall ultrastructure are not included in the classification at this stage because many specimens have partly recrystallized walls and no consistent stratigraphic analysis of the significance of the wall structure can be made. The families and genera discussed here are: Syzraniidae (*Syrania*, *Tezequina*); Dentalinidae (*Vervilleina*, *Laevidentalina*, *Dentalina*); Nodosariidae (*Protonodosaria*, *Nodosaria*, *Pseudonodosaria*, *Pyramidulina*); Lingulinidae (*Cryptoseptida, Lingulina, Paralingulina*); Frondicularidae (*Lunucammina*, *Howchinella*, *Ichthyolaria*, *Frondicularia; Dagysina*); Tristixidae (*Tristix*, *Quadratina*); Vaginulinidae (*Eocristellaria*, *Astacolus*, "striate/costate *Astacolus*", *Lenticulina*, *Spincterules*, *Enantiomarginulina*, *Marginulina*, *Marginulinopsis, Sarcenaria*); Palmulinidae ("*Laevipalmula*", *Palmula*); Plectofrondicullariidae (*Berthelinella*); and Polymorphinidae (*Ramulina, Eoguttulina*).

The Permian to Early Jurassic interval includes two major mass extinction levels affecting the global biota (i.e., the Permian–Triassic and the Triassic–Jurassic boundaries). These events appear not to have severely affected Nodosarian evolution, at least at genus level. In contrast, major diversifications took place during the Early Permian, late Early to Middle Triassic and Early Jurassic. By the Late Triassic, most Nodosarian morphotypes recognized throughout the Mesozoic and Cenozoic had been established. During the Early Jurassic, while test morphology remained the same, many species acquired striate or costate ornament.

The reason why Nodosarians exhibited such conservative evolution may be related to an infaunal life within sea-floor mud and the ability to adapt to rapidly changing conditions in shallow-water estuarine-like interior seas. While the Middle Triassic and Early Jurassic diversifications took place after major mass extinctions, the Early Permian diversification (involving the first appearance of radiate apertures in different generic groups) came with warming after the melting of the Gondwana ice sheets. Perhaps the diversifications were associated with compositional changes in food (organic detritus and bacterial/algal micro-organisms) that were concomitant with the major climate or extinction events.

The effect of carbonate chemistry on the incorporation of trace elements into shells of benthic foraminifera: Paleoceanographic and biomineralization implications

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Na/Ca in biogenic $CaCO_3$ has recently been introduced as a proxy for past seawater Ca^{2+} concentrations. This proxy was calibrated for the large benthic foraminifer *Operculina ammonoides*, an extant relative of the fossil *Nummulites*. Additional calibrations were performed for the planktonic foraminifera *Globigerinella siphonifera*, *Trilobatus sacculifer*, *Globigerinoides ruber*, and *Orbulina universa*, and also for hermatypic corals. These experiments demonstrate significant positive correlations between seawater and shell Na/Ca (as well as for other major and trace elements), when the main variable in these experiments was Ca^{2+} concentration in seawater. In contrast, the influence of salinity on Na/Ca in *O. ammonoides* was shown to be very small. However, other possible parameters could potentially influence the Na/Ca ratio in foraminifera. Here we present a set of carbonate system experiments to test the effects of pH and dissolved inorganic carbon (DIC) on the incorporation of Na^{+}, Li^{+}, Mg^{2+}, and Sr^{2+} into the shells of the high-Mg foraminifer *O. ammonoides*. Foraminifera were cultured under constant DIC (~2170 µmol kg^{-1}) with varying pH (7.5-8.4 NBS scale), and under varying DIC (830-2470 µmol kg^{-1}) with constant pH (~7.9). Based on alkalinity depletion, the foraminiferal growth was assessed and linearly correlated with pH, DIC, and calcite saturation state (Ω). The lowest pH and DIC treatments showed low population growth, and some of the specimens died during the experiments and their shells were partially dissolved.

Na/Ca_{shell} and Li/Ca_{shell} in *O. ammonoides* are positively correlated with seawater carbonate chemistry (CO_3^{2-} and Ω), while Sr/Ca_{shell} and Mg/Ca_{shell} are much less sensitive to these factors. Low-Mg planktonic foraminifera (and possibly some benthic species), did not show any sensitivity of Na/Ca_{shell} to the carbonate system. However, the sensitivity of Na (and Li) in *O. ammonoides* to the carbonate system does not compromise the use of this proxy to reconstruct past seawater Ca concentrations, given that past changes in seawater Ω were probably small and can be reconstructed, thus allowing a small correction for this proxy over timescales of the Cenozoic. Thus, the Na/Ca proxy in the extinct *Nummulites* may be utilized for Ca^{2+} reconstructions. The distribution coefficients of multi-element and isotope systems (e.g., Li, Sr, Mg, K, B, $\delta^{11}B$, and possibly others) may therefore provide new insights for reconstructions of past ocean chemistry. Furthermore, based on this information we propose a modified biomineralization model for hyaline foraminifera where seawater vacuolization is the main source for major, trace and minor elements incorporated into low and high-Mg foraminiferal species.

A changing response of planktic foraminifera to seasonality in the California Current Ecosystem: Updates from 2018-2021

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The rapid response of foraminiferal assemblages to a changing climate makes their fossil shells an invaluable geological record of past ecological conditions. The drivers of planktic foraminifera presence and abundance, however, are complex and involve a combination of oceanographic and ecological processes. Seasonal and interannual variability affect the interpretation of foraminiferal records throughout geologic time. For example, if a species is most abundant in one season, geochemical records from that species will be skewed towards that season. The Santa Barbara Basin sediment trap, located off the coast of California, USA, provides a record of sediment and foraminifera flux to the basin since 1993. The region experiences strong seasonal cycles due to changing winds and ocean currents. We present data on planktic foraminiferal assemblages collected between 2018-2021, at two-week intervals (> 75 samples) and compare results to previously published data collected between 1993-1998. We focus on the seasonality of flux and relationships to seasonally variable conditions. The most abundant species between 2018-2021 are *Globigerina bulloides*, *Neogloboquadrina incompta*, and *Turborotalita quinqueloba*, with the greatest flux in the spring and late summer. Peaks in both total foraminiferal flux and abundance of *G. bulloides* and *T. quinqueloba* frequently follow the onset of upwelling conditions but also occur independently of apparent upwelling. The winter season is characterized by low foraminiferal flux and an assemblage dominated by *G. bulloides* and *N. incompta*. Flux of *Globigerinita glutinata* peaks in winter. We also find that some species' seasonalities (*Globigerinoides ruber*, *Globigerina rubescen*s, *Orbulina universa*) may have changed over the past decades. Understanding how modern foraminifera, including classic upwelling species (*G. bulloides*), respond to seasonal changes can inform paleontological interpretations and help to place foraminifera in a broader ecological context.

Foraminiferal evidence for the provenance and flow history of turbidity currents triggered by the 2016 Kaikōura Earthquake, New Zealand

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The 2016 Mw 7.8 Kaikōura Earthquake triggered simultaneous turbidity currents down ten submarine canyons along a 200 km stretch of the continental slope, east of New Zealand. Some discharged into the Hikurangi Channel which flows >1500 km northwards along the abyssal trench floor. To better understand provenance continuity in deep-sea sedimentary records, 136 foraminiferal samples from the 2016 turbidites and preturbidite sediment from 25 canyon and channel cores (1000-4000 m water depth) provide insights into flow behaviours and provenance of the turbidity currents.

All turbidite and pre-turbidite faunas have signatures of downslope displacement (shallow-water benthics, size-sorted test distributions, low planktic %). Pre-turbidite faunas were displaced by turbidity currents >150 years before 2016. They can be distinguished from the recent turbidite faunas by the increased presence of tests of deep-water benthics and planktic rain, which have been added into the pre-turbidite sediment since emplacement. There are no consistent changes in foraminiferal parameters in the 2016 turbidite with distance displaced (10-650 km). Intra-turbidite faunal variability in a single core is attributed to incorporation of deep-seafloor tests by early turbidity current pulses, different source canyons, and test-size sorting during transport and deposition. There is no evidence of increased breakage and abrasion of foraminiferal tests with distance transported in the turbidites.

Cluster analyses suggest the canyon provenances for most 2016 turbidite faunas are mostly determinable using a combination of the relative abundance of key benthic genera, planktic foraminiferal index (dissolution), absolute test abundance and planktic % of the foraminiferal faunas. Two ordinations (PCA, PCO) based on these parameters were used to infer provenance and flow history. One hundred kilometres down the Hikurangi Channel, faunas in the 2016 turbidite confirm a Kaikōura Canyon source. Further downstream, 200–500 km north of the confluence with Campbell, Cook and Opouawe canyons, faunas indicate that the 2016 turbidite in the northern, distal Hikurangi Channel is a composite deposit, from an initial proximal Opouawe-Cook canyon-sourced turbidity current over-ridden and partly mixed with, a Kaikōura Canyon-sourced flow that arrived sometime later.

Middle Badenian foraminiferal assemblages from Papuk Mt, North Croatian Basin

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The North Croatian Basin (NCB) in the southwestern part of the Pannonian Basin System (PBS) paleogeographically belongs to the area of the Central Paratethys. The Nježić outcrop is in the central part of the NCB, on the southwestern slopes of Papuk Mt, where five lithofacies were distinguished within the 140 m thick sequence: metagabbro, algal limestones, marl, bioclastic limestone, and tuff.

Marls contain a rich fossil assemblage of benthic and planktonic foraminifera. Micropaleontological analyses were performed on 40 samples prepared using a standard washing procedure (sieve fractions – 0.5; 0.25; 0.2; 0.125; 0.09; 0.063 mm).

The planktonic foraminifera association consists of representatives of the genera *Trilobatus*, *Praeorbulina*, *Orbulina*, *Paraglobototalia*, *Globigerinella*, and *Globigerina*. Among them, the most important species are *Trilobatus trilobus* (Reuss), *T. quadrilobatus* (d'Orbigny), *T. sicanus* (De Stefani), *Praeorbulina curva* (Blow), *P. glomerosa* (Blow), *P. circularis* (Blow), *Orbulina suturalis* Brönnimann, *Globigerinella obesa* (Bolli), *Paragloborotalia mayeri* (Cushman & Ellisor), and *Globigerina tarchanensis* Subbotina & Khutsieva. The planktonic foraminifera association indicates middle Badenian age (*Orbulina suturalis* Zone or M6 planktonic foraminifera zone)

According to benthic foraminifera, the Nježić section belongs to the Lagenidae Zone (Moravian substage of the Badenian). The index species for the Lagenidae Zone is *Uvigerina macrocarinata* Papp & Turnovsky, while *Uvigerina grilli* Schmidt is the index species for Lagenidae Zone and Spirorutilus Zone. Also, species like *Vaginulinopsis pedum* (d'Orbigny) and *Uvigerina bulbacea* (Galloway & Heminway) are determined that do not cross the stratigraphic boundary of the Lagenidae Zone.

Benthic foraminifera are significantly represented only in the lower part of the section, while in the rest of the section, planktonic foraminifera dominate. Along the entire section, a similar *Cibicidoides-Bolivina-Cassidulina* assemblage of benthic foraminifera was detected with distinct domination of the species *Cibicidoides ungerianus* (d'Orbigny), *Cassidulina laevigata* d'orbigny, and *Bolivina dilatata* Reuss.

The gradual increase of planktonic assemblage in the total foraminiferal community going upwards of the Nježić section and the gradual increase of deepwater species within the benthic assemblage indicate a continuing deepening of the depositional environment. The plankton/benthos ratio reaches up to 94 % in the upper part of the section and suggests an

upper bathyal environment. At the same time, the gradient analysis, based on the overlap of benthic foraminifera depths, points to an outer shelf marine environment (with a water depth of about 200 m).

Determined planktonic and benthic foraminifera biozones are in accordance with $^{40}Ar/^{39}Ar$ dating on volcanic glass fragments from the oldest tuff layer in the Nježić section, which yielded an age of 14.40 ± 0.03 Ma.

Retrospective benthic foraminiferal community studies: a sensitive method to determine early environmental changes

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Two short sediment cores (< 50 cm), taken in the Sørfjord and Veafjord (Southwest Norway), were analyzed for benthic foraminifera, as well as geochemical (bulk TOC, C_{org}/TN, stable $\delta^{13}C$ isotopes and heavy metals) proxies. In addition to the core samples, living (rose Bengal-stained) benthic foraminifera were examined to determine the current ecological status at the study sites. The purpose of the study was to define the natural ecological condition in the Sørfjord and Veafjord, two sheltered inland fjords with restricted deep-water exchange with open coastal areas. An assessment of the development of the local environmental status over the last centuries was required in connection with plans for the disposal of road and railway track construction residues in the fjord systems.

The sediment cores were radiometrically dated by ^{210}Pb and ^{137}Cs back to the mid-19th and 20th centuries. Foraminiferal diversity was relatively high in the first half of the 20th century and earlier, indicating 'very good' ecological quality status (EcoQS) at both sites, according to the Norwegian ecological classification system. The EcoQS only showed minimal changes over time and was still 'very good' in the youngest sediments, which was also reflected by the living assemblages. Benthic foraminiferal accumulation rates increased from the 1960s to 1970s; however, this increase was more evident in the Sørfjord than in the Veafjord core. The foraminiferal assemblages showed increasing abundances of *Brizalina skagerrakensis*, *Bulimina marginata* and *Stainforthia fusiformis* during the same time period, which might indicate a general increase in primary production triggered by higher nutrient supply in the area.

Corresponding to the faunal changes, the organic carbon accumulation rates indicate increasing organic matter flux to the sea floor during the last 50 to 60 years. Both $\delta^{13}C$ and C_{org}/TN ratio showed a shift to slightly lower values at the same time, supporting the interpretation of higher nutrient supply and related primary production in the area.

Based on our study, we propose to carefully evaluate whether existing ecological indicators, required by the authorities' environmental monitoring guidelines, are sensitive enough to detect early changes or deterioration of the environment. The study underlines the potential of using benthic foraminiferal assemblages in environmental monitoring programs.

The response of benthic foraminiferal assemblages to copper mine tailing deposits at the Repparfjord, Northern Norway

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Benthic foraminiferal assemblages at a historical mine tailings deposit site provided new insight into the utility of foraminifera as biomonitoring tool. Copper mine tailings in a subarctic fjord in Northern Norway were found to affect recent sediment layers up to the sediment-water interface by leaching processes, exposing benthic communities to high copper concentrations over the last four decades.

We assessed the current diversity and composition of the benthic foraminiferal community at the Repparfjord, Northern Norway, as well as a retrospective reconstruction from sediment layers of a period prior to the mine tailings discharge. The ecological quality index based on the diversity of the assemblage (EcoQS) and the percentage of abnormal tests (FAI) was compared to the concentration of trace metals in the sediment pore water.

We identified three clusters of similar composition: (1) historical assemblages below the mine tailing layer in the sedimentary record; (2) more recent assemblages from the uppermost 5 cm of sediment in the mine tailing disposal area; (3) a pristine assemblage from the outer fjord. Our results show that the original benthic foraminiferal community disappeared almost entirely during the disposal period and is now dominated by stress-tolerant and opportunistic species. Against previous assumptions, the community composition changed, while the overall diversity (ExpH`bf) and the formation of abnormalities (FAI) were unaffected by elevated copper concentrations. EcoQS classes based on benthic foraminifera were generally lower than at other sites due to naturally lower diversity in the Subarctic region.

The improved understanding of the dependency of the benthic foraminiferal community structure and their diversity on physical disturbance and heavy metal concentrations will be helpful in the development of an indicator variable, allowing for the use of benthic foraminifera as biomonitoring tool in high-latitude ecosystems.

Perspectives of growth in Foraminifera

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Growth in foraminifera can be continuous or discontinuous showing growth steps. Continuous growth is typical for monothalamous foraminifera and ends when the growth ratio is minimum in biomass production against the maintenance used for the organisms' life. Protection of the monothalamous cell is performed by simple structured tests with organic or agglutinated walls.

Growth steps (intercepts) characterize the discontinuous growth in testate foraminifera. At the end of a growth intercept, test walls cover the new segment. Primarily, test walls can form either tubes or spheres leading to the molecular-genetically supported main separation in testate foraminifera between Tubothalamea and Globothalamea.

Growing tubes can be open at both ends (unilocular tests) or start with a spherical initial chamber (bilocular tests). Growth steps are undetectable at the test outside or can be found as weak, often irregularly positioned constrictions leading to pseudosepta.

Constricting the open tube segments creates chambers with small openings (apertures). The chamber front becomes a septum by the superposition of the following chamber, and the aperture transforms to a foramen. Growth based on spherical chambers automatically leads to the development of septa characterizing the grade of chambers' overlapping. Tests based on tubular or spherical chambers are called multilocular.

Multilocular foraminifera show unlimited or limited growth. The former can be modelled by linear or exponential functions, while sigmoidal functions characterize the latter. Maturation is size dependent in linear and exponential growth, while the inflection point in sigmoidal functions separating increasing from decreasing growth rates determines maturation. Replacing the independent variable time t by the chamber number n, test (cell) growth can be modelled by mathematical functions, where the Gompertz and Richards functions render the best fitting of sigmoidal functions. While test growth is modelled by the growth functions, the first derivatives of these functions characterizing the volumes of chambers determine chamber growth.

The timing of chamber construction depends on the growth ratio between biomass production and maintenance. The growth ratio decreases monotonically with increasing test size. Time intervals in chamber construction keeps constant in linear growth and increase in exponential and sigmoidal growth. This increase can be modelled by the Michaelis-Menten function, where the inverse function allows estimation of the individuals' birthday based on the number n of chambers.

The combination of chamber growth with the chamber-building rate leads to the time dependent mean growth function. Deviations from the mean growth rate can be calculated using standardized residuals. Decomposition into sinusoidal periods allows the interpretation of time dependent environmental influences (tides, raining seasons, etc.) on growth.

Chamber form determined by the morphogenetic program keeps constant during growth, affected by environmental disturbance only in chamber size. Deviation from optimal light conditions reduces chamber growth of symbiont-bearing larger foraminifera kept in cultures, while the chamber-building rate is extended in comparison to natural conditions, which can be experienced also under optimal conditions. Further, the effects of acidification and recovery as well as recovery after predation are demonstrated.

A Comparative Morphological Analysis of *Planoheterohelix* Across the Cretaceous Western Interior Seaway during Oceanic Anoxic Event 2

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As foraminifera grow, they sequentially add chambers to accommodate their expanding cellular material such that their tests record their full ontogeny. The intraspecific variation of tests, referred to here as trait plasticity, documents the physiological response of foraminifera to environmental stimuli. As heterotrophs, changing oxygenation and trophic conditions influence their metabolism, their body size, and the shape of the test's constituent chambers. Therefore, trait plasticity observed in fossil foraminifera tests may be used to reconstruct paleoenvironmental conditions. However, recent

morphological studies on foraminifera have revealed that the phenotypic expression of foraminifera is not fully understood, especially in terms of the morphological variation resulting from changes in oxygenation. In order to test multiple drivers of morphological variation, we employ a comparative analysis of morphological variation of the same taxa at different localities in a single basin during an interval of global environmental change. Oceanic Anoxic Event 2 (OAE2) represents a major perturbation to the marine carbon cycle as evidenced by the globally observed positive carbon isotope excursion, in both organic carbon and carbonates, that defines the event. During OAE2, the Western Interior Seaway (WIS) was generally dysoxic and highly productive, but regional differences, such as water mass mixing, caused distinct local environmental conditions. The planktic foraminifera genus *Planoheterohelix* thrives during periods of dysoxia and was ubiquitous in the WIS during OAE2. This variability in local conditions during a global event presents a unique opportunity to test how foraminiferal trait plasticity changes across a geographically constrained area. In this study, specimens of *Planoheterohelix* from central New Mexico and northeastern Kansas will be compared to observe how trait plasticity varies on the western and eastern margins of the WIS throughout OAE2. Specimens of *Planoheterohelix* from both localities have been picked and prepared on microfossil slides. The New Mexico slides were imaged and preliminary results showed significant changes in final chamber size associated with the OAE2 interval. Differences and similarities in trait expression between the two sites would reveal important information about what conditions trigger intraspecific test variation in *Planoheterohelix.* In particular, a stronger understanding of the response to low oxygen conditions can be applied to other foraminiferal assemblages, both past and present, to test and predict how their test morphology reflects their environment. Furthermore, this study leverages previously picked slides and provides an example of the use of 2D morphometric techniques. This study demonstrates a potential mechanism for how foraminifera cope with differing environmental conditions, the utility of foraminiferal morphology as a geologic archive, and the potential impact of future hypoxic events on foraminiferal communities.

First occurrence of the nonindigenous Asian foraminifera *Ammonia confertitesta* Zheng in the northeastern Pacific Ocean: Vancouver Island, British Columbia, Canada

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In May 2022, the U.S. Geological Survey conducted sampling operations (USGS Field Activity 2022-625-FA) along the coast of western North American to update the evidence of occurrences of the nonindigenous Asian foraminifera *Trochammina hadai* Uchio 1962. An effort was made to sample bays and harbors that were either subject to large ship operations (bulk carriers and tankers) or exclusively small boats to provide a better understanding of the vectors responsible for the species' introduction. During sampling along the central-eastern coast of Vancouver Island, British Columbia, Canada, it was noted that in addition to the presence of *T. hadai*, a species of *Ammonia* with taxonomic features distinct from those associated with the native species *Ammonia kitazatoi* Hayward and Holzmann 2021 was observed. These new observations of foraminiferal faunas at three localities along the central-eastern side of Vancouver Island, British Columbia, Canada, as well as molecular analyses, document the first occurrence of the nonindigenous Asian species *Ammonia confertitesta* Zheng in the northwestern Pacific Ocean. The species was present at these localities: 1) dead specimens at a subtidal site (2022-625-1; 49°10'16"N, 123°56'03"W; 4 m water depth) off the end of the Swy-A-Lana Lagoon Fishing Pier in the Port of Nanaimo where the species comprised 0.6% of the benthic foraminiferal assemblage; and 2-3) living specimens at intertidal sites on the southern (2022-625-3; 48°57'50"N, 123°46'26"W) and northern (2022-625-4; 48°57'52"N, 123°46'25"W) sides of Highway 1A at Davis Lagoon, south of the town of Ladysmith, where the species comprised 4% of the benthic foraminiferal assemblage in the lagoon and 49% of the beach assemblage, respectively. The vector of introduction of this nonindigenous species is thought to be the release of ballast water and associated sediment from foreign bulk carriers and tankers. These releases probably occurred in the Port of Vancouver, which were then transported by means of the cyclonic circulation across the Strait of Georgia to Vancouver Island, or from local anchorages on the island close to the sampling sites. The timing of the introduction is impossible to determine because no stratigraphic record is presently available. However, foraminiferal studies in the late 1980s near the Port of Vancouver that recovered calcareous taxa did not report the presence of this species.

Freshwater and soil foraminifera: an overview

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Foraminifera are a diverse taxon present in all oceanic habitats and represent one of the best studied groups of marine meiofauna Much less, however, is known about their non-marine relatives. The presence of foraminifera in freshwater environments was well documented by 19th century European and North American protistologists but interest in them was only marginal during much of the 20th century. The advent of molecular systematics and the application of molecular barcoding allowed the identification of new foraminiferal species in freshwater and terrestrial environments. Furthermore, metabarcoding studies revealed a substantial diversity of foraminifera in environmental DNA samples of freshwater sediments and soils. These molecular approaches have contributed to the establishment of the first family-level classification of non-marine foraminifera and the characterization of the main phylogenetic clades. Much remains to be learned about non-marine foraminifera, especially their ecology. Foraminifera inhabit different freshwater environments and are also found in soil samples from different habitats and climatic zones. Like their marine counterparts they are omnivorous and consume detrital material and a wide variety of smaller protistan prey, so they appear to be involved in food webs at different trophic levels. Further ecological as well as taxonomic studies will certainly increase our knowledge on this much-neglected group.

Establishing the baseline assessment levels for monitoring coastal heavy metals in seawater using benthic foraminiferal shells

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A considerable growth of industrial facilities has been taking place along coastal environments over the past century. Some of these facilities have major economical and national importance, yet their operation can introduce a wide range of potentially harmful chemicals, such as heavy metals (HM), that might impact local ecosystems and human health. Efforts to monitor the presence of HM at low concentrations before damaging the ecosystem are contingent for protecting and conserving these coastal environments.

Many recent studies have shown the applicability of benthic foraminiferal shell chemistry for monitoring HM in coastal environments. Foraminiferal shells grow by sequential addition of chambers, thereby yielding a chronological record of HM concentrations in ambient seawater. This study introduces a new concept of defining a HM baseline assessment levels (BAL) in coastal seawater environments using foraminiferal shells. The BAL provide an absolute reference for documenting the temporal variation in HM that can be used to quantify the magnitude and duration following pollution events.

We demonstrate the potential of this approach by examining a pristine site in a nature reserve along the Mediterranean coast of Israel. Our previous investigation of this site in 2013-14 using foraminiferal single chamber LA-ICPMS created a large dataset that consisted of HM measurements in the last few chambers of two species *Lachlanella* and *Pararotalia calcariformata*. This database was used to establish the BAL metals/Ca ratios of Zn, Cu and Pb, three HM associated with anthropogenic sources.

The BAL of each metal was defined as the 5th lower percentile value from the LA-ICPMS dataset of each species. To encompass the natural variability of non-contaminant natural sources in the BAL, 2 STDEV (in RSD%) of the observed variation of the alkaline earth metal Sr/Ca ratios were added. The potential biological variations between specimens to the resulting ratios based on laboratory culturing experiments of the two species added.

In February 2021, a significant oil spill event affected the entire Mediterranean coast of Israel, and included a considerable out wash of tar onto the shore. The event provided a unique opportunity to test the applicability of foraminiferal BAL by revisiting the previously studied site. Our strategy was to compare whole shell ICP-MS measurements of the two species collected shortly after the event and six months later, and compare them with the established BAL values. Our results revealed a significant increase (2-20 folds) in Zn/Ca, Cu/Ca, Pb/Ca ratios between 2013-14 and 2021. Among these, the increase in Pb/Ca is the most substantial and observed in both species. This implies a possible linkage between the oil spill event and the substantially elevated metals/Ca ratios measured by the foraminifera in 2021. Our study also demonstrates that bulk ICP-MS analyses will most likely yield similar ratios as those of average values of single chamber LA analyses of shells from the same location and period. This observation confirms that once BAL values are established, the analysis of bulk shell ICP-MS is effective for monitoring HM contamination of coastal environments.

Use of a standard format (DarwinCore) on an information system (BISMaL) to integrate recent foraminifera data and to estimate recent past habitat condition

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Due to growing concerns about effects of climate change on ecosystems, many scientific projects to collect biodiversity information on a global scale have been launched. Oceanographic Biodiversity Information System (OBIS, https://obis.org/) is one of the major data collecting project on marine biodiversity information, which has integrated and published over about 100 million biological occurrence records covering the entire ocean. In terms of detecting marine ecosystem changes, foraminifera could become the best sensitive indicator organism, because they distribute all over the ocean from shallow to deep water zones. However, only 0.1 million occurrence records of foraminifera are available in OBIS. This number is much lower than that would be expected from their wide distribution compared with 30.5 million records in Actinopterygii, and 10.3 million records in Crustacea (data accessed on March 31, 2023). Re-organising existing data from various scientific surveys on foraminifera into machine readable data format, and integrating the data on accessible information platform are helpful to know the current condition of marine ecosystems and to provide base-line data for predicting effects of climate change on the ecosystems in the future.

Most information systems on biodiversity including OBIS adopts DarwinCore (DwC, https://dwc.tdwg.org/) format as a data standard. DwC provide rules on describing location information (latitude, longitude, footprint WKT or geodetic datum), time (year, day, time or time zone), and methodology of the observation. Using standardized data format of DwC makes it easier to merge and analyse with other data source. In addition, there are many analysis tools or libraries specialized for DwC data, which is one of the large merits of using DwC. In this presentation, we will present a newly generated dataset on large benthic foraminifer occurrence pattern around Southern Japanese in DwC format, and also present our information system, BISMaL (a data portal of OBIS Japan node, https://www.godac.jamstec.go.jp/bismal/e/) that was originally developed to estimate environment conditions for past observations specialized for the north-western Pacific region.

We extracted and generated DwC data on foraminiferas belonging to *Amphistegina* (Amphisteginidae); *Baculogypsina*, *Calcarina*, *Neorotalia* (Calcarinidae); *Heterostegina* (Nummulitidae); *Peneroplis* (Peneroplidae); *Amphisorus*, *Marginopora*, *Sorites* and Soritinae (Soritidae) from 47 papers published in 1925-2011. As latitude and longitude are a required term in DwC, we carefully detected location information in the publications. When maps or location names were only available, the coordinate (latitude and longitude) was estimated from GoogleMaps and the uncertainty of the coordinates was set. A total of over 1500 valid occurrence records were generated in a DwC format, and annual fluctuation of the water temperature for about 900 locations where the foraminifera species were recorded were estimated quantitively as past habitat condition.

It is quite usual that data structures or formats differ among scientific surveys with different purposes. However, by re-organising these data into DwC format, it can be merged into a single dataset. In addition, water temperature that was not observed during the survey can be estimated by registering them with BISMaL in DwC format. BISMaL can provide a useful information platform for integrating and analysing foraminifera occurrences from the past (but limited to "recent" past) to the present.

A high-resolution morphological record of planktonic foraminifera across the K-Pg boundary

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Morphology is one of our primary sources of data for understanding biological evolution in deep time. Here, I present a high-resolution morphological record of planktonic foraminifera across the K-Pg boundary generated using high-throughput image processing and deep learning methods. This record spans a time period of ~2.5 MY, from 0.5 MY (66.507 MYA; late Maastrichtian) before the boundary to 2 MY (63.998 MYA; early Danian) after. The purpose of generating this record is to investigate morphological evolution on a community level through a catastrophic extinction event and determine the correlations between planktonic foraminifer community structure and morphospace occupation and environmental/climatic patterns and parameters, including the collapse and recovery of the biological pump. The samples used here originate from the Walvis Ridge (Ocean Drilling Program [ODP] Leg 208, Site 1262, South Atlantic, 27˚11.15’S, 1˚34.62’E). The covered time period is split into 200 time slices with an average time interval of 12.610 kyr between each slice. Segmentation and

measurement of 2D and semi-3D morphological information is achieved using the open-source software AutoMorph and mask R-CNNs (region-based convolutional neural networks) implemented using the Detectron2 library in the PyTorch open-source machine learning framework. The methods developed and discussed here will allow for the rapid generation of large morphological datasets of foraminifera and other microfossils for understanding community evolution and interactions between the biosphere and the environment in deep time.

Albian–Cenomanian planktonic foraminifera and the warm to hot Cretaceous greenhouse climate transition at southern high latitudes: Results from IODP Sites U1513, U1514, and U1516 (SE Indian Ocean)

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Albian–Cenomanian sediments from IODP Expedition 369 Sites U1513, U1514, and U1516 on the Mentelle Basin (MB) in the SE Indian Ocean (60°S paleolatitude) yield extraordinarily well-preserved foraminiferal assemblages that provide new insight to biotic, paleoceanographic, and paleoclimatic changes at southern high latitudes (SHL). The planktonic foraminiferal assemblages are very low in species diversity and age-diagnostic taxa are very rare and sporadic in their occurrence. Fortunately, generally good age control is provided by calcareous nannofossils, and their distribution are the primary observations used to construct age models at each of the sites.

In addition to the overall low diversity of the planktonic foraminiferal assemblages, each site contains one or more carbonate-poor intervals up to 37 m thick that have few or no calcareous microfossils. Where they occur, the planktonic foraminiferal assemblages are consistently dominated by abundant and well-preserved, small-sized, long-ranging species of *Microhedbergella* that co-occur with varying abundances of radiolarians and calcispheres. The carbonate-poor intervals yield common to abundant radiolarians and clinoptilolite, a diagenetic zeolite. Morphology of the clinoptilolite suggest it may have replaced tests of calcareous plankton and/or radiolarians. The carbonate-poor intervals correlate among all three MB and extend from 96.5–100.5 Ma. The most extensive carbonate-poor intervals occur at Site U1516, with carbonate-poor intervals spanning from 96.5–104 Ma and >106.5 Ma. Occurrence of clinoptilolite in carbonate sequences is considered as a proxy for enhanced biogenic silica productivity. Thus, the primary control on the presence of biogenic carbonate or dominance of authigenic clinoptilolite probably depended on the amount of primary biogenic silica in the sediments that was available to react with interstitial clay minerals.

Oxygen isotope records were generated for the Albian-Cenomanian intervals that yielded well-preserved specimen foraminifera. Compiled results show a parallel trend in planktonic and benthic results suggesting gradual warming from the early Albian through late Cenomanian. Early Albian benthic and planktonic $\delta^{18}O$ values average -0.3‰ and -1.3‰, respectively at ~111 Ma and average -0.9‰ and -1.7‰, respectively, at 95 Ma, indicating a 2–3° warming of bottom and surface waters. Previously published foraminiferal oxygen isotope analyses demonstrate a relatively rapid warming of surface and bottom waters across the Cenomanian-boundary by an average of 2.0 to 2.5°C, with some benthic specimens recording $\delta^{18}O$ values as low as -2.6‰ and planktonic specimens as low as -3.8‰. Transition from the warm greenhouse of the Albian–Cenomanian to the hot greenhouse of the latest Cenomanian–Coniacian may explain why planktonic foraminiferal diversity increased and of age diagnostic planktonic foraminiferal became more common in the SHL Indian Ocean starting in the Turonian.

A benthic foraminiferal stable isotope record of changes in overturning circulation of the Red Sea during the 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-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 remineralization of organic matter, drives the strength of the oxygen minimum zone. Here, we present stable isotope data of benthic

foraminifera from core KL11 core (central Red Sea) for the quantification of orbital and millennial-scale changes in the bottom water during Marine Isotope Stage 3. Three shallow infaunal species have been chosen to create a composite record: *Cibicides mabahethi*, *Discorbinella bertheloti* s.l. and *Hanzawaia boueana* s.l. Our results indicate that changes in the overturning circulation of the Red Sea are a result of the influence of (i) the high-latitude millennial-scale climate variability and, (ii) the African-Arabian monsoon system. Specifically, the comparison of $\delta^{18}O$ signals from KL11 and NGRIP shows the influence of Heinrich Stadials and Dansgaard-Oeschger events on the deep-water formation in the northern Red Sea. The $\delta^{13}C$ signal exhibits orbital variations, which are in phase with northern hemisphere summer insolation. This suggests an additional influence of the African-Arabian monsoon system and related surface-water productivity in the central Red Sea.

Geochemical differences between alive, uncrusted and dead, crusted shells of the planktic foraminifera *Neogloboquadrina pachyderma*: Implications for paleoreconstruction

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Planktic foraminiferal-based trace element-calcium ratios (TE/Ca) are a cornerstone in paleoceanographic reconstructions. While TE-environment calibrations are often established through culturing experiments, shell growth in culture is not always consistent with growth in a natural setting. For example, many species of planktic foraminifera thicken their shell at the end of their life cycling, producing a distinct 'gametogenic' crust. Crust is common in fossil foraminifers, however, shells grown in culture do not often develop a thick crust. Here we investigate potential vital effects associated with the crusting process by comparing the trace element (Mg/Ca, Na/Ca, Ba/Ca, Sr/Ca, Mn/Ca, Zn/Ca) and stable isotope ($\delta^{13}C$, $\delta^{18}O$) composition of alive, fully mature, uncrusted shells to recently deceased, crusted shells of *Neogloboquadrina pachyderma* collected from the same plankton tows off the Oregon coast. We find that uncrusted (N = 55) shells yield significantly higher Ba/Ca, Na/Ca, Mn/Ca, and Sr/Ca than crusted (N = 66) shells, and crust calcite records significantly lower TE/Ca values for all elements examined. Isotopic mixing models suggest that the crust calcite accounts for ~40 to 70% of crusted shell volume. Comparison of foraminiferal and seawater isotopes indicate that *N. pachyderma* lives in the upper 90 m of the water column, and that crust formation occurs slightly deeper than their average living depth habitat. Results highlight the necessity to establish calibrations from crusted shells, as application of calibrations from TE-enriched uncrusted shells may yield attenuated or misleading paleoceanographic reconstructions.

'Unmixing' Deep-Sea Sedimentary Records of Planktic Foraminifer Community Turnover during the PETM through Isotopic Filtering

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Microfossil records provide a wealth of information about the biotic consequences of abrupt climate change. Yet their diminutive sizes make microfossils susceptible to sediment reworking, which can mask primary ecological signals in the sedimentary record. Here we present a method for deconvolving the effects of sediment mixing on foraminifer assemblages associated with periods of abrupt biogeochemical change called "isotopic filtering". Isotopic filtering was employed to assess the planktic foraminifer response to the Paleocene-Eocene thermal maximum (PETM) at Ocean Drilling Program (ODP) Site 865 in the equatorial Pacific Ocean and ODP Site 1135 in the southern Indian Ocean. The PETM was an ancient (ca. 56 Ma) global warming event associated with a rapid perturbation of the global carbon cycle that is delimited by a distinct negative carbon isotope ($\delta^{13}C$) excursion (CIE) in the global rock record. The abrupt decrease in the $d^{13}C$ of dissolved inorganic carbon at the onset of the PETM imparted markedly lower $\delta^{13}C$ signatures to foraminifer shells calcified during the event compared to shells calcified prior to the PETM. Abundant isotope analyses (~500 per site) of individual foraminifer shells representing the major taxa from within the CIE interval were used to estimate the proportions of reworked, non-CIE shells within the CIE interval. Frequency distributions of individual-shell $d^{13}C$ values from within the CIE intervals of the Site 865 and Site 1135 PETM records are distinctly bimodal where approximately 49% and 39% of shells were found to be reworked contaminants, respectively. To obtain a clearer picture of the planktic foraminifer

community response, we corrected our faunal census counts by removing the proportions of reworked shells for each major taxon. Diversity metrics for these isotopically-filtered assemblages show that planktic foraminifer communities suffered a transient but significant decrease in diversity at the onset of the PETM in both the low- and high-latitude records. Isotopic filtering also provides unprecedented resolution into the biotic response of individual taxa. For example, several taxa at Site 865 were found to be entirely represented by reworked contaminates within the CIE interval (e.g., *Morozovella aequa-subbotinae*, *Subbotina* spp.). However, these same PETM "zombie" taxa are clearly present below and above the CIE interval in the Site 865 biostratigraphic record, suggesting that they underwent extratropical migration in response to ocean warming during the PETM and subsequently repopulated the Site 865 study area following the PETM. Such an extratropical migration is corroborated by PETM records from the circum-Antarctic region where the relative abundance of specimens belonging to the *M. aequa-subbotinae* plexus increases sharply over the CIE interval at austral ODP Sites 1135 and 690 in the Southern Ocean. The results of this study demonstrate the utility of isotopic filtering for deconvolving the time-averaging effects of sediment mixing on microfossil assemblages associated with paleoclimate events signalled by abrupt biogeochemical change.

Under the south-eastern deep Mediterranean Sea: Benthic foraminifera serve as sentinels for various microhabitats definition

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Benthic foraminifera constitute an important part of the deep-water (> 200 m) meiofauna, including in the Mediterranean Sea, where their spatial distribution and assemblage composition are influenced by food quantity and quality, sediment characteristics, topographic features and bottom-water dissolved oxygen concentration. The southeastern part of the deep Levantine basin (LB), the most oligotrophic part of the Mediterranean, was the least studied region, despite the urgent need for delineating a firm baseline for future studies of sea-floor changes due to increasing activity of gas/oil companies in Israel exclusive economic zone (EEZ) and in the surrounding region (Turkey, Greece, Cyprus and Egypt). Hence, in August 2013 a multi-survey study was conducted in 50 sites, including quantitatively characterization of the live and dead benthic foraminiferal macrofauna (> 250 μm) of the deep south-eastern LB and their relationships to environmental conditions. In addition, water depth, particle size distribution, $CaCO_3$ (wt.%), clay fraction (wt.%), TOC (wt.%) and continental slope processes were correlated with foraminiferal composition. Overall, we identified 100 species of living foraminifera and 197 species of dead foraminifera, many of them, for the first time in this region. Surprisingly, the living foraminifera revealed heterogeneous seafloor consisting six different biotopes, including unique slope habitats as the cold-seeps in Palmachim and Dor disturbance areas and the lower continental slope and the bathyal (> 800 m water depth) that were enriched with aragonite pteropods-associated agglutinated foraminifera, therefore showing an increase in carbonate content. We concluded that the "pteropods habitat" in the bathyal is unique to the eastern Mediterranean, with epibenthic foraminifera using pteropods shells as a hard substrate, which enriches the deep LB in meiofauna.

During the years 2017-19, we conducted complementary surveys at 16 stations along two transects, Haifa and Tel-Aviv, between 45-1900 m. In these surveys we sampled three Perspex-cores in each site, and examined the living BF (in size fraction > 125 μm) in each cm along the top 10 cm. The northern part of the Israeli EEZ (Haifa section) contains higher species richness and living foraminifera down to 10 cm, and show heterogenic upper slope assemblages similar to the observations made in the 2013 survey. Its inhabiting infaunal species are mainly opportunistic such as *Globobulimina*, *Bolivina* and *Chilostomella* dominating water depths > 120 m where TOC is increased. However, the bathyal region of Tel-Aviv section (central Israeli EEZ) contains the highest agglutinated foraminiferal species richness associated with pteropod shells.

Besides the heterogeneity in the lower continental slope in Haifa section, we also observed shallow foraminiferal shells (e.g. *Ammonia tepida* and *Sorites orbiculus*) that were transported to the bathyal region in the northern part of the Israeli territorial water and EEZ, indicating a recent marine landslide only where the shelf is narrow. Similarly, shelf transported foraminifera were also detected in the submarine blind Canyon off Nahariya (northern Israel), which was studied during 2018. Utilizing Lead-210 and Cs-137, we dated sediments from the upper 30 cm of the Canyon to the last 150 years. In these sediments down to 915 m water depth in the outlet of this blind Canyon, we observed live and recently dead benthic foraminiferal species that originated from the shelf, which implies intense turbidities along that period.

Taken together, we demonstrate that benthic foraminifera serve as perfect sentinels defining biohabitats as a function of environmental parameters as well as environmental disturbance (as marine landslides and turbidites).

Time-course analyses on foraminiferal strain *Ammonia veneta* reveal unique adverse physiological effects and metasbolic changes when exposed to nanoplastics

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Plastic pollution is one of the most urgent issues in marine environments. Recent scientific studies have revealed that persistent plastic debris drifts through ocean gyre, then break into micro-to-nano size pieces. Because of their physical and chemical properties, nanoplastics have considerably more toxic effects due to their higher surface area to volume area that increase the capability of adsorbing or leaching toxic substances. Two kinds of functionalized nanoplastics, namely carboxylated- (PS-COOH) and cationic amine- (PS-NH_2) terminated polystyrene are known to induce adverse effects on marine organisms. Although nanoplastics are recognized to lead to harmful effects spanning from physiological to cellular alterations such as enhanced productions of reactive oxygen species (ROS) and lipidic polarity changes, the underlying mechanisms and metabolic pathways remain largely unknown.

Here, we tackle these gaps through a time-course (1, 6 and 24-hours) experiment of two characteristic (PS-COOH and PS-NH_2) nanoplastics based on confocal laser scanning microscopic (CLSM) observations with three specific probes (CellROX@Green for ROS, Acridine Orange for normal and acid endosome, and Nile Red for polar and neutral lipid) and transcriptome analyses on the benthic foraminiferal strain, *Ammonia veneta*. The PS-NH_2 is commonly more harmful than PS-COOH in several marine organisms, however foraminifers exhibit an opposite trend. The CLSM observations on foraminifera show that ROS production continuously increases through 24 h and neutral lipids and acidic endosomes increase in 6 h in PS-COOH. On the other hand, PS- NH_2 treated specimens reveal an enhanced ROS production, polar lipids, and acidic endosomes only at 1 h, and normal conditions are substantially re-established within 6 h. The transcriptome analyses document that both nanoplastics are taken into the cell via endocytosis. The comprehensive results of both transcriptome analyses and CLSM observations indicate that ROS are mainly produced under endoplasmic reticulum (ER) stress and porphyrin metabolism in mitochondria. Such ROS are then quenched by sulfide oxidase, glutathione peroxide, and neutral lipids (i.e., unsaturated fatty acids). Cytotoxicity of PS-NH_2 is suggested to be related to the positive charge of its surface in acidic endosome. Indeed, PS-NH_2 treated foraminifers exhibit a decrease of ROS production with respect to decreasing of acidic endosome after 1 h. Moreover, NAD(P)H quinone dehydrogenase (NQO1) is significantly expressed at 6 h. This enzyme not only disrupts ROS production in mitochondria but also slows down ATP synthesis, which accelerates endosome acidity. These metabolic patterns enable to dismiss ROS production in PS-NH_2 treated foraminifers, but not in PS-COOH ones. Finally, both foraminifers treated with PS-COOH and PS-NH_2 show a significant increase of ceramide biosynthesis. This indicates that foraminifers are capable of excreting nanoplastics using ceramide envelopes. As foraminifers expel these ceramide envelopes via exocytosis, coat foreign nanomaterials could isolate such toxicants from foraminifers and float out from the environment.

Quantifying oceanic regime shifts south of Iceland across glacial/interglacial transitions and millennial scale oscillations using the planktonic foraminifera record

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Iceland's oceanic regime and the marine ecosystem it supports are modulated by the Atlantic Meridional Overturning Circulation and associated changes in surface water mass properties of the northern North Atlantic and Nordic seas. Recent warming has led to a decline in cold-adapted, commercially important marine fish species in southern Iceland. During previous warm periods such as the Eemian interglacial (ca. 150 – 130 ka BP), oceanic conditions were mediated by rapid migrations of the subpolar front. To chart the evolution of past regional (sub-) sea surface conditions in response to global climatic variation, we use a selection of marine cores from the Iceland and Irminger Basins, located both along the transect of the northward ocean heat advection and below known subpolar frontal positions. Using the fossil planktonic foraminifera record, we combine stable isotope analysis and Mg/Ca paleothermometry on *Neogloboquadrina pachyderma* (sin.) to

reconstruct (sub-) sea surface temperatures and salinities across these two basins. A combination of absolute dating methods (radiocarbon dating, tephrochronology and paleomagnetic dating) indicates that these marine records extend back to between 30 and 60 ka BP, thus capturing glacial/interglacial transitions and several series of the millennial-scale Dansgaard-Oeschger cycles. We assess how these differing climate states and millennial scale oscillations propagated into, and influenced, Iceland's oceanic and ecosystem regimes, both in terms of their magnitude and timing.

Submicron Computed Tomography to analyse and quantify microstructures in *Uvigerina* spp.

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Visual study of foraminiferal test is commonly done using light or scanning electron microscopy, both of which are non-destructive 2D surface analyses. To study the tiny structures inside the foraminiferal wall (pores, microborings), it was necessary to use destructive methods. In our work, we want to show the possibilities of submicron Tomography for the visualisation and morphometry of these structures.

Our study focuses on pores (1-2 µm), which size and density yield important palaeoceanographic information (e.g. oxygen levels, phytodetritus input), and bioerosion traces (1-10 µm), another significant aspect of foraminifera caused by microboring organisms like fungi and cyanobacteria. Bioerosion traces are also important features, even though often overlooked. Observation and quantification of bioerosion traces can provide valuable insights into the environmental conditions of early burial of foraminiferal tests.

Three *Uvigerina* sp. were scanned by Computed Tomography (CT). The bioerosion traces and the pores were segmented (specific post-processing and segmentation protocol) from the test material. Their shape, orientation, volume, distribution, location in the test were analysed.

CT allows the observation of the surface and internal structures of a foraminifera test in 2D and 3D, providing more detailed information about the microstructures' shape, distribution, orientation, but also quantification information. CT can achieve high resolution (submicron) and contrast, enabling the observation of small characteristics (nm-µm) related to the morphology of foraminifera non-destructively.

CT uses x-ray projections of an object at different angles to reconstruct a fully three-dimensional distribution of x-ray attenuation. Moreover, CT can be used to analyse specimens that are too delicate or rare to be examined using traditional "preparation" techniques, such as broken specimens or resin-casting, and observation techniques, such as stereo and scanning electron microscopy. These analytical methods are limited to surface or cross-section views (2D).

Our study demonstrates that CT is a powerful tool for the analysis of foraminifera, providing detailed information about their morphology and internal minute structures. Because this technique is non-destructive, specimens can be scanned and analysed without being damaged or altered. This allows the preservation of specimens for further analyses or storage in museums, which can be used by future generations of researchers to study these important microfossils.

Classification challenges from overlapping distributions of final whorl chamber numbers

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Morphological-based taxonomy underpins how we identify species, but current definitions for many Neogene and Quaternary planktic foraminifera species are not up to date, making species identification difficult and biased by individuals. For example, current definitions for *Menardella limbata* and *Menardella multicamerata,* are based on the classical taxonomy and do not separate the species distinctly enough. The two species share many characteristics, including a low trochospiral test with lobulate periphery and pronounced keel; chambers increasing slowly in size; sutures curving backwards into keel on the sutural side and almost radial on the umbilical side; a smooth and densely perforate surface; with a low aperture bordered by a lip. *M. multicamerata* is only distinguished from *M. limbata* by the circular outline of the test, a deep and circular umbilicus, and an increased number of chambers (8-10) in the final whorl. However, *M. limbata* is defined as having 6-8 chambers in the final whorl, creating an overlap in definitions, and the other diagnostics are not always obvious. Other

species within the menardii lineage also overlap in chamber number in the final, adding to the confusion: *M. menardii* has 5-6, *M. pertenuis* has 6-8, and *M. exilis* and *G. miocenica* have 6-7.

Therefore, I aim to provide more succinct definitions of problematic species using updated morphological parameters. In *M. limbata* and *M. multicamerata*, initial morphological clustering analysis, using the size and shape of 500+ specimens of each species from 2D imaging, has shown a distinct difference between the species when applying the newly proposed definitions. These patterns cannot be detected when using traditional classification, which is based largely on chamber numbers, and therefore supports the need to update the current definitions. This study will be completed with further morphometrics analysis, using 2D light-microscope imaging and 3D Computer Tomography (CT) imaging, for both *Menardella* species and analysis via Gaussian Additive Mixture Modelling, which aggregates similar individuals into clusters that vary in size, shape, and orientation without *a priori* classification. The species refinement will be incorporated into the Neogene and Quaternary Planktic Foraminiferal Atlas.

Using spatial patterns in planktonic foraminifera biodiversity to assess climate models

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The Last Glacial Maximum (LGM) remains a prime target to evaluate climate models outside modern boundary conditions. However, climate reconstructions are indirect and associated with marked uncertainty, complicating model-data comparison. Here we take a different approach and use macro-ecological patterns in fossil marine zooplankton to evaluate simulations of LGM near-surface ocean temperature.

We use the distance-decay pattern in planktonic foraminifera assemblage similarity to evaluate modelled thermal gradients. Distance decay emerges because of species-specific habitat preferences, which causes species assemblages to increasingly differ from each other with increasing environmental distance between them. Temperature has consistently been shown to be the most important environmental variable for planktonic foraminifera species assembly. Indeed, their assemblages preserved in surface sediments show decreasing similarity with increasing thermal distance between them. Because the ecological niches of planktonic foraminifera have remained stable over time scales much longer than studied here, the distance-decay relationship based on simulated LGM temperatures and LGM assemblages should in principle be identical to the modern pattern. Thus we can use fossil planktonic foraminifera assemblages to evaluate climate model simulations based on ecological principles, without the intermediate step of transforming assemblage composition into temperature estimates.

Our analysis is based on an extended LGM planktonic foraminifera database (2,085 assemblages from 647 unique sites; 50% larger than a previous synthesis) and a suite of 10 simulations from state-of-the-art climate models (PMIP3 and 4). We find that the distance-decay pattern that emerges when the LGM assemblages are combined with simulated ocean temperatures is different from the modern pattern. All simulations show large thermal gradients between regions where the planktonic foraminifera indicate no, or only weak, compositional gradients. This difference arises from a shift to polar species assemblages in the North Atlantic, where the simulations predict only moderate cooling. Importantly, simulations with a reduced AMOC due to coastal freshwater forcing and hence lower North Atlantic temperatures, yield a distance-decay pattern that is much more similar to the modern pattern, suggesting that simulations using the PMIP protocol for the LGM lack important ice-ocean feedbacks.

By combining insights from different disciplines we have demonstrated the power of using ecological principles to evaluate simulations of past climate. Because distance decay arises from the presence of thermal niches among planktonic foraminifera, our novel method can be applied to any time period, potentially even using assemblages containing extinct species as long as marked niche adaptation can be ruled out.

Towards FAIRer micropalaeontological data

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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 meta-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, in turn, is often hindered by inconsistent formatting. Finally, reusability issues arguably present the largest challenge to meeting FAIR standards. They primarily stem from the complexity of taxonomic data and insufficient metadata.

Standardisation 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. Together with the tendency to report relative, rather than absolute, abundances and the habit to include counts of 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 microfossil assemblage data. Here we propose a set of measures that will help to harmonise legacy taxonomic data and summarise these in a form of recommendations for reporting standards that includes metadata requirements. 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.

Plastic particles can be mistaken as a food source and incorporated into benthic foraminifera tests

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Large benthic foraminifera (LBF) are essential components of tropical coral reef communities and key carbonate-producing organisms. Among other applications, LBF can be utilised as indicators of pollution and environmental change. Marine litter, particularly plastic debris, presents a novel, yet largely unquantified, stress on foraminifera. While the effects of plastic pollution are increasingly being documented, most studies have focused on physiological responses of few organism groups (e.g., fishes, corals). Many previous studies showed negative effects of microplastics and nanoplastics on organismal physiology and ecosystem functioning, but potential responses of foraminifera remain widely unknown.

We here present some of the first feeding choice experiments on LBF, comparing plastics with common food choices. Initially, we document the impact of microplastics (150-300 µm) on the heterotrophic feeding behaviour of *Amphistegina gibbosa* incubated with *Artemia* sp. nauplii only, with pristine microplastic particles only, or with a choice of nauplii and pristine microplastic. In a duplicate experiment, we compared the effect of pristine microplastic vs. microplastic that was pre-conditioned in artificial seawater. Feeding responses in both cases were evaluated a day later. Our results indicate a strong feeding selection against pristine microplastic, suggesting a selective ability of the foraminifera to discern between potential food sources. However, the presence of pre-conditioned microplastic caused similar feeding interaction rates as with the natural food source *Artemia*. This suggests that feeding behaviour (and subsequently energy resources) of LBF may be more severely impacted by microplastics with longer residence times in marine environments.

In a subsequent long-term study, we exposed *A. lobifera* and *A. gibbosa* to nanoplastic particles (~1 µm) and sterilized *Nannochloropsis* algae cells as a natural food source within the same size range. Here, we did not only observe the uptake of polymer nanoparticles deep into the foraminiferal test, but also the incorporation of plastic particles into the outer calcite walls of the tests. Despite the high degree of specialisation regarding the skeletal formation of LBF, abundant cases of nanoplastic encrustation in the calcite tests were observed. Nanoplastic incorporation into the test was associated with LBF growth by formation of new chambers, in conjunction with continuous nanoplastic ingestion and subsequent incomplete

egestion. Microalgae presence in nanoplastic treatments significantly increased the initial feeding response after 1 day, but regardless of microalgae presence, nanoplastic ingestion was similar after 6 weeks of chronic exposure. While ~40% of ingesting LBF expelled all nanoplastics from their cytoplasm, the nanoplastic was still attached to the outer surface of the test and was later encrusted with calcite. These findings highlight the need for further investigation of the impacts of plastic pollution on foraminifera, such as their function as potential plastic sinks or plastic pollution indicators, as well as the effects of alterations in the structural integrity of foraminiferal tests. The large-scale incorporation of nanoplastic into LBF tests as well as potential consequences (e.g., test instability, toxicity) could impact ecosystem functions related to LBF, such as carbonate sediment generation on coral reefs.

Foraminiferal communities of intertidal estuarine mudflats – The MII and EFDI indices, a first step towards solving the estuarine quality paradox

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Today, there is still a lack of reliable indices of environmental quality for estuaries. Because of the harsh environmental conditions, leading to low diversity communities, most biotic indices systematically indicate poor environmental quality, the so-called estuarine paradox. In this context, a thorough understanding of the relationships between environmental parameters and assemblage composition is crucial. It will only be possible to recognise an anomalous assemblage composition due anthropogenic pollution once the response to natural parameters is fully understood and correctly described. There is a wide consensus that salinity is the main controlling parameter in estuaries. However, due to the huge small-scale temporal and spatial variability of intertidal estuarine mudflats, it is almost impossible to obtain salinity measurements that are relevant for the biota. To overcome these problems, we developed two new indices:

1) the MII (Marine Influence Index) describes the extent of "marine influence", a composite factor including salinity, nutrients, marine biota, hydrodynamics, etc., for any point in the estuary,

2) the EFDI (Estuarine Foraminiferal Diversity Index) is based on the diversity of each of four species groups with different tolerance of lowered salinity and associated estuarine constraints.

The good correlation between these two indices suggests that they adequately describe the relationship between natural controlling parameters and assemblage composition in natural intertidal estuarine mudflats. As such, they are the first step to the development of a foraminiferal index of environmental quality.

Foraminifera as indicators of late Holocene sediment contamination in the Bay of Sept-Iles

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In recent decades, coastal environments all over the world have been experiencing rapid change due to increasing anthropogenic impacts. Coastal sediments act as a repository for contaminants entering the coastal marine systems and can preserve a reliable record of their sources. This contamination is not always directly evident but can make the sediments toxic for benthic and epibenthic organisms, which spend a large part of their life cycle in or on the sediment. Foraminifera (or forams) is one such single-celled organisms that are sensitive to their environment and form tests which are preserved in the sediment record, making them useful environmental and paleoenvironmental indicators. The Bay of Sept-Iles (BSI) is a high-use, deep-water mineral port, located in eastern Québec (Canada) where recent anthropogenic activities may show a marked effect on surface sediments and the benthic and pelagic communities that inhabit them. In this context, 50 surface sediment samples and 2 sediment cores were collected to investigate the presence of potential sources of contamination and to assess their effects on foraminiferal assemblages. Foraminifera analysis of the surface sediments revealed an abundance of agglutinated species. *Lepidodeuterammina ochrcea, Crypostomoitus sp, Ammotium cassis* and *Eggerella advena* were the major agglutinated species identified, whereas the calcareous *Haynesina* sp.*, Elphidium* spp.*, Buccella, Calida, Cornuspira planorbis*, and *Buccella frigida* were identified. *E. advena* was vastly dominant at some of the sites that had higher metal

content in the sediments. Morphological deformities, such as crooked tails of *E. advena,* bulged shell in *Elphidium adventum*, and Siamese twinning indicate the presence of a stressful environment in this region.

For a better correlation of these anomalies with the deposition environment, bulk mineral and elemental composition for surface sediment samples were studied using quantitative X-ray diffraction (qXRD) and X-ray fluorescence (XRF), respectively. The qXRD and XRF data suggests that the abnormal morphology of the forams from sites located near a large aluminum smelter could be due to the presence of high Fe-oxides (mainly, hematite) and metal contents (Fe, V, Al). Thus, further foram analysis on these archives will help us develop a better spatio-temporal picture of the effects of anthropogenic activities on benthic communities in the Bay of Sept-Iles in the past half millennium.

Turnover in agglutinated foraminifera across the Cretaceous/Paleogene boundary at Contessa, Umbria-Marche Basin, Italy: assessing the Signor-Lipps Effect

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The record of deep-water agglutinated benthic foraminifera (DWAF) from the Cretaceous–Paleogene boundary (K/PgB) section in the Scaglia Rossa Formation of the Umbria-Marche Basin has been studied in the Contessa Highway Section. The section was been sampled bed-by-bed in the lowermost 50 cm of the Paleocene, and every 10 cm thereafter. The DWAF obtained from hydrochloric acid residues were compared with the record of the Maastrichtian DWAF. The purpose of this study is to assess the degree of faunal turnover among the DWAF at the K/PgB.

Three groups of DWAF are distinguished, namely: survivor species (including Lazarus taxa), extinction species, and incoming species. The total foraminiferal record consists of 86 species and is dominated by the epifaunal morphogroup (*Rhizammina, Caudammina, Ammodiscus* and *Glomospira*). Our record shows an abrupt decrease in the number of species across the K/Pg boundary. The lowermost Paleocene is characterised by the loss around 38% of the species (including *Caudammina gigantea, C. ovuloides*, *Recurvoides retroseptus*, *Gerochammina* spp., and *Bicazammina* spp.). A comparison with the uppermost Maastrichtian DWAF assemblages results in a combined total of 94 DWAF species over the K/PgB interval at Contessa Highway. Of these, 49 species are listed as extinction taxa, nine are survivor taxa, 19 are Lazarus taxa, and 8 taxa display first occurrences in the lowermost 50 cm of the Paleocene. Blooms of opportunists are observed in the lowermost Paleocene. Some species reappeared gradually in the lowermost Paleocene and may be considered Lazarus taxa. Based on our samples, we report around 9% incoming species (including *Ammomarginulina aubertae*, *Spiroplectammina spectabilis*) in the basal Paleocene, some of which are described as new species. The common occurrence of some infaunal forms such as *Reophax/Nodulina* spp. and *Spiroplectinella* is regarded as opportunistic behaviour because they were rare in the Maastrichtian, survived the K/PgB, and then bloomed in the Early Paleocene.

For the purpose of estimating the apparent extinction rate of the DWAF, we considered nine stratigraphic intervals: The first interval above the K/PgB with five samples and successive intervals adding multiples of five samples. This approach to calculating the extinction rate therefore takes into account the Signor-Lipps Effect, and provides an estimate of the number of samples required in order to account for the presence of Lazarus taxa. Our results show that apparent species extinction rate varies from 84% if only the lowermost five samples of Danian are considered, but decreases to 53% when all 44 Paleocene samples are taken into account. We estimate that at least 30 samples are needed in order to calculate an accurate extinction rate across the K/PgB.

The Lazarus taxa are lowering the apparent extinction rate, and create a linear model to represent its additive decrease as additional samples are added to the calculation: simply stated, the calculated extinction rate across the boundary is a function of height of the stratigraphic interval studied and the number of samples collected from the interval overlying the boundary clay. A quantitative comparison between the Maastrichtian and Paleocene DWAF assemblages in Contessa yields new insight into the nature of the extinction rates and changes in the trophic structure across the K/PgB in the western Tethys. The K/PgB interval records a major shift in the proportions of DWAF morphogroups, from a suspension-feeding community in the Maastrichtian to one dominated by epifaunal detritivores in the lower Paleocene, reflecting a fundamental change in trophic structure following the bolide impact, while total marine primary productivity undergo relatively small changes. Our ultimate goal is to produce an unbiased record in order to quantify extinction and origination rates. These data, together with details of recognition of foraminiferal assemblages, taxonomic studies, and paleoenvironmental analysis can address the complex paleoecological problems associated with the K/PgB.

Analysing source and transport of submarine mass wasting along the continental margins of southeastern Mediterranean Sea using assemblages and taphonomy of benthic foraminifera

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Cross-shelf sediment transport is responsible for conveying sediment towards the upper-slope of the southeastern Mediterranean continental margins, yet it has been relatively understudied compared to the longshore transport of Nile-derived sediments. In order to evaluate the cross-shelf vs. longshore component of sediment transport for better understanding mass wasting processes along the slope, we analysed benthic foraminiferal assemblages and their shell taphonomy along cores sampled in the upper and lower scars of three submarine landslides along the Israeli slope: Goliath, Apollonia and Owl landslides located at the southern, middle and middle-north parts of the slope respectively, as well as in the Nahariya blind canyon located north of those landslides.

At each site we first identified the major autochthonous (auto) benthic foraminiferal species (which naturally inhabit the continental slope area) vs. the allochthonous (allo) species (transported from the continental shelf) and then we calculated the allo/auto ratio. Where the ratio is larger than zero a contribution of transported shelf sediment to the slope is indicated. Moreover, where the ratio is higher than 1 a major contribution of shelf material exists. We also qualitatively analysed the taphonomy of the benthic foraminiferal shells and considered high fragmentation as an indication for long transport distance. Planktonic indicative foraminiferal species were used as an age constraint.

Glacial deposits (hosting *Globorotalia scitula*, indicative of glacial period) were sampled only in the lower parts of the cores sampled in the toe of Goliath and Apollonia landslides at water depth of ~900 m, with allo benthic foraminifera found only in Apollonia. Glacial sediment is overlain in both sites by Holocene hemipelagic sediment (including *Globigerinoides ruber* pink, indicative of the Holocene), where allo foraminifera are rare. Likewise, Holocene sediment from the upper scars of Goliath and Apollonia landslides at water depth of ~500 m shows rare allo foraminifera. The top ~1 m of this Holocene sediment in Apollonia is finely laminated with a high percentage of poorly preserved allo foraminifera dated to the last millennia and interpreted as shelf-origin turbidites. Similarly, the sediment of the last 600 years from the Owl landslide upper scar at 280 m water depth consists of two alternating distinct sedimentary facies: laminated intervals showing a high allo/auto ratio of benthic foraminiferal species and a high percentage of fragmented shells, indicating contribution of transported sediments originating from the shelf. These laminated intervals are interpreted as turbidites; Non-laminated intervals showing a low allo/auto ratio and low percentages of fragmented shells, indicating mostly hemipelagic deposition.

For the landslides, we conclude that the observed transported benthic foraminifera only in glacial but not Holocene deposits, suggests that cross-shelf sediment transport decreased following the post-LGM transgression and widening of the shelf, no longer reaching beyond the upper slope. Yet, the cross-shelf sediment transport renewed in the last millennia resulting intensified turbidite activity.

Two cores sampled in the middle and the outlet of the Nahariya submarine Canyon revealed glacial period with mostly-homogeneous sediment, which is uncomfortably capped by fine laminated sediment dated to the last 200 years. The recent sequence consists of fining upwards cyclic layers, interpreted as turbidites. Fragmented shells of shallow shelf foraminiferal species were found abundantly throughout both cores, indicating that shelf sediments are prevalent along glacial and recent sediments. Living allo foraminiferal species that were found in surface sediments indicate that sediment transport processes along this canyon exist to this day.

The reported studies demonstrate that foraminifera are a valuable tool to identify and analyse sediment transport and submarine mass wasting events.

Recovery of planktic ecosystems following the end-Cretaceous mass extinction at El Kef, Tunisia

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Anthropogenic warming is altering our oceans, impacting complex systems such as primary productivity and the global carbon cycle. Ongoing ecological changes include poleward shifts of plankton such as planktic foraminifera and diatoms. However, our understanding of how planktic ecosystems will respond to ongoing global change is limited. The geological record contains climate analogues to present and future ocean-climate states that can be investigated to gain a better understanding of ecosystem responses to climate perturbations. Planktic foraminifera, calcareous nannofossils, and organic biomarkers for non-fossilizing plankton can be recovered to investigate the ecological changes in planktic ecosystems during the aftermath of the Cretaceous mass extinction 66 million years ago.

Using sedimentary rocks recovered from the El Kef Coring Project, near the Cretaceous-Paleogene Global Stratotype Section and Point at El Kef (Tunisia), we generated a record of planktic foraminifera diversity at a ~20cm resolution from the latest Maastrichtian *Plumerita hantkeninoides* Zone to the early Danian Zone P2. We then combined this record with nannofossil and organic biomarker records to provide a holistic view of ecosystem responses. We show that planktic foraminifera assemblages in the immediate aftermath of the K/Pg are dominated by the survivor species *Guembelitria cretacea*. The domination of *Guembelitria* then gradually reduces concurrently with increased genera abundance at the top of Pα. This change in diversity is accompanied by an increase in mean test size. Nannofossil assemblages show a quick transition from disaster taxa, such as *Cervisiella,* to acme events of incoming Paleocene taxa such as *Neobiscutum* spp. transitioning to a more even, diverse assemblages in P1b. Furthermore, we show through organic biomarkers that non-fossilizing plankton were undergoing rapid turnover through Pα into P1b signifying ongoing ecological changes. Organic biomarkers show a shift from brown algae and pelagophytes in the immediate aftermath of the K/Pg followed by blooms of dinoflagellates, diatoms and prymnesiophytes which are gradually replaced by red algae. Looking at any of these planktic ecosystems in isolation would lead to conflicting interpretations ecosystem recovery and stability following the end-Cretaceous mass extinction. Instead, by using an interdisciplinary approach we show that turnovers in phytoplankton may have increased niche stability for zooplankton enabling non-synchronous diversity increases and an overall relatively quick recovery for parts of the planktic communities.

Elevated productivity during Oceanic Anoxic Event 2 in the Mentelle Basin, Western Australia (IODP Expedition 369), indicated by benthic foraminifera and geochemical proxies

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Oceanic Anoxic Event 2 (OAE2) was a period of geologically abrupt greenhouse gas release ~94 Ma, associated with Large Igneous Province (LIP) volcanism and severe ocean anoxia. However, relatively little is known of palaeoceanographic changes in the Southern Hemisphere. We refined the stratigraphy of International Ocean Discovery Program (IODP) Site U1516 by measuring high resolution carbon and oxygen stable isotopes from bulk rock carbonate ($\delta^{13}C_{CARB}$, $\delta^{18}O_{CARB}$) and total organic carbon ($\delta^{13}C_{TOC}$), and benthic foraminiferal isotopes. Published records of bulk rock $\delta^{13}C_{CARB}$ show a clear positive excursion, which is traditionally used to correlate OAE2 globally, but biostratigraphic age control at Sites U1513 and U1516 suggests that OAE2 was stratigraphically more extensive than $\delta^{13}C_{CARB}$ suggests. We resolve this discrepancy by compiling a composite benthic foraminiferal stable isotope record ($\delta^{13}C_{FORAM}$, $\delta^{18}O_{FORAM}$) from several species at Site U1516, after defining species-specific isotope offsets. Our composite $\delta^{13}C_{FORAM}$ record agrees with biostratigraphic age control that OAE2 in the Mentelle Basin was stratigraphically more extensive than suggested by bulk $\delta^{13}C_{CARB}$ alone.

We reconstruct palaeoceanographic change through OAE2 in the Mentelle Basin by comparing published records of biogenic silica and Nd isotopes with our new records of benthic foraminiferal assemblages and stable isotopes for Site U1516. Benthic foraminifera are moderately well preserved in most samples – outside of a prominent carbonate dissolution horizon – with 69 taxa identified, an average diversity of 14 taxa per sample, and species indicative of outer neritic to upper bathyal environments. Correspondence analysis indicates two clear assemblages in the record, with the assemblage change occurring over the dissolution horizon during the main phase of OAE2. Species characterised as high organic carbon flux/low oxygen indicators proportionally increase within OAE2, indicating a likely change to elevated primary productivity. Productivity appears to have increased substantially during the dissolution horizon in the early main phase of OAE2, occurring with increased biogenic silica, occasional pulses of high TOC, and more negative εNd values, indicative of enhanced terrigenous runoff and eutrophication. Within the later part of the main phase of OAE2, terrigenous runoff and productivity fell, carbonate reappeared, but benthic foraminifera indicate productivity was likely higher than before OAE2, and $\delta^{18}O_{FORAM}$ indicates warmer bottom waters, indicative of possible upwelling from less thermal stratification.

An indoor thermal acclimation of *Symbiodinium* endosymbionts within a foraminiferal host

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Tropical calcifiers are key organisms for understanding marine ecosystem responses to global changes. Expressly, holobiont organisms such as corals and Large Benthic Foraminifera (LBF) represent a more complex biological system for coping with the expected environmental changes. One of the most known and well-studied marine endosymbiosis is between the dinoflagellate algae of the genus *Symbiodinium* and reef-building corals. This symbiosis is the key to reef-building corals' success, allowing them to form massive structures that support many marine organisms. This interaction determines the holobionts' functionality and their resilience to environmental stressors. Many studies have shown an influence on this symbiosis upon exposure to various stressors such as light, high salinity, and warming that caused photoinhibition and downregulation of photosynthates. One of the most noticeable signs of such stress is a phenomenon known as bleaching, which could result from a loss of symbionts cells and/or the loss of photosynthetic pigments, eventually leading to death. For the last decades, massive global coral reef mortality has been promoted by coral bleaching, and it is predicted to increase due to ongoing global climate change and warming. Previous studies have shown that the heterogeneous thermal sensitivity among *Symbiodinium* symbionts in corals could be manifested by 1. Changing in situ *Symbiodinium* populations from heat-sensitive to heat-resistant ecotypes or by 2. Ecophenotypic thermal acclimation mechanisms that develop high-temperature tolerance. Here we use the common cosmopolitan LBF species, *Sorites orbiculus*, and its dinoflagellate symbionts for tackling the mechanisms of thermal tolerance of *Symbiodinium* symbiosis in foraminiferal using temperature-manipulated physiological experiments that were done separately on summer and fall populations in July 2021, and November 2022. Three weeks of culturing were done on each population under four temperatures 15, 25, 30, and 35˚C. Calcification of the *S. orbiculus* holobiont was evaluated by measuring alkalinity loss in the culturing seawater as an indication of carbonate ion uptake. The symbiont's photosynthetic performance was determined by measuring dissolved oxygen in the same seawater. At the beginning of the experiment and the end of each week, a sub-set of specimens were frozen for molecular analysis of the algal symbionts. Both experiments show that the *S. orbiculus* exhibits optimal calcification performance at 25˚C and 30˚C, and its growth is significantly reduced upon exposure to the two extreme temperatures. *Symbiodinium* symbiosis recorded the highest oxygen levels at 25°C and 30°C in the summer experiment and only at 25°C in the fall experiment. In both experiments, net oxygen values at 15 °C were significantly lower than those at 25°C, yet positive, indicating sub-optimal conditions for photosynthesis. The most intriguing observation was the drop below zero of oxygen values, at 35°C in week 1, and the consequent increase in weeks 2 and 3 to the levels of the 30°C and 15°C treatments. A similar increase in oxygen production was observed in the 25°C and 30°C. This distinct recovery in time could be explained by either shuffling of different algal types or by acclimation. The mechanism of this recovery will be unraveled by the metagenomic analysis of the symbionts that will be obtained soon.

The effect of the end-Cretaceous ocean acidification on the community structure of planktic foraminifera

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The Cretaceous – Palaeogene (K-Pg) boundary mass extinction is marked by the disappearance of more than 70% of planktic foraminifera. About 25% of the Cretaceous species were short-term survivors into the Palaeogene. *Guembelitria cretacea* is a disaster opportunist species that is the only known long-term survivor of this event. Severe biotic stress preceding the K-Pg boundary is observed in individual planktic species as dwarfing, deformation and decreased calcification. On a community level, stress is identified in the extinction of specialized K-strategists, higher abundance of generalist species and acme of opportunistic species. The proposed stress mechanisms include climate shifts, oceanographic changes and trophic system collapse and ocean acidification. This study presents new evidence for restructuring of planktic communities due to surface ocean acidification based on species-specific test carbonate budgets.

The test weights and/or volumes of three Cretaceous morphogroups (globotruncanids, rugoglobigerinids and planoheterohelicids) from four size-fractions (<63-120µm, 120-150µm, 150-250µm and >250µm) were measured. Results show that an average globotruncanid, a rugoglobigerinid and a planoheterohelicid is equivalent to ~5-188X, ~6-44X and ~4-21X tests of *Guembelitria cretacea*. The outcome from this study is important in understanding the link between carbonate crisis and demand related to ocean acidification in context of survivorship of these morphogroups during the Late

Maastrichtian stress interval. However, other detrimental environmental factors in this critical stress interval cannot be ignored.

Epiphytic Foraminifera in *Posidonia oceanica* Meadows as a Tool for Monitoring Heavy-Metal Pollution in the Balearic Islands (Spain)

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Because of their toxicity, persistence and difficult biodegradability heavy metals are one of the most significant pollutants in marine environments, including seagrass meadows. Epiphytic foraminifers are conspicuous in the *Posidonia oceanica* meadows and can be utilized as cost-effective bioindicators. To evaluate the ecological conditions of *P. oceanica* meadows around the Balearic Islands four indices based on benthic foraminiferal assemblages, such as, the modified FORAM Index (FI'), the "Long vs Short life span" index (ILS), the Foram Stress Index (FSI), and Shannon-Weaver index (H'), were calculated. High index values for all sampling sites with different anthropogenic activities indicated a good ecological status of the seagrass. In contrast, the proportion of abnormal foraminiferal tests (FAI), based on morphological analysis, was variable among the study sites and reach very high abundances in areas with a priori low anthropogenic impact. Although there is not a univocal cause-effect pattern between the occurrence of deformed individuals and heavy metal pollution (such as Cu, Zn, Cd, Pb, Co, Ni, As and Sn), abnormal growth forms were significantly more abundant in sites where the tests contained higher concentrations of trace elements, and certain deformities (occurrence of protuberances and supernumerary chambers) seemed to be associated with specific pollutants (Zn, Ni and As). The disparity between the foraminiferal biotic indices and the percentage of aberrant forms associated with the heavy metal uptake can be explained by differences in the type of environmental impact and the mineral composition of the foraminiferal tests. Thus, the use of foraminifera as bioindicators, combining different approaches such as ecological indices, quantification of abnormal growth patterns and geochemical analysis of their tests, are very helpful in determining the health of seagrass meadows ecosystems. The indices are proxies to show dominant conditions over a large area, whereas the morphological and geochemical analysis of the foraminiferal tests shows very localized but long-lasting impacts with sublethal effects.

Coiling direction and biostratigraphic utility of mid Miocene paragloborotaliids and globorotaliids (planktonic foraminifera)

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Trochospiral planktonic foraminifera will exhibit either a sinistral (left-handed) or dextral (right-handed) coiling direction. This morphological trait is unambiguous and so can be readily recorded and tracked through a stratigraphic interval within a given species. The ratio of sinistral to dextral forms can change through time, leading to a dominance in coiling direction. Coiling prevalence holds biostratigraphic value with a number of bioevents being recognised in Recent to late Miocene (~0-7 Ma) biochronology within the tropical-subtropical realm. Although a change in preferential coiling direction is known to occur within several species through older time intervals, no such events have been applied beyond the late Miocene. One such example is the genus *Paragloborotalia* which has been shown to undergo a change from random to sinistrally dominated coiling in the mid Miocene (~15 Ma).

We investigated *Paragloborotalia siakensis* from multiple sites in the equatorial Pacific Ocean (IODP Sites U1337 and U1338, ODP Site 871), equatorial and mid latitude Atlantic Ocean (ODP Site 925 and JOIDES-3 respectively) and the Caribbean (Trinidad, Jamaica and Barbados). We also studied material from the high latitude Southern Ocean (ODP Site 747) to assess the global the global synchronicity of the coiling change. However due to the scarcity of *P. siakensis* at Site 747, we instead recorded coiling in the more prevalent paragloborotaliids, as well as the genus *Globorotalia* due to their dominance in the mid to late Miocene at this site.

Our high-resolution record from Site U1337 indicate a change from a random to sinistral coiling preference at 15.37 Ma within planktonic foraminifera Zone M5, and shows excellent correlation with our lower resolution records from Site

U1338, JOIDES-3 and Trinidad. The sinistral coiling preference in *P. siakensis* is maintained up until the extinction of the species in the late Miocene (~10.50 Ma; Site 925). In the high latitudes (Site 747), the absence of *Paragloborotalia* through a portion of the mid Miocene precludes accurate dating of the coiling change. However random coiling trends are found in the older paragloborotaliids between ~19.8-17.3 Ma (*P. semivera* and *P. incognita*) compared to the sinistral coiling adopted by *Paragloborotalia continuosa* in the younger part of the record (~13.5-9.0 Ma). *Globorotalia* at Site 747 show two changes in coiling direction namely one from random to sinistral at 15.14 Ma, within a *G. praescitula* and *G. zealandica* dominated assemblage, and at 10.02 Ma within *G. scitula*.

We propose the recognition of the coiling change in *Paragloborotalia siakensis* as a secondary bioevent in the mid Miocene at ~15.37 Ma, and a useful biostratigraphic means of recognising the base of the Langhian in the tropical-subtropical realm. The bioevent will be of particular use in regions where the historic base Langhian planktonic foraminifera event, namely the *Praeorbulina-Orbulina* lineage, are rare or poorly represented. Our preliminary investigation of coiling changes within *Globorotalia* suggest coiling is biostratigraphicially useful in the high latitudes, particularly as foraminiferal assemblages are typically lower in diversity compared to tropics.

The influence of the Caribbean in Oligo-Miocene planktonic foraminifera taxonomy and biostratigraphy

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The Caribbean region represents one of the most historically important regions in planktonic foraminiferal research, accounting for the description of over 100 species with a full or partial range in the Oligocene and/or Miocene between 1839-1980. The vast majority of these species are still valid with 14 species being erected as the type taxa for the relevant genus either at the time of description or in subsequent studies.

The region was also the birthplace of planktonic foraminiferal biostratigraphy in the mid part of the 20th century. In 1945 Joseph Cushman and Robert Stainforth produced the initial biozonations for the Oligo-Miocene sediments exposed at the Cipero Beach section in Southern Trinidad. Subsequent work within Trinidad, spearheaded by Hans Bolli, allowed for a near complete planktonic foraminifera zonation from the late Cretaceous to late Miocene with much of this being detailed in the seminal United States Museum Bulletin 215 "Studies in Foraminifera". Subsequent studies in the 1960s focused on filling in the late Miocene to Recent interval with eastern Venezuela and Jamaica being of particular importance. Although the advent of ocean research drilling in the late 1960s allowed for more complete and higher-resolution records, the impact of the Caribbean provided the backbone for subsequent zonations.

Here we present a review and reassessment of Caribbean region to bring the original findings in line with our modern day understanding of Cenozoic planktonic foraminifera taxonomy and biostratigraphy. Unfortunately, many of the original localities applied in the aforementioned studies are no longer accessible. Thankfully, the original authors had the foresight to distribute material, including type slides and residues, to museums and academic institutions worldwide. A number of these classic sections have been re-examined as part of this study, with a particular focus on Trinidad. In terms of biostratigraphy, there is remarkable consistency in the bioevents applied within the tropical-subtropical realm, with some (e.g. Top *Paragloborotalia kugleri* and Top *Catapsydrax dissimilis*) being applied consistently in biozonations since their initial recognition. Regarding taxonomy, we have focused on species where the original description was based only on the holotype (e.g. *Globorotalia lenguaensis* and *Globorotalia archeomenardii*) with no other associated type specimens (e.g. paratypes). Analysis of topotypic material, such as the original residue and subsequent specimen slides, allowed us to ascertain the abundance of the relevant species and the morphological variability exhibited, as well as illustrating additional specimens to aid our taxonomic concepts.

When stress creates high diversity: the case of Thermaikos Gulf (NW Aegean Sea)

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Living and dead benthic foraminiferal assemblages were analysed to determine their seasonal variation and evaluate the effects of environmental factors on their abundance, species composition and distribution, in the semi-enclosed Thermaikos Gulf, in the NW part of the Aegean Sea. Three major rivers, two minor ones and several ephemeral streams flow into the

shallow Thermaikos basin. During the high precipitation period (January-May) the fresh water intrusion extends to the major part of the gulf (surface salinities <25). The high river water supply to the gulf enriched in nutrients and terrigenous matter, causes great amounts of dissolved solids in the water column, enrichment of heavy metal content and eutrophication. Therefore, the gulf is considered as one of the most anthropogenically impacted coastal regions of Greece.

A twelve-month monitoring was carried out in order to investigate the foraminiferal abundance and distribution, in relation to a multi-parameter environmental dataset (temperature, salinity, pH, total dissolved solids and nutrients), metal content and organic carbon. One station (S1) was sampled on a monthly basis (January-December), whereas five stations (S1-S5) during winter (January), spring (April), summer (July) and autumn (October), located in the inner part of Thermaikos Gulf.

A total of 82 living benthic foraminiferal species were identified out of stained specimens, while 150 species have been defined in the total assemblage. In combination with the high species richness and diversity indices the inner Thermaikos Gulf is indicated as a high diversity environment. Interestingly, the muddy substrates in the eastern and central parts of the gulf are dominated mainly by stress-tolerant taxa, whereas samples from the sandy western part are characterized by a more diversified assemblage including also sensitive foraminiferal species such as miliolids and a variety of small epiphytic rotaliid species.

Hence, the exceptional environmental conditions that prevail in the environments of the inner Thermaikos Gulf, although deriving from a combination of stressful parameters, create a high diversity foraminiferal fauna in a natural but physiochemically complex environment.

Paleoenvironmental changes in the Gulf of Corinth (eastern Mediterranean) during MIS 5 from benthic foraminifera and geochemical proxies

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The Gulf of Corinth is a relatively young (<5 Ma) and active continental rift zone in the eastern Mediterranean Sea, which is currently connected to the Ionian Sea through a shallow sill (60 m of depth) and to the Aegean Sea via the Corinth canal. The closed drainage system and the high sedimentation rates (approx 0.5-3 mm/yr) make the study area a natural laboratory for the investigation of the complex interaction between sedimentary input, tectonics and climate through its evolution. In this study, we investigate the paleoenvironmental changes in the IODP Expedition 381 core M0080A during MIS 5 (21-36.5 mbsf), using a multiproxy approach including a combined benthic foraminiferal (assemblages and abundances), sedimentological (grain size) and geochemical (inorganic carbon content, benthic foraminifera oxygen and carbon isotopes) dataset.

The benthic foraminiferal record is highly variable, with two intervals (22.8-25.5 mbsf and 30-35.8 mbsf) characterized by high abundances of *Hyalinea balthica*, *Bolivina spathulata*, *Melonis affinis*, *Bulimina aculeata, Bulimina marginata* and *Cassidulina carinata* indicative of mesotrophic to eutrophic marine conditions, likely occurring during high sea-levels. These intervals are separated by periods when benthic foraminifers were very low in numbers or even absent, suggesting a sea-level drop below sill level and the subsequent (semi-) isolation of the basin. The inorganic carbon content varied following the interpreted sea-level fluctuations, with higher values occurring during low sea level intervals. Furthermore, several aragonite layers were found during the transition from high to low sea level (marine to isolated intervals), whereas the predominant grain size is very fine silt and clay.

The benthic foraminifera oxygen isotope record is discontinuous and conditioned to the presence of well-preserved benthic foraminifera. The species *Melonis affinis* and *Bulimina aculeata* were used to construct a benthic foraminiferal composite record corresponding to MIS 5a, early MIS 5c and MIS 5d-e periods, where the sea level was inferred to be above the sill level.

Ongoing high-resolution studies and a new age model will improve our understanding of paleoenvironmental changes in the Gulf of Corinth during glacial and interglacial stages and allow us to define the factors driving changes in this unique active rift of the eastern Mediterranean.

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New approach to calculating dissolved marine oxygen values with the Enhanced Benthic Foraminifera Oxygen Index

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Changing climates and anthropogenic influences disrupt the oceanic metabolic cycle leading to major changes in biodiversity. Tracking oxygen minimum zones (OMZs) gained much interest due to their effect of trapping greenhouse gases and the reduction of livable habitat. This makes changes in dissolved oxygen (DO) a driving factor of changing biodiversity. A frequently used tool to reconstruct DO values is the Benthic Foraminifers Oxygen Index (BFOI). We realized major differences using the original BFOI calculation and quantitative analyses. Therefore, we revised and enhanced this method by using all available data, including oxic, suboxic, and dysoxic indicators. Our enhanced BFOI (EBFOI) thus considers calcareous and agglutinated foraminifers and infaunal and epifaunal taxa for calculating the livable habitat of benthic foraminifers, including bottom water oxygenation and pore water oxygenation.

Additionally, we introduce a transfer function to directly convert the EBFOI into DO values in ml/l for the first time ($DO[ml/l]=5.28475*e^{0.00616*x}-3.78475$).

Our new approach significantly improves the definition and reconstruction of marine oxygen levels and eutrophication. All formulas are calibrated on modern samples, showing an accuracy increase of up to ~38% near OMZs compared to the BFOI. The EBFOI was subsequently also applied to three Cenozoic fossil datasets. Thus, our new formulas provide a major improvement in reconstructing oxygen levels and the reliability of benthic foraminifers as an oxygen proxy in general. This allows a better understanding of past changes and tracking and predicting future expanding OMZs.

Assessing Heavy Metal Contamination Along the Mediterranean Coast of Israel Using Foraminiferal Shell Geochemistry

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Heavy metals (HM) pollution can have a critical impact on the sustainability of the marine environment, with potential effects on marine ecosystems, human health, and economical activity. Direct monitoring of water chemistry is logistically difficult and analytically expensive, particularly in coastal areas. Here, we present a systematic study of the HM pollution of the Israeli Mediterranean coast using the compositions of benthic foraminifera shells, which act as "living data loggers" of pollution levels. Our research question was: "What is the spatial and temporal variability of HM pollution along the Israeli Mediterranean coast, as recorded by benthic foraminifera shells?"

The study was carried out in eight stations spread over 150 km, between Achziv in the north and Palmahim in the south. Some stations are located in pristine environments (e.g., nature reserves), while others, such as Haifa Bay and Jaffa Coast, are proximal to industrial or urban areas and are suspected to be polluted. Samples were collected from each station and three species were selected to demonstrate variability among foraminiferal calcifications: *Lachlanella* sp., *Amphistegina lobifera*, and *Pararotalia calcariformata*. Samples were collected seasonally between November 2022 and September 2023 to evaluate temporal variability. The samples were stained with Rose-Bengal solution to mark living specimens at the time of sampling. Live specimens were picked and rigorously cleaned in an ultraclean lab to remove organic matter and other external contaminants. The samples were subsequently digested, and the HM content of group of specimens of each species was measured using ICP-MS.

Our study found that the HM content was higher near Haifa Bay and the coast of Jaffa, but no clear geographic trend was observed in other areas. As expected, the HM content of the miliolid species *Lachlanella sp.* was higher than those of *A. lobifera*. These results provide the first documentation of the distribution of HM pollution along the Mediterranean coast of Israel and illustrate the benefits of using benthic foraminifera as environmental monitors. The significance of these findings lies in their potential implications for environmental policy, public health, and future research directions.

During this study, we made another discovery regarding the staining of samples in Rose Bengal solution. This method was chosen due to the need to process a large number of samples. Upon comparing the dyed samples with those that were

not, we observed an unexpected pattern of lower values of in the dyed specimens relative to the stained ones. We interpret this observation as an indication that the Rose Bengal staining process causes specific elemental impurities to detach from the foraminifera shells, leading to a counter-intuitive decrease in some of the HM contents. This phenomenon was observed across all three species we examined.

When rose Bengal fails to detect living foraminifers by simple observation through the tests – methodological approaches in the Santos Basin, Brazil (Southwestern Atlantic)

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The samples of this study were provided within the "Santos Project - Santos Basin Environmental Characterization" – coordinated by Petrobras/CENPES. The samples were collected in triplicates at eight sampling stations located 150 m deep; they were fixed with 4% buffered formaldehyde and stained with rose Bengal (2 $g.L^{-1}$). The wet volume was standardized to 20 mL at the laboratory, and the samples were washed on a 63 μm mesh sieve with water. Further, they were dry and separated by density with trichloroethylene PA. All supernatant material was thoroughly analysed; the residue was split, and a 5 mL subsample had all non-transparent agglutinated specimens selected for counting and identification.

The rose Bengal is a dye widely used to identify living foraminifers, and for most of the specimens, the stained protoplasm is visible by the transparency of the tests. A total of 45,916 living benthic foraminifers from the continental shelf of Santos Basin were studied, the classical staining technique worked for most individuals, and the protoplasm's colour was adequately seen through the tests. However, in some non-transparent agglutinated foraminifers, it was impossible to detect the stained protoplasm through the test, even when the specimens were immersed entirely under water or glycerine, observed under transmitted and incident light. For those specimens, no pattern allowed a confident decision to distinguish living from non-living individuals. Thus, to correctly estimate the contribution of these organisms to the density at the Santos Basin's outer shelf, the tests of non-transparent agglutinated foraminifers had to be broken to inspect their contents, and the percentage of living individuals registered for each species was confidently quantified.

Two of the three collected replicates had the non-transparent agglutinated foraminifera broken and inspected for stained protoplasm. The percentage of living foraminifers of each species was applied to extrapolate the amount of the living foraminifers from the unbroken replicate. Of 20,457 tests, 5,075 were broken, and 322 were considered alive, representing 1.6% of the non-transparent agglutinated tests. Considering other living foraminifera groups, 6,874 individuals were registered at the outer shelf and the density of living non-transparent agglutinated corresponded to 4.5% of the total. In the Northern portion, non-transparent foraminifers represent up to 18% of the total density.

A non-metric Multidimensional Scaling analysis (nMDS) was performed with the non-transparent living foraminifers; four groups were detected (two from the northern area, one transitional, and one from the southern area). Canonical correspondence analysis (CCA) showed that non-transparent agglutinated foraminifers were related to declivity, distance from the coast, phaeopigments, and sedimentary properties (size and grain selectivity); three groups (north, south and transitional) were identified. The Correlation Analysis with 5 mL and 10 mL aliquots showed that the abundance of the sub-samples was positively correlated with the whole sample.

We are applying living foraminiferal assemblages to characterize the Santos Basin; if they are not adequately quantified, some regions will not be adequately distinguished from others. Therefore, incorporating qualified data is vital; if these foraminifers were not considered, density would have been underestimated. These non-transparent individuals are essential components of the benthic foraminiferal assemblages. They differentiate some portions of the continental shelf, and in the case of Santos Basin, they are significant components of the northern outer shelf.

The Albeşti nummulitic limestones: biostratigraphic, paleoenvironmental and paleogeographic remarks

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Within the territory of Romania, the Albeşti nummulitic limestone is considered one of the classical Eocene successions, which consists of abundant larger benthic foraminiferal (LBF) tests. The Albeşti type limestone has been exploited and used as building stone over the centuries. Despite its economic interest and paleontological importance just few papers discuss its paleontological and sedimentological aspects. Even the LBF assemblages and age of the Albeşti limestone have been

discussed in some papers in the second half of the twentieth century, questions, as its exact age, depositional environment and paleogeographic affinity still remain open.

To answer these questions, we performed a high resolution taxonomical and microfacies analaysis based on 40 samples collected along seven exposures located in and near Albeşti locality (Argeş county, southern foot of the S Carpathians, northern part of the Getic Basin).

Based on the sedimentological features and paleontological content of the investigated thin-sections, four main microfacies types were established (in statigraphic order): 1. densely packed bioclastic grainstone-rudstone; 2. fine-grained packestone; 3. glauconitic grainstone; and 4. bioclastic packstone and floatstone.

Tha taxonomical studies revealed an abundant and diverse LBF assemblage, composed of 20 orthophragminid taxa (Discocyclinidae: *Discocyclina*: *D. archiaci bartholomei*, *D. augustae sourbetensis*, *D. dispansa taurica*, *D. fortisi*, *D. furoni*, *D. weijdeni* and *Nemkovella*: *N. bodrakensis*, *N. evae evae*, *N. strophiolata fermonti*. Orbitoclypeidae: *Orbitoclypeus*: *O. douvillei douvillei*, *O. droogeri, O. furcatus palaeofurcatus*, *O. multiplicatus kastamonuensis*, *O. munieri munieri*, *O. schopeni crimensis*, *O. varians portnayae* and *Asterocyclina*: *A. alticostata*, *A. schweighauseri schweighauseri*, *A. stella praestella*, *A. stellata adourensis*) and 10 radiate *Nummulites* species (*N. nitidus*, *N. irregularis*, *N. distans*, *N. pratti*, *N. rotularius*, *N. anomalus*, *N.* aff. *variolarius* and *Nummulites sp*. 1-3). At the same time granular *Nummulites* are missing, as well as representatives of the genus *Assilina*, which are usually abundant in the Tethyan Eocene.

Based on the identified main microfacies-types and the abundance of the LBF a high energy depositional environment, situated in the middle parts of a carbonate ramp has been inferred for the studied carbonatic succession. The recovered LBF assemblages are typical for the SBZ10/11 (LBF in general) and OZ 6/7 (orthophragminid) biozones and confer a late Ypresian (early–middle Cuisian) age to the studied sedimentary record.

The exclusive presence of taxa belonging to the non-granular *Nummulites* shows affinity to the northern nummulitic bioprovince (Dobrogea: SE Romania and NE Bulgaria, Crimea, Mangyshlak and the vicinity of Lake Aral) and suggests that the northern part of the Getic Basin was in a direct connection with the Peri-Tethyan realm during the Eocene. No provinciality could be detected, however, in the case of orthophragmines, similar lower-middle Cuisian assemblages have been reported from SW France, the Crimea and from N and Central Turkey.

An in-depth study of macroperforate and microperforate Neogene planktonic foraminifera speciation events

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Planktonic foraminifera are marine microorganisms with one of the most complete fossil records of the Cenozoic era. Due to this fact they are often utilised as a tool to investigate micro- and macroevolutionary questions. In this study a high-resolution direct sampling approach was taken to analyse multiple speciation and extinction events across both microperforate and macroperforate lineages within the Neogene. The speciation of *Globigerinella siphonifera, Globigerinella calida, Globigerinella adamsi* and *Beella megastoma* and the extinction of *Globigerinella praesiphonifera* were studied in detail with paired single specimen morphometric and geochemical data allowing the investigation of relationships between macroperforate planktonic foraminifera test morphology and ocean depth habitat through time. A further analysis of speciation events was carried out on the microperforate genera *Polyperibola* and *Globigerinatella*. This work allowed the in-depth study of *Globigerinatella* sp*., Polyperibola christiani* and the identification of a new species within the *Polyperibola* genus.

Phylogeny of the Cenozoic planktonic foraminifera

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Here we present an updated phylogeny and relational database of the Cenozoic planktonic foraminifera. The phylogeny is graphically integrated to display morphospecies contained within lineages as stratigraphic ranges calibrated to GTS2020 and linked to datums, with additional pop-up and digital information on species ecologies, biogeographies, and key

morphological traits, providing an unparalleled resource for empirical analyses aimed at investigating macroevolutionary processes and responses of biodiversity to climate change.

New developments include the erection of new species from new core material from previously understudied regions of our global oceans, developments in molecular analysis, and the revision of taxonomic concepts as part of the efforts of the Paleogene Planktonic Foraminifera Working Group. The most recent synthetic phylogeny produced in 2011 was restricted to the Cenozoic Globigerinoidea, as this group was considered to be the most well studied and with the richest fossil record. This new phylogeny expands its scope and incorporates the Superfamilies Globigerinitoidea, Guembelitrioidea and Bolivinoidea.

The recent formation of the Neogene and Quaternary Planktonic Foraminifera Working Group (NQPFWG) will revisit the most comprehensive synthetic taxonomic revision of the Neogene planktonic foraminifera that was completed in the 1980's and the construction of this phylogeny will provide a phylogenetic framework against which the NQPFWG can test existing evolutionary hypotheses.

Planktonic foraminifera microbial associations in the subtropical Pacific

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Molecular techniques reveal the microbial associations within planktonic foraminifera, with implications for shell geochemistry. Many planktonic foraminifera species contain photosymbionts, and some species could contain bacterial symbionts. For example, previous research has found that *Globigerina bulloides,* a species commonly used in paleoproxy reconstructions, contains the cyanobacterial photosynthetic endobiont *Synechococcus*. The photosynthesis and cellular respiration of these endobionts could explain the elevated isotope signature of *G. bulloides* compared to other spinose foraminifera species. It is not yet known if planktonic foraminifera have a specific microbiome associated with their life cycle, whether as symbionts or preferential prey, or if their microbiome reflects the water mass they live in. In this study, the prokaryotic community associated with subtropical western Pacific planktonic foraminifera were identified using next-generation sequencing. Six planktonic foraminifera species – *Candeina nitida, Globigerinita glutinata, Globorotalia menardii, Neogloboquadrina dutertrei, Hastigerina pelagica* and *Pulleniatina obliquiloculata* - were collected in May 2019 nearshore to Green Island, Taiwan, located in the Kuroshio Current. Water samples were collected to provide information on the background bacterial community. To identify the bacterial community, all foraminifera and water samples were sequenced using 16S Earth Microbiome Primers metabarcoding. Preliminary results suggest foraminifera have a distinct microbiome, separate from the water column, although the bacterial community is not always consistent by foraminiferal species. We examine whether these differences can be explained by genotypic variability or environmental factors. Understanding the ecology and symbiotic relationships of more foraminiferal species' various genotypes can explain variability in shell geochemistry, which has been a limitation in paleoclimate research.

Genotypic & geochemical variability of a planktonic spinose foraminifera species, *G. bulloides,* across the Northeast Pacific

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The discovery of genetic diversity within morphologically identical foraminifera species has complicated the well-established use of foraminiferal fossils as geochemical proxies as many genotypes cannot typically be identified under the microscope. Foraminifera of different genotypes are thought to have habitat preferences that could explain variability in shell geochemistry within populations. However, identifying the genotype and distinguishing shell variability definitively has

been challenging as many DNA extraction techniques destroy the foraminiferal shell. Some DNA extraction methods do not destroy the shell and thus offer promising potential to pair molecular and geochemical techniques to resolve population variability with the same shells. In this research, we paired molecular and geochemical techniques with Northeast Pacific *Globigerina bulloides*, a species associated with the thermocline and upwelling regimes that has known genotypic and geochemical variability. The *G. bulloides* morphospecies is genetically diverse, with seven genotypes recognized so far. Three genotypes have been identified in the North Pacific: types IIa, IId, and IIe. Type IId might be endemic to the region. Type IIa is thought to calcify with a thicker, more encrusted shell than type IId, but genotyping and geochemical analysis have never been conducted on the same shell. We collected samples from the Channel Islands, in California and from opportunistic research cruises in the North Pacific (Oregon Coast and Subtropical Gyre). Genotype and shell geochemistry were analysed on the same individual foraminifera shells, with the aim of identifying if consistent morphological or geochemical signatures of specific genotypes exist and further, testing whether DNA extraction alters trace metal geochemistry. We compare the morphology, using microCT scans, and trace metal geochemistry, using laser-ablation-ICP-MS, of air-dried and extracted samples. We will also genotype specimens to see if there is genotypic variability in the collected samples. This research will help elucidate how genotypic population variability is reflected in a common geochemical proxy species and may inform paleo reconstructions for this genetically diverse species.

Biogeography of modern larger symbiont-bearing foraminifera: A fully revised update

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Modern larger symbiont-bearing foraminifera (LBF) are prominent carbonate producers and perform vital roles in tropical and subtropical reef and shelf environments. In this presentation, a fully revised update on the world-wide biogeographic distribution of LBF is presented. The analysis constitutes the most comprehensive data compilation available to date and includes a total of 105 LBF species and almost 4800 occurrence records covering a latitudinal range between 45°N and 33°S. The spatial patterns that emerge from this study were employed to (1) visualize species-specific distribution patterns, (2) to identify latitudinal and longitudinal species richness gradients and hotspots of diversity, and (3) highlight some of the major variables exerting control over the modern biogeographic distribution of larger foraminifera.

Species distribution modeling using Maxent was then applied on the fully updated dataset to assess future species richness patterns on a global scale for the time periods 2040–2050 and 2090–2100 with a focus on Representative Concentration Pathway 6.0 (RCP) from the Intergovernmental Panel on Climate Change. The RCP 6.0 scenario projects mean surface temperature changes of +2.2°C by the year 2100. Our results project substantial range extensions, an increasing widening bimodal latitudinal pattern of species diversity, a temperature-driven decline in low-latitude species richness, and support hypothesis that biogeographic patterns of LBF will fundamentally change under future climate conditions.

Benthic foraminifera mediate oxygen penetration and prokaryotic diversity in intertidal sediment

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Bioturbation processes influence particulate (sediment reworking) and dissolved (bioirrigation) fluxes at the sediment-water interface. Recent works showed that benthic foraminifera largely contribute to sediment reworking in intertidal mudflats; yet their role in bioirrigation processes remains unknown. In a laboratory experiment, we showed that foraminifera

motion-behavior increased the oxygen penetration depth and decreased the total organic content. Their activity in the top 5 mm of the sediment also affected prokaryotic community structure. Indeed, in bioturbated sediment, bacterial richness was reduced and sulfate reducing taxa abundance in deeper layers was also reduced, probably inhibited by the larger oxygen penetration depth. Since foraminifera can modify both particulate and dissolved fluxes, their role as bioturbators can no longer be neglected. They are further able to mediate the prokaryotic community, suggesting that they play a major role in the benthic ecosystem functioning and may be the first described single-celled eukaryotic ecosystem engineers.

Eukaryotic symbioses of large benthic foraminifera

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Eukaryote-eukaryote endosymbioses are less common than eukaryote-bacteria endosymbioses. However, they can be surprisingly abundant in a few understudied groups of microbial eukaryotes. One of such groups are large benthic foraminifera (LBFs) which host a wide range of eukaryotic photosymbionts including diatoms, dinoflagellates, red algae, and green algae. LBFs are single-celled eukaryotes mostly thriving in coral reef flats and creating cm-long calcium carbonate shells (i.e., they are among the largest single-celled organisms). Here, we used multiple methods such as fluorescent microscopy, electron microscopy, and single-cell metagenomics to understand the evolution and cell biology of the foraminiferal-algal symbioses. We show that LBF symbioses are host-specific with different foraminiferal lineages hosting distinct clades of symbionts. Phylogenetic analyses showed unexpected results. In green-algae hosting *Parasorites* sp., we identified that the symbiont does not belong to the *Chlamydomonas* genus but likely to a new undescribed genus. Similarly, the diatoms symbionts of *Amphistegina lobifera*, *Calcarina gaudichaudii* and *Baculogypsina sphaerulata* also belong to undescribed *Serratifera* and *Nitzschia* species. Surprisingly, we also revealed that the dinoflagellate symbionts are the most dynamic and that some dinoflagellates can co-exist with other symbionts in diatom- and red algae-housing foraminifera. Assembled plastid genomes of the algal photosymbionts then uncovered potential differences in their photosynthetic abilities. Foraminifera-algal symbioses are thus emerging as a useful comparative model of eukaryote-eukaryote endosymbioses.

A new species of pink pigmented *Globigerinoides* (planktonic foraminifera) from the Pleistocene

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Shipboard scientists on International Ocean Discovery Program (IODP) Expedition 363 reported the presence of unusual pink coloured planktonic foraminifera at two sites in the tropical Indian Ocean off northwest Australia (IODP Sites 1482 and 1483). These exhibit “mosaic morphology”, combining morphological characteristics typical for *Globigerinoides conglobatus* and *Globigerinoides ruber*, suggesting potential evolutionary relationship with either. They were provisionally referred to as ‘*Globigerinoides* sp. cf. *conglobatus* (pink)’.

Here we present morphometric image analysis data acquired from a series of 860 specimens from IODP Site U1483, documenting morphological variability of these new foraminifers and both similar species of *Globigerinoides*, all of which co-occur within the Pleistocene sedimentary sequence. We find that the newly discovered foraminifer occurs as two colour variants, a pigmented (pink) form and a non-pigmented (white) form. Non-pigmented forms are on average ~50% larger than their pink counterparts. As genetic information is not available for fossil species and both colour variants share many morphological characteristics, we regard the pink and white forms as variants of a single morphospecies. The new foraminifer is morphologically distinct from both potential sister taxa, indicating that it should be regarded as a separate species with biostratigraphic potential. It most likely evolved from *G. conglobatus*, although that has yet to be demonstrated, and became extinct about 0.8 Ma.

We also report its presence in the tropical Pacific, at IODP Site U1486 north of Papua New Guinea, expanding its known geographic range. In fact it is likely that the species has occasionally been described in the past from Pacific sediments under the name *Globigerinoides gomitulus*, a form originally described from the Pliocene of Italy, but we argue from comparative morphology that the identification as *G. gomitulus* is incorrect and it is appropriate to erect a new species. This is so far only

the third instance of planktonic foraminifera known to exhibit pink pigmented shells, after commonly recognised *Globoturborotalita rubescens* and *Globigerinoides ruber*.

Foraminifera as indicators of trophic state in tropical lagoons: Rio de Janeiro, Brazil

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Rio de Janeiro Coast presents a unique series of lagoon systems formed during the regression that followed the last Holocene maximum, circa 5,000 years ago, that is confined within a narrow coastal plain, approximately 120 km long and 10 km wide. The essential differences among then are related to the region's climate, which varies from humid tropical to semi-arid, and the intensity of anthropic impacts on its catchments. The impacts of human activities have transformed most of these lagoons in environments with strong eutrophication processes, due to the launch of organic sewage, PAHs, and trace elements. In the last 10 years, studies on environmental characterization of the trophic state in these lagoons (Itaipu, Maricá, Saquarema, Vermelha, and Araruama) and their effects on foraminiferal fauna have been developed with the purpose of identifying species or groups of species that can be used in the biomonitoring of these ecosystems. In this context, the present study aimed to apply different statistical approaches to understand the relationship between the 87 species of foraminfera identified in the lagoons and organic matter compounds (organic matter -OM; total organic carbon – TOC; total sulphur – TS; total biopolymers – BPC; carbohydrates -CHO; protein -PTN; and lipids -LIP). The statistically significant differences in the behaviour of these variables among the lagoons were verified using the non-parametric Kruskal-Wallis test (KW). The samples (n=90) were classified into four classes of trophic conditions using K-means and the Euclidean distances between them were represented by the first two dimensions of a non-metric multidimensional scaling (NMDS).

The KW results showed that all lagoons differed from each other by at least two variables indicating trophic state. The K-means grouped all samples from Vermelha Lagoon in a single group (TROF-PTN) characterized by the highest PTN. This lagoon is reported as the most hypersaline lagoon in Brazil where the formation of recent stromatolites is verified. The other groups were: TROF-1 grouped the samples located near the tidal channels with the lowest TOC and TS contents; TROF-2 grouped samples from Maricá and Itaipu lagoons that present the highest values of LIP indicating regions of greater anthropic impact; and TROF-3 grouped most of samples from Saquarema, characterized by the highest values of TOC, TS, CHO, and BPC indicating high organic concentration, but still in the moderate trophic state because they are regions that present balance between the concentrations of biopolymers. A discriminant analysis was applied to evaluate if the foraminifera species (with abundance > 1%) allow discriminating the groups previously defined by geochemical variables. The linear discriminant model correctly classified 77.8% of samples in their respective trophic states. The best result was obtained for the TROF-PTN group where 35 of 36 samples were correctly identified, being *Quinqueloculina seminulum* and *Miliolinella subrotunda* the most important species for the regions under high PTN concentrations. The worst performance was observed for the TROF-1 group, with 43% misclassification. This was the smallest sample group (n=14) and was most strongly associated with *Ammonia rolshauseni* and *Quinqueloculina milletti*, which would be the indicators for regions with good trophic conditions. The TROF-2 grouped samples with species characteristic of both TROF-1 and TROF-3 presenting its centroid in the transition between both groups. In the TROF-3 group the importance of *Ammonia tepida, Ammonia parkinsoniana, Cribroelphidium gunteri* and *Elphidium excavatum* increases, and 68.8% of the samples were classified correctly. This assemblage is commonly found in several coastal ecosystems of Brazil with high concentrations of organic matter. The results show the potential use of foraminifera in the predictive modelling of trophic conditions in lagoons under different stages of eutrophication.

A Neritic Record of Oceanic Anoxic Event 2 from Coastal Utah: New Insights into U.S. Western Interior Seaway Paleoceanography and Foraminiferal Paleoecology

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The Upper Cretaceous Tropic Shale of southern Utah captures oceanographic changes that occurred along the western margin of the U.S. Western Interior Seaway (WIS) during Oceanic Anoxic Event 2 (OAE2). This study focuses on the

response of planktic and benthic foraminifera in a shallow (<80-100 m) marine environment as informed by high-resolution (1.5 - 5.0 ka) population counts and isotope measurements of specimens from a 40-m composite outcrop and core section of the lower Tropic Shale. The OAE 2 interval is identified by a distinctive $\delta^{13}C_{org}$ signature, and by correlation of bentonites and carbonate-rich units across the seaway.

Prior to the onset of OAE2 at Big Water UT, the foraminiferal assemblages are dominated by rare agglutinated taxa. The onset of OAE2 coincided with a very rapid transgression; surface waters were initially dominated by the tiny triserial planktic *Guembelitra cenomana*, with minor abundances of trochospiral *Muricohedbergella delrioensis*. The benthic assemblage was initially dominated by the infaunal species *Neobulimina albertensis,* suggesting low oxygen conditions in these coastal waters at the onset of OAE2. Other rare species of calcareous benthics just above Bentonite A, including *Hoeglundina charlottae*, demonstrate that this interval is correlative with the "Benthonic Zone" elsewhere in the WIS. A recent study shows that the development of the "Benthonic Zone" is diachronous across the WIS.

Epifaunal *Gavelinella dakotaensis* briefly proliferated as OAE2 intensified in the interval below Bentonite B during the latest Cenomanian. The "*Gavelinella* acme" coincides closely with the widespread "*Heterohelix* shift" and marks the plateau phase of OAE2. Biomarker data suggest that the "*Heterohelix* shift" was triggered by photic zone euxinia, and that *P. globulosa* dominated the planktic foraminiferal assemblages when productivity was high. By contrast, *Gavelinella dakotaensis* likely records higher seafloor oxygen levels, proposed to be a function of caballing along a Boreal-Tethyan oceanographic front, alternating with euxinic conditions dominated by *Planoheterohelix*.

The peak of OAE2 in Utah is marked by an abrupt shift back to *Neobulimina* dominance in benthic assemblages of the uppermost Cenomanian. We suspect incursion of oxygen-poor Tethyan waters with approach of peak transgression during the early Turonian, coupled with water column stratification and seasonally high productivity. Eutrophic nannofossil *Biscutum constans* sharply increased in abundance near the Cenomanian/Turonian boundary signaling cooler, highly productive surface waters along the western margin of the WIS following OAE2.

The idea of caballing (the mixing of two water masses to create a third denser water mass) in the WIS has been around since the early 1990s, and one study documented the presence of an oceanographic front in the Black Hills region of Wyoming and Montana, separating Tethyan and Boreal waters along which the process of caballing may have occurred. A later study proposed that such a water mass front extended southwestward into the Colorado Plateau region. The "*Gavelinella* acme" was a longer-lived bioevent along the western margin of the WIS and shorter-lived to the east in New Mexico and central Colorado, where it occurred just below Bentonite B. At an outcrop in Billings Montana, the "*Gavelinella* acme" occurs above Bentonite B, and the change to *Neobulimina* dominance does not occur until the Cenomanian/Turonian boundary suggesting that these bioevents, driven by the position of the ocean front and then stratification of Tethyan and Boreal waters, were diachronous from southwest to northeast in the U.S. Western Interior Seaway.

Recent benthic foraminifera from Marian Cove, King George Island, Antarctica

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West Antarctica has experienced rapid environmental changes since the middle of the 20th century. Accordingly, the need for endemic biodiversity research and environmental monitoring in the region, and paleoenvironmental research to respond to the climate change is increasing. Particularly, in Marian Cove, a small fjord located in King George Island (West Antarctica), significant environmental changes including the retreat of glaciers by 1.7 km have occurred since the 1950s. However, few researches on the diversity and distribution of foraminifera, common bioindicator for environmental monitoring and paleoclimate reconstruction, has been conducted in the region since the 1990s. During the austral summer of 2021/2022, we collected surface sediment samples from five sites in Marian Cove, at water depths of up to 111 m. Total of 2,890 benthic foraminiferal individuals belonging 45 genera, 29 families, seven orders and four classes were recognised. Thirty genera were identified at each of the two sites closest to the Cove entrance, which is the highest number among the sampling sites. Eleven genera were recognized in the innermost part of the Cove, which is the lowest number among the study sites. The most common genera in the study site were *Adercotryma*, *Cassidulinoides*, *Globocassidulina*, *Portatrochammina*, *Psammosphaera*, *Reophax* and *Spiroplectammina*, which were consistent to previous studies on King George Island. The data resulted from this study will be used as a basis for further molecular biodiversity, environmental monitoring studies using foraminifera as proxies of climate changes also by covering a wider area within Maxwell Bay in the King George Island.

The application of biostratigraphic studies in the energy and subsurface-storage industries. An example from the Ainsa Basin, Spain

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Biostratigraphic studies are commonly used in the oil industry for age calibration and facies characterization. Particularly in fine-grained sedimentary successions, integration of biostratigraphic data with sequence-stratigraphic interpretations and rock-property measurements are useful to understand and predict retention of fluids in the subsurface. This has application to petroleum exploration, as well as hydrogen and CO2 storage. Outcrop studies serve as powerful analogs to make subsurface predictions for such applications. Here, we present an integrated study of Eocene strata of the Ainsa Basin in Spain which is a great outcrop analog for many subsurface settings and issues. This tectonically-influenced siliciclastic deepwater to fluvial succession has been heavily researched for understanding reservoir architecture and seal properties, initially for oil and gas exploration, and more recently as an analog for CO2 storage. Our studies reveal the distribution and sealing potential of overall low Net-to-Gross successions (mudstones and siltstones) as well as their spatial and temporal relation to associated coarser-grained strata. We integrated biostratigraphy (foraminifera, nannoplankton, palynomorphs), pore typing (MICP), geochemistry, sedimentology, to build a predictive model for facies distribution and architecture in the subsurface.

We studied two stratigraphic sections: an older Upper Ypresian unit and a younger Upper Lutetian unit. The older unit (150m thick) is dominated by deepwater sediment-gravity-flow deposits interbedded with transitional to hemipelagic deposits with relatively abundant nannoplankton and planktonic foraminifera. Mudstones contain variable amounts of calcareous and agglutinated benthic foraminifera, with some clay-mineral-rich horizons exclusively containing agglutinated microfauna. These facies are interpreted as overbank deposits (levees) of channel complexes as well as distal fringes of lobe complexes. Paleoenvironmental conditions near the seafloor were at times stressful and sometimes dysoxic. Paleobathymetric estimations indicate upper to middle bathyal depths (200 - >500m). The younger section (170 m thick), in contrast, displays a progressive decrease of planktonic foraminifera and calcareous nannoplankton and a notable increase of diversity and abundance of calcareous benthic foraminifera and reworking of larger benthic foraminifera (mostly *Nummulites*). This pattern records an overall shallowing of water depth from upper bathyal (500m) to neritic water depths of no more than several meters. MICP data suggests the most favorable sealing facies correspond to mudstones with significant volumes of detrital clay minerals and variable amounts of biogenic carbonate. Mudstones with high biogenic carbonate content have poor capillary sealing capacity and also tend to have abundant natural fractures, which may adversely affect mechanical sealing capacity. The poor sealing capacity of biogenic-rich mudstones is due both to primary porosity associated with microfossils, as well as secondary dissolution porosity. Using biostratigraphic observations, we hypothesize that mudstone facies from hemipelagic settings with abundant nannoplankton and planktonic foraminifera, and slope facies with abundant calcareous benthic foraminifera would have lower quality seals. Mudstones deposited from muddy turbidites (overbank facies or distal fringe facies with abundant clay mineral aggregates) and moderate to abundant agglutinated foraminifera would make good quality seals.

This model is a useful analog to subsurface case studies of petroleum exploration and fluid storage projects, where the evaluation of capillary seal quality and fracture potential is a key uncertainty.

The distribution of some numerical parameters of *Nummulites perforatus* (Montfort) A-forms from the Bartonian of Transylvania (W Romania): evidence for trimorphic life cycle in fossil foraminifera?

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The general use of arithmetic mean in the biometric characterization of measured or counted numerical parameters of many fossils presumes that their distribution is normal in the given population, although this assumption has never been seriously tested. However, if the distribution were lognormal, we would have to calculate the geometric mean. Available fossil populations (with less than 100 specimens) are too small to decide this dilemma. To perform a reliable analysis on the distribution of crucial numerical parameters we need at least 1000 isolated, easily identifiable specimens of the same taxon

from a max. 10–15 cm thick stratigraphical interval of a section and excellent preservation for unequivocal and rapid measuring.

Non-cemented, Bartonian monospecific nummulitic accumulation made up by well-preserved specimens of both A- and B-forms of *Nummulites perforatus* (Montfort) with empty chambers in rock-forming quantity recovered from two outcrops (Văleni and Leghia) located in NW Transylvania (Romania), entirely fulfill the above conditions. We measured two external parameters on 1000 specimens of A-forms from both sites, the diameter (D) and the thickness (T) of the tests, from which their shape (D/T) could be calculated. Internally, in the equatorial section opened by splitting, we measured the inner cross-diameter of the proloculus (P, representing the same ontogenetic stage for each specimen) also on 1000 specimens.

The input data of the four parameters were used in their raw form and also in logarithmically transformed one, in order to test both (normal and lognormal) distributions. As a result, four types of normality tests on the eight datasets were proceeded using PAST. The null hypothesis in all tests applied was that the sample was taken from a population with normal (or lognormal) distribution. If the obtained probability is less than 5%, normal (or lognormal) distribution could be rejected.

Normal distribution of all external parameters in both samples could be definitely excluded. Their lognormal distribution is permitted in most cases by the normality tests, exclusions may be explained by sampling uncertainties. Thus, the lognormal distribution of external parameters is highly probable.

Both tested distributions of the internal parameter P are rejected in both samples by the normality tests. However, more detailed analysis shows that in both samples the strong deviation from the lognormal distribution may be caused by a few extra specimens with very small proloculus (25–30 in Văleni and 10–15 in Leghia out of 1000!), which are otherwise cannot be distinguished from other specimens with normal-sized proloculus. Indeed, mixture analysis (proceeded by PAST) suggests the presence of two size-groups for Văleni, while this is not confirmed for Leghia with very few specimens bearing small proloculus.

The size-overlap of the two groups hampers their separation in both assemblages, therefore specimens with very small-sized proloculus were picked out arbitrarily. Three different selections were tested for both samples: with 23–31 specimens with very small proloculus from Văleni, and with 10–16 such specimens from Leghia. The distribution of these groups can be both normal and lognormal due to the very small number of specimens. However, the distribution of the remaining specimens in the assemblages (all bearing normal-sized proloculus) turned out to be most probably lognormal while their normal distribution is definitely rejected in both cases.

Paleobiologically, the presence of two different A-forms can be explained most plausibly by trimorphism, well-known among recent foraminifera, but it is evidenced now for the first time on fossil assemblages. In addition to the B-forms with large-sized test (agamonts), we interpret the specimens with small-sized test bearing very small proloculus as A_1-forms (schizonts) whereas those with normal-sized proloculus can belong to the A_2-forms (gamonts).

Theoretically, the verification of lognormal distribution of numerical parameters in foraminiferal populations would imply the substitution of arithmetic means by geometric means. However, since in most cases the arithmetic mean in many larger foraminiferal populations exceeds the geometric mean only with 0.5–2.5%, and this corresponds only to 0.2–0.6% of the standard error of the arithmetic mean, there is no practical need for the change-over. However, the recognition of fossil trimorphism may imply more serious consequences, which are beyond the scope of this study.

Seasonal variation of Planktonic Foraminifera in the South China Sea and its paleoceanographic implication

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The Asian monsoon has played an important role on the heat and moisture distribution in the west Pacific Ocean and neighbouring continents. A stronger East Asian summer monsoon will lead to the northern movement of the raining belt in China, resulting in the floods of the middle and lower reaches of the Yangtze River, or even in the Yellow River region. Monsoon variations also influence the oceanographic and climatic conditions, such as the sea surface temperature, mixed-layer depth, upper water column structure and productivity.

In this study, planktonic foraminifers were investigated on the samples from two sediment traps deployed in the southwestern and northern South China Sea, to monitor their relationship with the monsoon variation. A stronger monsoon wind corresponds to the higher chlorophyll α concentration, higher content of *Neogloboquadrina dutertrei*, and higher *Globigerinoides ruber*/*Globigerinoides sacculifer* ratio. It indicates that *N. dutertrei* content, instead of the *Globigerina bulloides* as an upwelling indicator in the Arabian Sea, showing highly significant correlation with the strength of the upwelling/monsoon in the South China Sea, which suggests it might be a valuable upwelling/monsoon index in this region.

The speculation was applied on the down-core variation of the planktonic foraminifers in Core MD05-2901 from the southwestern South China Sea. The *N. dutertrei* indexed upwelling/monsoon variations is consistent with other

paleoceanographic reconstructions, such as the Mg/Ca sea surface temperature, organic carbon based primary productivity and faunal composition during the last 400 kyrs.

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Individual foraminifera analyses: comparison of morphometric and isotopic methods and application for the penultimate deglaciation

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Records of geochemical composition based on individual foraminifera analyses (IFA) have been used to reconstruct past interannual climate variability such as the El Niño-Southern Oscillation (ENSO). Due to sedimentary bioturbation and low accumulation rates, downcore sedimentary analysis can usually not record past climate variability at seasonal and/or interannual timescales. However, IFA can theoretically estimate the variance of a population of foraminifera that experienced hydrological variability changes at sub-centennial timescales. Previous studies suggested that IFA on thermocline-dwelling planktonic foraminifera captured changes associated with ENSO in sediments retrieved in the eastern equatorial Pacific. To test whether such changes have their counterparts in the western equatorial Pacific, or whether these changes reproduced over each glacial-interglacial transition during the late Pleistocene would provide some reliability to this approach. Here, we focus on a marine sediment core (MD05-2920) retrieved from the western Pacific warm pool, North off Papua New Guinea. This area is characterized by a weak seasonal variability of sea surface temperature (exceeding 28°C on annual mean). On the interannual timescale, the stratification of the water and the thermocline's depth is influenced by ENSO events with drier (wetter) conditions and a shallower (deeper) thermocline during El Niño (La Niña) years. We use a combination of two methods (i) an automated imaging and sorting system (MiSo) to pick the *Neogloboquadrina dutertrei* specimens and to count planktonic foraminifera assemblage using a convolutional neural network method. We focus on *N. dutertrei,* which maximum abundance is found within the thermocline and could be used as a proxy for interannual climate variability; (ii) IFA $\delta^{18}O$ analyses on *N. dutertrei* over the penultimate deglaciation (100 kyr BP-160 kyr BP). 5 samples of 50 individual specimens were selected for 5 different depths in the core to extract the thermocline variability, which is hypothesized to be directly related to ENSO activity. By this approach we will be able to characterize the frequency and the intensity of ENSO events over the studied period and compare it to results from MiSo that provides information on the total assemblages. Preliminary results suggest a higher value of the standard deviation of *N. dutertrei* $\delta^{18}O$ for the MIS5, characterizing an increased thermocline variability compared to MIS6.

Symbiont-bearing foraminifera *Heterostegina depressa* affected by sunscreens

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Heterostegina depressa is an extant representative of the family Nummulitidae and reported worldwide from tropical to warm-temperate, shallow-marine environments. It harbours obligatorily endosymbiotic diatoms, which provide essential photosynthetic products for the foraminiferal host. The photosynthetic performance of the photobionts is largely influenced by physical and chemical parameters.

We studied potential impacts of four sunscreen products, which might be found at higher concentrations especially along beach areas and river deltas. Two of them are sold as "conventional" and two more are offered as "ecofriendly". Further, the impact of pure Ensulizole (phenylbenzimidazole sulfonic acid) was tested, which is commonly added to sunscreens as UVB blocker. Foraminifera were incubated at varying concentrations (10, 50 and 200 mgL^{-1}) of the different sunscreens and the pure Ensulizole for 7 days. The non-invasive technique of pulse-amplitude modulated (PAM) fluorescence microscopy was used for analysing the effects. The photosynthetic performance was measured after 1,3, and 7 days.

Pure Ensulizole showed a strong negative impact on the photobionts, which was reflected by a significant reduction of the areal fluorescence signal. Additionally, "ecofriendly" sunscreens affected the health of foraminifera more severely

compared to "conventional" ones. We assume that metal nanoparticles like titanium dioxide or zinc oxide of "eco-friendly" sunscreens are causing this impact, because these substances were already classified as toxic for several microorganisms.

The use of VIS spectroscopy to detect kleptoplasts and food particles in foraminifera

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A large number of foraminifera feed on algae. Furthermore, some species are able to use kleptoplastidy, which allows them to incorporate functioning chloroplasts from their algal food source into their own cell body. Sincechlorophyll (a and c) can be detected in the intact cells using spectroscopic methods in the visible spectral range, this method allows indirect investigation of the presence of sequestered chloroplasts and food particles. Starving experiments of *Elphidium williamsoni* in the light (24 h continuous) showed that the greatest decrease in chlorophyll content was recorded within the first 20-30 days. From day 60 on, chlorophyll was hardly detectable. Through subsequent feeding on a renewed algal food source a significant increase in the chlorophyll content of *E. williamsoni* was noticed. The degradation of chlorophyll in the dark (24 h continuous darkness) during the starving period was much more complex. Chlorophyll was still detected in the cells after 113 days of starving time. Therefore, we hypotheses that the effect of photoinhibition applies to chloroplasts (kleptoplasts) in foraminifera under continuous illumination. The method used in our study also allows a precise search for food particles in each individual chamber of the foraminifera. In all specimens it was possible to record the food particles in the first chambers. However, the food particles were no longer detected in older chambers. This indicates that the digestion of the food particles takes place in the first 3-5 chambers of the foraminifera.

Late Pliocene-Early Pleistocene surface ocean conditions at the SW Iberian margin

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The Late Pliocene-Early Pleistocene marks a transition from a globally warmer climate with high CO_2 concentrations to a colder climate with the development of northern hemisphere glaciations. The West Iberian margin is a key region to study past climatic changes as it can document both high (Greenland) and low (tropical-subtropical) latitude climate variability during the Pleistocene. In addition, the high sedimentation rates make it an ideal location for high-resolution paleoceanographic and paleoclimatic studies. However, few marine climate records exist in the Iberian margin before 1 Ma due to the absence of long sediment cores.

In this study, we examined sediment samples from IODP Site U1391 (37°21.5′N; 9°24.6′W, 1085 m water depth), recovered at the Southwest Iberian margin during Expedition 339. This site provided an almost continuous marine record of the SW Iberian margin dating back to the Pliocene. To get a comprehensive understanding of changes in sea surface temperature, productivity, seasonality, and ecological diversity across Marine Isotope Stages (MIS) KM2 to 96 (3.11 to 2.44 Ma), planktonic foraminifer assemblages were compared to the alkenone-derived sea-surface temperature (SST), and the total alkenone concentration records of Site U1391.

From ~3.0 Ma to ~2.5 Ma, alkenone-derived SST shows temperatures typically between 22-26ºC, except during glacial periods MIS G6-4, 100, and 98 when SST reached ~17-18 ºC. The warm water taxa follow the changes observed in alkenone-derived temperature but also show a reduction at MIS G6-4, indicating warmer and more oligotrophic conditions prior to MIS G6-4. On the other hand, the cold-water taxa such as *Neogloboquadrina pachyderma* and *Turborotalita quinqueloba* increased after the glacial period MIS G6-4. *Globigerina bulloides* and *Neogloboquadrina incompta* represent the most abundant species linked to higher productivity conditions nowadays. *N. incompta* shows in general high abundance

during glacial periods with maximum abundances during MIS G16. *G. bulloides* abundances are lower from ~3.0 to ~2.76 Ma and tend to increase after that, suggesting that along with the onset of the Northern Hemisphere glaciations the seasonal upwelling that generates primary productivity in the Iberian margin increased.

Integration of Multiple Data Types to Reconstruct the Whole Plankton Ecosystem After the K/Pg Mass Extinction

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Microfossils, especially foraminifera and calcareous nannoplankton, have played a central role in our understanding of change in the oceans for over a hundred years, and the tireless work of micropaleontologists over that time has produced records of environmental and evolutionary change that are unmatched in geographic, temporal, and taxonomic resolution compared to other fossil groups. However, in the modern ocean, plankton with extensive fossil records represent just a fraction of the total plankton biomass (a small fraction at that, if you remove diatoms, which are only preserved under ideal conditions). There are thus large parts of the plankton ecosystem for which we have practically no record. This represents a problem for understanding past changes in ocean ecosystems as well as predicting future ones. For example, many non-fossilizing groups of phytoplankton are much smaller than calcareous nannoplankton or diatoms, which means that they can support a smaller overall biomass and lower export production compared to their larger cousins. By the end of the 21st century, anthropogenic warming and increased stratification are projected to favor smaller phytoplankton and cause a 5-10% decline in global primary productivity. We can use similar changes in the geologic past to contextualize what these changes might mean for marine ecosystems as a whole, but to do that we first need more complete records of all the plankton groups, not just the ones that fossilize.

The Cretaceous-Paleogene (K/Pg) mass extinction is an ideal interval to address this question because it represents a major and rapid perturbation of the entire marine ecosystem. ~90% of planktic foraminifera and calcareous nannoplankton went extinct as a result of the disruptions following the Chicxulub impact. Calcareous nannoplankton were important primary producers in the Cretaceous ocean, and their decline left a gap that was, presumably, filled by smaller, non-fossilizing phytoplankton like cyanobacteria and various algae. This change would have had a profound effect on ocean nutrient cycling and export production, and would have had consequences up the food chain, limiting the potential size of recovery communities. Did the eventual recovery of calcareous nannoplankton coincide with changes in nonfossilizing plankton community structure? Did the evolution or dominance of different groups of planktic foraminifera (and, by extension, other zooplankton) come about as result of changes in the composition of primary producer populations? Although detailed work on biomarkers at this interval has documented the recovery of non-fossilizing plankton groups, there is a need to integrate this data with microfossil records to fully understand how the whole plankton ecosystem recovered from this event. In this project we are working to integrate records of calcareous nannoplankton, non-fossilizing phytoplankton, and planktic foraminifera from the earliest Danian at El Kef, Tunisia, Brazos River, TX, and Caravaca, Spain. This poster highlights the importance of this approach and shows how multiple data types can be used to recognize interactions between plankton groups. Similar work across other major climate events will help us to better understand plankton ecosystems more broadly, beyond the well-studied world of calcareous microfossils.

Eocene Evolution of Surface Circulation and Export Production in the Western South Atlantic

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The Eocene-Oligocene Transition (EOT) represents the first major glaciation of Antarctica and a significant reorganization of global ocean circulation. Prior to this abrupt event, the Eocene records the gradual cooling from the peak warmth of the Early Eocene Climate Optimum and the progressive openings of the Drake Passage and then the Tasman Gateway. These long-term changes gradually set the boundary conditions in which the EOT was able to occur, but are more poorly understood than the EOT itself. Here, we utilize new cores from International Ocean Discovery Program Sites U1557 and U1558, collected in the western South Atlantic by the South Atlantic Transect Expeditions 390C, 390, and 393. Located within the South Atlantic Gyre, these sites are well positioned to reconstruct the evolution of Eocene ocean circulation and accompanying shifts in primary and export production, both of which may be linked to Eocene cooling. We utilize shipboard data as well as foraminifera accumulation rates, X-ray fluorescence core scanning data, and preliminary planktic foraminifera assemblage counts to document shifts in surface ocean circulation and export production throughout the Eocene. Following a short-lived peak in mass accumulation rate and export production in the late Paleocene, we find changing conditions throughout the Eocene with a shift in the middle/late Eocene at approximately 40 Ma (6 Myr prior to the EOT) toward gradually increasing export production. This shift is associated with an increase in mass accumulation rate and associated increases in foraminifer accumulation rate, organic carbon accumulation rate, and carbonate accumulation rate. These increases, prior to the opening(/deepening) of the Tasman Gateway, the development of the Antarctic Circumpolar Current, and the glaciation of Antarctica, track a late Eocene increase in export production in the South Atlantic Gyre that we hypothesize is related to gradual changes in surface ocean circulation preceding the major shifts of the EOT.

Pattern of foraminiferal diversity change across the Eocene-Oligocene transition

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The Eocene-Oligocene transition (EOT) - 33.9 million years ago (Ma) - is regarded as a turning point in Earth's history, when the Earth's climate shifted from a "warmhouse" to an "icehouse" state. Significant biotic responses, especially from foraminifera, have often been discussed for this period. However, due to the lack of high-resolution diversity data, the detailed evolutionary history of different types of foraminifera during this period is still unclear. Here, we use a quantitative method, CONOP, to reconstruct a species diversity history of foraminifera during the EOT with an average temporal resolution of ~26,000 years. We find a significant decline in diversity from the middle Eocene to the Oligocene, eliminating 74% of foraminifera species. This pattern of foraminiferal diversity change can be separated into four major factors by using Q-mode factor analysis, i.e. foraminiferal fauna, which are dominant in the early Eocene, middle Eocene, late Eocene-early Oligocene and late Oligocene, respectively. In addition, foraminifera are usually divided into three groups that are generally distinct in their life-history strategy, morphology, and ecology, including planktonic foraminifera, larger benthic foraminifera, and smaller benthic foraminifera. Among these three major foraminiferal groups, larger benthic and planktonic foraminifera show similar trends in diversity change during this period, since the correlation coefficient ρ of them is considerably high (0.89). In contrast, the smaller benthic foraminifera suffered a longer decline in diversity (~7.53 Myr) throughout the Eocene and Oligocene.

Early Cretaceous (Aptian–Albian) depositional environments of Sergipe-Alagoas Basin (northeastern of Brazil): microbiofacies and foraminiferal assemblages

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During the Early Cretaceous, several extensive carbonate shelves were deposited in the sedimentary basins located on the Central Segment of the South Atlantic Ocean. These marine successions were characterized by mixed calcareous and siliciclastic sediments with a diverse fossil content. For the Aptian–Albian interval, one of the most complete marine stratigraphic records among all the basins of the Brazilian and African continental margins is found in the onshore portion of

the Sergipe-Alagoas Basin, Brazilian continental margin. Although many basins of the Brazilian and African continental margins have a relatively continuous onshore and offshore record from the Early Cretaceous, the Sergipe-Alagoas Basin stands out for its fossil-rich units and sedimentary sequences that represent all the phases that comprise the fragmentation of Gondwana and the opening of the South Atlantic Ocean.

The Aptian–Albian studied deposits correspond to the Riachuelo Formation, which are characterized by a mixed shelf system (carbonatic-siliciclastic), composed of sandstones/packtones with quartz, deposited in a transitional system partially protected by carbonate banks (packstones, grainstones, and rudstones), representing as bars and shelf-edge, grading to more stable and deeper outer shelf environments, characterized by mudstones/wackestones. In this work, we studied the microbiofacies content of two continuous cores (SER-01 and SER-03), each approximately 200 m deep, drilled on the onshore portion of the Sergipe Sub-basin. Core SER-01 consists of mudstones, wackestones, packstones, grainstones, rudstones, marls, claystone, shales, and sandstones, while the sediments from Core SER-03 are essentially constituted by fine-grained lithologies such as mudstones, wackestones, claystone, and shales.

Six sedimentary microfacies were recognized. They indicate deposition in a high energy shallow marine environment with a bar system, which later evolved into a low energy deep marine environment (outer shelf). The microfossil content includes planktonic and benthonic foraminifera, which are dominant in both cores, as well as macrofossils such as echinoderms and mollusks. The microfossil content is impoverished with low-diversity. Planktonic foraminiferal assemblages are composed of globular chambered specimens with trochoidal, planispiral and, very rarely, biserial tests (favuselids, hedbergellids, globigerinelloidids and heterohelicids). *Favusella washitensis* is the dominant taxon in both wells. The benthonic microfauna is characterized by agglutinated lituolids, textularrids, as well as rarely nodosarrids (*Dentalina* sp.) and vaginulinids (*Lenticulina* sp.). Most planktonic and benthonic specimens (textularids and nodosarrids) show pyrite-filled molds. Such feature is probably due to post-mortem under reducing conditions, shortly after burial or during the early stages of diagenesis of the more susceptible (thinner and porous) calcareous tests.

Extremely rapid evolution of earliest Danian planktonic foraminifera? Evidence from the Brazos River Cretaceous-Paleogene boundary sequence

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The Cretaceous/Paleogene (K/Pg) 'River Bank South' boundary section, which crops out along the Brazos River in Falls County, Texas (USA), provides an extraordinary record of foraminiferal morphologic and sedimentary geochemical changes following the terminal Cretaceous asteroid impact. Foraminiferal specimens with excellent test preservation are consistently present in the section, and the basal Paleogene P0 Planktonic Foraminiferal Zone is quite thick at this locality (2.9 m). The K/Pg boundary is placed at the contact between the scoured upper surface of the Corsicana Fm and overlying beds rich in impact debris. The top of the P0 Zone is placed at lowest occurrences of *Parvularugoglobigerina eugubina* and *Globoconusa daubjergensis*, 2.9 m above the boundary.

A number of events and excursions that document changes within the first millennia of the Paleogene are present within the 2.9 m thick P0 Zone. The lowest 75 cm of the Paleogene are represented by high energy storm and/or tsunami deposits. Projecting in from nearby sections, organic carbon paleothermometry provides evidence for an impact winter with coldest temperatures at ~100 to 140 cm above the boundary; the level of a diffuse Ir anomaly projects to ~120 to 150 cm above the boundary. The relative abundance of *Guembelitria cretacea* starts to increase at 150 cm and peaks at 230 cm above the boundary whereas blooms of calcareous nannoplankton 'disaster taxa' project to levels starting at ~180 cm above the boundary.

An interval of dramatic warming starting at 170 cm above the boundary is suggested by an ~1‰ decrease in $d^{18}O$ values (~5°C warming) in visually screened fragments of individual crushed specimens of the benthic foraminifer *Lenticulina*. The lowest occurrence (LO) of the first new Paleogene foraminiferal species (*Woodringina claytonensis* and *Parvulorugoglobigerina extensa*) also occur at the 170 cm level, and the LO of *Parvulorugoglobigerina alabamensis* is documented at 190 cm. Finally, the LO of *Parasubbotina* aff. *pseudobulloides* and *Eoglobigerina eobulloides* occur in a sample from 310 cm above the boundary (20 cm above the base of the Pα Zone), and the LO of *Chiloguembelina moresi* occurs at 330 cm.

A 290 cm thick P0 Zone already requires high average sedimentation rates, but, if the ~5°C warming pulse was the direct consequence of CO_2 released by post-impact wildfires, which should incur within decades of the impact, sedimentation rates would need to be extremely high over the first 1.5 to 2.0 m of the Paleogene (10-20 cm/yr). Biostratigraphic and sedimentological observations allow the possibility of such high sedimentation rates, but they lack the resolution to rigorously demonstrate them. If model predictions for impact-induced warming are correct, though, the evolution of the *Woodringina–Parvulorugoglobigerina* lineages must have occurred within decades of the impact rather than the previously assumed 1000's of years afterwards. By extension, if the decadal timescale is correct, the profound changes in wall structure,

chamber coiling and apertural position that characterize the evolution from the trans-K/Pg ancestor *Guembelitria cretacea* to the descendent lineages of *Woodringina* and the first species of *Parvulorugoglobigerina* would need to have occurred within only a few hundred planktonic foraminiferal generations.

Depth-influenced variation of symbiont relationship between large benthic foraminifera and Symbiodiniaceae

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The symbiont relationship between dinoflagellates in the family Symbiodiniaceae and marine organisms supports the coral reef ecosystems. Although foraminifera in the family Soritidae hosting Symbiodiniaceae forms unique symbiont relationships, environmental influences on the diversity of Symbiodiniaceae in soritid individuals have not been understood. We investigated variations of Symbiodineaceae community in *Amphisorus kudakajimensis* at individual level collected in nine depths at three sites in Akajima island, Okinawa, Japan. Next-generation sequencing and the Symportal pipeline specific to analyses of Symbiodiniaceae resulted in the 39 lineages in 137 specimens using internal transcribed spacer region 2 of nuclear ribosomal RNA gene (ITS2). The dominant lineages are clade C, F, and H, and multiple lineages constitute a Symbiodiniaceae assemblage in a single specimen. Clade H is dominant in the assemblages at the deep population (> 9 m), while clade H was not detected in the shallow population (< 2 m). The diversity of Symbiodiniaceae community is higher in the deep population dwelled on narrow points than in the shallow population distributed around the reef flat zone. The specific combination of clade C and F in *A. kudakajimensis* under large environmental fluctuations in the shallow reef suggests that symbiont communities converge a low diverse combination to adapt to a severe environment. In this presentation, we discuss the full range of depth adaptations associated with the genotypic composition of shallow-water foraminifera zooxanthellae.

Benthic foraminiferal communities (stained) in sub-Antarctic fjords of South Georgia

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Sub-Antarctic fjords are among the environments most affected by the recent climate warming. These vulnerable settings are strongly understudied, but as they may serve as sentinels for the climate change, they do deserve more scientific attention. Here, we present a baseline study of rose-bengal-stained benthic foraminifera from fjords of South Georgia, including fjords with and without tidewater glaciers. Their distribution is analysed in the light of oceanographic and sedimentological data.

Four assemblages are recognized. *Miliammina earlandi*, dominating in the near-shore and glacier-proximal habitats, can tolerate strong glacial influence, including high sedimentation and sediment anoxia. This versatile species can thrive on different types of food. A smooth-walled variant of *Cassidulinoides* aff. *parkerianus*, dominating in mid-fjord areas, seems endemic to South Georgia. It is the calcareous rotaliid best adapted to inner-fjord conditions characterized by moderate glacial influence and sedimentation rates and showing no preference for particular sedimentary redox conditions. The outer parts of fjords with clear, well-oxygenated bottom water are inhabited by *Globocassidulina* aff. *rossensis*. *Ammobaculites rostratus*, *Reophax subfusiformis*, and *Astrononion echolsi* dominate in the deepest-water settings in the outer parts of the fjords, with water salinities ~33.9 PSU and temperatures 0.2–1.4 °C, characteristic of winter water and Upper Circumpolar Deep Water. The inner- and mid-fjord foraminiferal assemblages seem specific to South Georgia, although with continued warming and deglaciation, they may become more widespread in the Southern Ocean.

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Impact of the invasive foraminifer *Amphistegina lobifera* Larsen on infralittoral benthic foraminiferal assemblages in the Sicily Channel (Central Mediterranean)

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Among the emerging threats that are currently affecting marine ecosystems, the invasion by alien species is one of the most impacting, because alien species have the potential to cause decline or even extinctions of native species, with effects ranging from the individual to the entire ecosystem level. The Mediterranean Sea is one of the marine ecosystems most affected by invasion of alien species. In recent decades, several studies have reported the ecological effects of invasion by marine alien macrobiota, such as macroalgae, crustaceans, bivalves and fishes, but very little is known about the effects of small-sized alien taxa, such as unicellular foraminifera. These 'hidden invaders' are able to colonize wide marine areas without being noticed due to their small size (< 2 mm). In some severe cases, alien foraminifera have been recorded only after having already caused significant changes (often irremediably damaging) to native communities and, consequently, to local ecosystems.

In the Mediterranean Sea, the most successful and widespread benthic foraminiferal invader is *Amphistegina lobifera* Larsen 1976, a non-indigenous species coming from the Red Sea through the Suez Canal. Although *A. lobifera* has been considered as one of the benthic foraminiferal alien species with the highest potential impact, the effects of its invasion on native assemblages are poorly known, especially in the Central Mediterranean, where the species was only recently recorded.

This research documents, through a quantitative approach, the negative effect of the highly invasive species *A. lobifera* on native benthic foraminiferal assemblages of coastal areas in the Sicily Channel (Central Mediterranean). To this purpose, a nested sampling design was applied through the comparison of benthic foraminiferal community structure across three areas that are known to be at different stages of invasion (i.e. Maltese islands - advanced, southern Sicily – medium, and eastern Sicily - early). Additionally, given that sediment grain-size can influence the distribution and abundance of benthic species, including foraminifera, because it is related to the extent of hydrodynamism, the grain-size of soft-bottom sediments was also taken into account in the applied design.

Results suggested that both diversity and richness of benthic foraminiferal community from the Maltese islands were strongly modified by increased abundances of *A. lobifera*. In contrast, this phenomenon is less impacting in southern and eastern Sicily, where the invader displayed lower abundances and the community structure was more diversified. The invasion success of *A. lobifera* is promoted, and probably also accelerated, by climate change, which is causing a rapid increase of Mediterranean Sea surface temperature; thus the negative effects recorded in the present work can be expected to extend over larger areas of the Mediterranean basin in the future.

Hotspot pattern of benthic foraminifera in highly productive environments of the Levant

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Given the role of foraminifera as ecosystem engineers, it is very important to characterize the foraminiferal hotspots around the world. It is well-known that benthic foraminifera are ubiquitous in lagoonal and reefal habitats where they are often referred to as living sands. Vermitid reefs are an underrated coastal habitat with a great potential as substrates for foraminifera that is yet to be completely understood. The intertidal carbonate platforms of the Levant basin are the longest known vermitid reefs at the forefront of Lessepsian invasion and rapid ecological community shifts. However, with increasing anthropogenic pressures and ongoing climate change, these habitats face the greatest risk, making this ecosystem a top priority for marine biomonitoring studies. This study deals with efforts undertaken to characterise the presence of benthic foraminifera in this complex ecosystem. Four microhabitats were seasonally sampled along the 150 km Israeli coastline to obtain standing crop and numerical abundances of benthic foraminifera species on suitable substrates.

We found the densities of foraminiferal communities on the vermitid reefs to be very high along the coast with an average of 14,785 specimens per m^2. We identified two specific hotspots in Shikmona and Nahsholim where the densities of

foraminifera reached remarkably high numbers of up to 5 x 10^5 individuals per m^2 in the colder seasons. These densities are equivalent to those reported from coral reef habitats in the North Pacific. The assemblages mainly consist of eight foraminifera including both symbiont-bearing and non-symbiont bearing species, most of which are invaders (in descending order): Quinqueloculinids*, Textularia agglutinans*, *Pararotalia calcariformata, Amphistegina lobifera*, *Peneroplis, Sorites orbiculus, Hauerina diversa and Rosalina.* Among these, the first two taxa are by far the most dominant making up to 80% of the entire assemblage.

The foraminiferal assemblages display a distinct heterogeneity along the coast with the largest distinction between the south-most station of Palmachim to all the other stations of the Northern coast. The assemblages in Palmachim are composed of only three foraminiferal taxa: Quinqueloculinids, *P. calcariformata* and *T. agglutinans* while all other taxa are absent. Interestingly *P. calcariformata* displays its highest abundance at this station making it a hotspot for this known thermally resilient species. Our study also reveals a hotspot pattern within the Northern stations. For example, *H. diversa* in Akhziv, *S. orbiculus* in Shikmona and *A. lobifera* and *Rosalina* in Nahsholim.

At present we have massive foraminiferal production along the Israeli coast with a peak in the North-Central area forming an optimum habitat for most of the species. The observed hotspot pattern along the seemingly homogenous habitat indicates a possibility of variable biotic and environmental parameters that are yet to be explored. These ecological observations combined with environmental and experimental data will give insights on the future of the foraminiferal community and their carbonate production potential in the context of the ongoing global changes.

Symbiont-Bearing Foraminifera and their Potential as Major Carbonate Producers in Coastal Environments Undergoing Global Warming

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First-order estimates suggest that benthic foraminifera are essential players in the global carbon cycle contributing to 4% of the total carbonate production in the modern oceans. Specifically, Large Benthic Foraminifera (LBFs) are the major contributors to carbonate production in tropical reefal habitats. Even though the major presence of foraminifera in the Eastern Mediterranean (EaM) is widely accepted in the scientific community, robust baseline research quantifying the contribution of benthic foraminifera in carbonate production potential in the EaM is notably lacking.

This study aims to provide some of the data required to allow an estimation of foraminiferal carbonate production in highly productive environments of the shallow Eastern Mediterranean shelf, which is at the forefront of ocean warming.

Four microhabitats hosting vermitid reefs were seasonally sampled along the 150 km Israeli coastline for a period of one year to analyse the distributional characteristics of key-habitat forming foraminiferal species, their carbonate producing capabilities, and assess their role as ecosystem engineers.

We calculated the gross foraminiferal carbonate standing stock on vermitid reefs to be 20,000 mg of $CaCO_3$ m^{-2}. Empirically calculated mass-diameter relationships were combined with the seasonal population dynamics for three invasive LBFs, *Amphistegina lobifera*, *Sorites orbiculus,* and *Peneroplis*, to compute their calcium carbonate standing stock for each season. We found that these three LBFs contribute to 83% of the gross foraminiferal carbonate standing stock. *A. lobifera* appears to have the most significant contribution, despite its small or comparable diameter relative to *S. orbiculus* and to *Peneroplis*. The experimentally derived thermal resilience of these invasive LBFs indicates they will continue to proliferate and enrich the calcium carbonate production in these environments. Carbonate production estimation combined with data on the foraminiferal substrate preferences, holobiont thermal thresholds, and their response to environmental changes should be used to gain insight into the future of the dominant players of the community and their role in carbonate production in these coastal environments threatened by rising ocean temperatures.

Modern agglutinated foraminifera in the surface sediments of NE Mediterranean environments

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Aim of this study is to record and present the agglutinated foraminiferal assemblages retrieved from eight surface sediment samples, collected from relatively shallow (3 samples: 335 m – 485 m) to bathyal (5 samples: 1150 m- 2150 m) environments of the central and southern Aegean Sea and the Levantine Sea in the NE Mediterranean. The study material was recovered with a box corer during R/V Aegaeo MSFD cruise in March 2019 and stored in an ethanol-Rose Benghal mixture. In the laboratory the samples were carefully wet sieved through 63 μm and 125 μm sieves, oven dried, and the sediment fraction >125 μm was examined for the micropaleontological content. The faunal analysis revealed rich assemblages consisting of pteropods, planktonic and benthic foraminifera, ostracods as well as otoliths.

Benthic foraminifera represented the most diverse group of benthic organisms in the samples and their assemblages were composed of calcareous (hyaline) and agglutinated taxa. The latter were particularly dominant in the deep basins of the Cretan Sea and off Rhodes Island (up to about 76% of the total foraminiferal content).

The agglutinated foraminifera group in the studied material was composed of arborescent, tubular, and globular taxa and a total of 13 genera and 15 species have been so far identified. *Saccorhiza ramosa* (Brady, 1879) is the most abundant taxon (11-84% of the agglutinated fauna), constantly present in all the samples. Its wall is made of mineral grains and sponge spicules and in certain samples radiolarians and pteropods are also incorporated in the test structure. Other common taxa are *Rhabdamminella cylindrica* (Brady, 1882) (present in six samples; 0.2-12.5%); *Rhizammina algaeformis,* Brady, 1879 (present in five samples; 1-26%), being coarsely agglutinated, beside inorganic grains, with planktonic foraminifera, radiolaria and pteropods; *Glomospira* spp. (present in four samples; 1-57%) and *Psammosiphonella* spp. (present in four samples; 7.85-63%). Other taxa with scarce presence in the studied samples are *Psammosphaera fusca* Schulze, 1875 and species of *Bathysiphon*, *Marsipella*, *Hyperammina*, *Reophax*, *Cribrostomoides*, *Ammoscalaria* and *Ammodiscus*.

Reconstructing Eocene mid-latitudinal environmental changes through *Nummulites* geochemistry

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The early Eocene is characterized by warming trend towards the Early Eocene Climatic Optimum (EECO), which is followed by a general cooling trend towards the Oligocene. Both trends are interrupted by brief episodes of global warming. The Eocene warm phases resulted in (sub)tropical conditions in the southern North Sea Basin enabling the proliferation of *Nummulites* at relatively high northern latitudes ~45°N. The geochemical signal (Mg/Ca) of their calcareous tests can be used as a paleotemperature proxy for nearshore conditions, enabling a reconstruction of this mid-latitude environment, and the parameter that constrain their distribution. We present our results for the early (Ypresian) and middle Eocene (Lutetian), using our developed preparation methodology, taking post-depositional alterations into account, accompanied with $\delta^{18}O$ data. Specimens are derived from outcrop and core material from Belgium and northern France: Ypresian, pre-EECO: Aizy-Jouy, Moen-Bossuyt, Mont-Panisel and Kester sites; Ypresian, EECO: Ampe site; Lutetian: Zemst, Balegem and Mont-de-Récollets sites.

The Mg/Ca data display a pre-EECO averaged temperature rise of ± 6°C (from 20 to 26°C) and a further warming pulse during the EECO to ± 30°C. Stable isotope data do not indicate any significant temperature or salinity changes linked to layers containing *Nummulites*, but do record regional long-term paleoceanographic changes in the southern North Sea Basin. Early Eocene *Nummulites* are mainly found in sandy deposits and are absent in clay-silt rich intervals, indicating that the driver for their occurrence relates to water depth and/or clarity. The warmest conditions were optimal, as the largest tests reflect the highest annual temperature estimates. Preservation of early Lutetian *Nummulites* from Belgium is poor, but published data from the Cuise-la-Motte outcrop indicate the continuation of (sub)tropical temperatures (30-34°C). Smaller *Nummulites* species reappear in middle Lutetian deposits in Belgium, recording maximal annual temperatures of 20-25°C. Our temperature record thus documents the rise and fall of large nummulites in the North Sea Basin, related to the range of (sub)tropical conditions in this region. Late Eocene *Nummulites* from Belgium are too poorly preserved to provide useful information, but specimens from the Hampshire Basin provide a reliable paleotemperature record for the late Eocene, reflecting their final presence in the region.

Paleoclimatic and paleoceanographic changes and their impact on planktic foraminifera in the Tyrrhenian Sea during the last 32 ka

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The marine sediment core NDT_22_2016 was recovered offshore of La Spezia Gulf at 436 m depth in 2016 during an oceanographic survey by the National Research Council (CNR), as part of the NextData project. Within the 320 cm-long core, only one stratigraphic level (at 150 cm) was dated at 15.912 ±111 cal kyrs BP by means of AMS ^{14}C on planktonic foraminifera *Globigerina bulloides*. So, considering a constant sedimentation rate, we can estimate a possible age of ca. 32 kyr BP for the bottom of the core.

The main aim of this research is to investigate the paleoenvironmental and paleoceanographic changes that took place in the northern sector of the Tyrrhenian Sea over the past 32,000 years, as revealed by planktic foraminifera (PF). This area received little attention in the past decades studies from this point of view, despite it has the potential to record both high and low latitude climatic forcings in response to the variation of the characteristics of the Modify Atlantic Water (MAW), which forms the upper water, and the Levantine Intermediate Water (LIW), which forms the intermediate water.

The preliminary quantitative analyses, performed on >125 μm size fraction, identify that in the first 80 cm (cmbsf), the thanatocoenosis is composed of a rather wide PF biodiversity, mainly composed of *Globigerinoides elongatus*, *G. ruber*, *Globoconella inflata*, *Globorotalia truncatulinoides*, *Globigerina bulloides*, *G. falconensis* and *Neogloboquadrina incompta*. Below 80 cm, the planktonic foraminiferal assemblage exhibits a drastic reduction in biodiversity, as the 70% of the association is commonly composed by cold species such as *G. bulloides*, *Turborotalita quinqueloba*, and *Globorotalia scitula*, while *Neogloboquadrina pachyderma* is absent. Since this variation occurs in a stratigraphic level younger than 15.912 ±111cal kyr BP, we believe that this faunal change reflects the transition from warmer conditions, occurring during the Holocene, to colder conditions which were established during the Younger Dryas event. Work is in progress to increase the sample resolution to achieve a century-scale resolution and identify paleoceanographic oscillations both during the warm (interglacial) and cold (glacial) configurations.

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Comparative analysis of potential toxic element extractions in environmental micropaleontology: "Bioavailability" anyone?

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Potential toxic element (PTE) concentrations are generally measured in sediments following "total" chemical extraction. This is an incorrect approach because total concentrations do not reflect PTE physiochemical behavior related to their bioavailability. The working statement is that PTEs found in both the "exchangeable" (adsorbed) and "oxidizable" (complexed to organic matter) fractions are bioavailable to benthic foraminifera. We compared two different sequential extraction methods (Method A: Tessier's five-step; and Method B: BCR's three-step) to elucidate which provided the most realistic results.

(1) "Exchangeable" fraction: Principal component analysis (PCA) showed how different the methods are in terms of the distribution of the PTE concentrations in the samples. As expected, Method B extracted PTEs from the carbonate fraction as well, which showed higher concentrations that are not truly bioavailable and led to an overestimation of the effects in this fraction. This overestimation becomes evident when looking at the results of the canonical correspondence analysis (CCA), which clearly shows that the relative abundance of *Ammonia beccarii* was influenced differently by the PTEs extracted from Method A (negatively by Pb-Se-Co) and B (negatively by Cu-Pb and positively by Co-Cr). Similar observations were recorded for the relative abundance of *Quinqueloculina rhodiensis*.

(2) "Oxidizable" fraction: The PCA showed "similarities" between methods and how the sample distribution was influenced by the concentrations, although Method A produced higher PTE concentrations. The dissimilarities observed in how the PTEs influenced foraminifera (CCA) were evident and unexpected. This is attributed to the differences in the leachant molar concentrations between methods. The data produced by Method A show that the relative abundance of *A. beccarii* was positively and negatively influenced by As-Cr-Ni and Cu-V-Zn respectively. However, this species was influenced positively (Method B) by Cr-As-Co-Ni-Pb and negatively by Zn-Cu.

The widely used Method B overestimated the influence of the "exchangeable" PTEs on the foraminifera. Thus, the extraction step from Method A is recommended as more realistic in leaching out PTEs that were not co-precipitated with carbonate minerals. The results are more complicated for the "oxidizable" fraction and making a proper recommendation without further research and reassessment is more challenging. Both methods "target" PTEs associated with organic matter and sulfide ligands. Method A's use of leachants with higher molar concentrations explains the higher PTE concentrations. It could be argued that this could lead to an overestimation of the influence of this fraction on foraminiferal ecology. However, PTEs-bound to organic matter must be considered labile and bioavailable as these could be leached out of food particles due to enzymatic degradation while feeding, which suggests that Method A may be more accurately reflecting PTE availability than Method B.

Historical foraminiferal and microbial environmental health assessment of Guánica Bay (Puerto Rico)

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In 2022, the United States Environmental Protection Agency added the Ochoa Fertilizer Co. site adjacent to Guánica Bay to the National Priorities List of hazardous waste sites as a Superfund site. Pollutants such as nickel and chromium have been found in the bay's waters, surface sediments, fish tissue, and human blood (Polychlorinated biphenyls). To assess the historical changes in environmental health, a 52 cm sediment core collected in 2021 was analyzed for trace metals. The water column at the time of collection was stratified with anoxic conditions at depths >2.2 m. This is critical because redox conditions play an integral role in the fate and transport of microbially-mediated pollutants. A noticeable change in sedimentation was observed at a core depth of 36 cm (pending ^{14}C dating) where total organic carbon, carbon-to-nitrogen molar ratios, and mud-sized sediments began to decline towards the core top. Trace metals like Cu-Zn-Pb and Co-Ni decreased and increased in concentrations respectively at the same core depth. Relatively high bulk concentrations of U (9–11 mg/kg) and Hg (0.06–0.2 mg/kg) showed an up-core increase, and it is unclear if the source is allochthonous or autochthonous. All trace metals exceeded the Effect Range Median values stipulated by EPA, strongly suggesting that the benthic communities have been impacted. More interestingly, the historical sediment deposition occurred during anoxic (borderline euxinic) conditions based on Mo/U plots.

The three most abundant foraminiferal species were *Ammonia beccarii* (total: 4,495), *Quinqueloculina seminula* (total: 1,217), and *Quinqueloculina rhodiensis* (total: 350). The temporal variability of their relative abundances (RA) (*A. beccarii* > *Q. seminula* > *Q. rhodiensis*) showed a decreasing trend between 52–40 cm, with the *A. beccarii* (RA range: 67–42%) increasing between 40–1 cm reaching a maximum 92% RA at 3 cm. The *Q. seminula* and *Q. rhodiensis* combined RA mirrored that of *A. beccarii,* reaching a maximum value of 48% at 40 cm and a minimum of 4% at 8 cm. The ecological indices show similar trends. For example, species richness varied from 7–13 between core bottom and 18 cm followed by an overall decreasing trend reaching the lowest value of 5 at 7 cm. Similarly, the Shannon Diversity Index showed an increasing trend starting at the core bottom and ending with a maximum value of 1.4 at 14 cm. The diversity then decreased towards the core top reaching a minimum value of 0.4 at 3 cm.

The environmental health of this estuary is considered severely compromised based on bacterial eDNA and benthic foraminifera. The bacterial community-based microgAMBI index is showing that although the site is regarded to have an average of "poor" condition (average = 3.9), opposing up-core trends were observed. A "bad" to "moderate" stepwise trend between 47–22 cm was followed by a deteriorating "moderate" to "poor" trend between 20–2 cm. Likewise, the Foraminiferal Stress Index mostly evaluated the site as "heavily polluted" with two trends also recorded. A relative slight improvement was observed between 52–12 cm almost reaching "moderately polluted" conditions followed by a deteriorating trend towards core top.

A matter of choice: The interactions between foraminifera and their seagrass host as a model ecosystem for biomonitoring environmental and anthropogenic stressors

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Seagrasses and foraminifera are both widely used as bioindicators to monitor and predict changes in marine ecosystems. Seagrass meadows are recognized as one of the most important ecosystems of coastal environments due to their role as ecosystem engineers and their ability to sequester and bury blue carbon. In sub/tropical water, benthic foraminifera are among the most abundant epiphytic organisms inhabiting seagrass meadows. Although both are extensively studied, little is known about their ecological interactions with each other. With the growing anthropogenic pressure on coastal regions, providing predictions on the interactions between these two model organisms could benefit conservation and management efforts in coastal areas.

This study explored the nature of the association between foraminifera and the tropical seagrass species *Halophila stipulacea*, aiming to determine whether these interactions are facilitative or random. A "cafeteria" experiment was conducted, in which foraminifera were given a choice to settle on *H. stipulacea* or alternative plastic plants in both roots and shoot compartments. *Halophila stipulacea* and sediments were collected from the Gulf of Aqaba-Eilat and planted in a dedicated seagrass mesocosm, fully controlled for salinity (40 ppm), light (100 □mol photons m^{-2} s^{-1}), and temperature (25°C). In five aquariums, four *H. stipulacea* plants (thoroughly cleaned from foraminifera and microbiome) and four plastic plants were planted. On days 10, 20, and 30, one *H. stipulacea* and one plastic plant were pulled out for foraminiferal analysis. At the end of the experiment, a microbiome analysis was performed to identify possible variances in the microbial community and diversity of the substrates.

Results showed that the foraminiferal numerical abundances and species diversity were significantly higher in *H. stipulacea* plants than in the plastic plants (1-5 and 5-20 specimens per cm^2, d=1-3 and 4-14, respectively). While foraminiferal abundance increased with time on all plants, this increase was more pronounced in *H. stipulacea* compared to the plastic plants, particularly in *H. stipulacea*'s roots. Foraminiferal abundances also increased with shoot age (~1 and up to 16 specimens per cm^2 in younger and older shoots, respectively). Microbiome analysis showed that epiphytic microbial community abundance and species diversity were higher in *H. stipulacea* compared to the plastic plants. Moreover, the oldest shoot had a higher microbial community than the younger ones, which correlated with the leaf-age changes in foraminiferal abundance. This correlation suggests that the older seagrass leaves offer the foraminifera substrate richer in biofilm.

This study reveals that seagrass meadows are important hosts of the foraminifera community and suggest the potential facilitative effect of *H. stipulacea* on epiphytic foraminifera, which might be attributed to a greater diversity of the microbial community inhabiting *H. stipulacea*. Our results demonstrate the importance of understanding the relationship between foraminifera and their plant hosts, especially in light of impending population decreases due to global changes. This study emphasizes the urgent need to protect seagrass meadows, which can equally preserve and facilitate the abundance and diversity of foraminifera and other organisms.

Late Silurian (Ludlow, Pridoli) and Earliest Devonian (Lochkovian) Foraminifers of South-Central Oklahoma, USA

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In south-central Oklahoma, Late Silurian and Early Devonian strata are represented by the Henryhouse and Haragan Formations of the Hunton Group and are exposed in the Arbuckle Mountains and Lawrence Uplift. The formations consist mainly of argillaceous wackestone and mudstone with some beds of skeletal wackestone and packstone. In samples from seven outcrop localities, agglutinated foraminifers are common and occur with stratigraphically important conodonts. To date, foraminifers of the Henryhouse and Haragan Formations have never been systematically described, with only three species previously reported from the Henryhouse, and six from the Haragan. A well exposed and most complete section is present in the Highway 77 road cut, in which the age of the Henryhouse Formation extends from the Gorstian (*Kockelella*

crassa conodont Zone) into the late Pridoli. The Henryhouse Formation is overlain by the Lochkovian Haragan Formation (*Caudicriodus hesperius* conodont Zone). Evidence of the mid-Ludfordian Lau Event is present in the very top of the extremely argillaceous lower member of the Henryhouse Formation and the base of the upper member, and the Klonk Event crosses the Henryhouse - Haragan boundary.

A diverse foraminiferal fauna is found in all sections studied, composed of unilocular, colonial, and bichambered foraminifers. Unilocular genera include common *Psammosphaera*, *Thurammina*, *Thuramminoides*, uncommon *Amphitremoida*, *Colonammina*, *Lagenammina*, a *Saccammina*-like genus, and rare *Shidelerella*. Colonial foraminifers are diverse and include *Sorostomasphaera*, *Webbinelloidea*?, and *Thekammina*. Common tests of bichambered genera include *Tolypammina*, *Rectoammodiscus*, and *Hyperammina*.

The foraminiferal fauna of the studied stratigraphic interval is subdivided into three assemblages. The first assemblage occurs in the lower member of the Henryhouse Formation, which is divided into three units. The foraminifers of Unit 1 share an affinity with the fauna of the underlying Clarita Formation, especially with respect to *Rectoammodiscus*, *Psammosphaera*, and *Thurammina*. Unit 2, the middle portion of the lower member, contains a pyritic interval devoid of foraminifers. In Unit 3, the upper portion of the lower member, the fauna of the first assemblage reappears with fewer *Rectoammodiscus* and more *Thuramminoides*. In this unit, many species have their last appearance and do not survive the Lau Event. Following the Lau Event, the fauna of the upper member forms a second assemblage, in which the abundant *Rectoammodiscus* characteristic of the lower member almost entirely disappear, and new species of *Thurammina* and *Sorostomasphaera* appear, replacing species of those genera from the lower member. Likewise, whereas *Webbinelloidea*? and *Thekammina* are rare in the lower member, they become common in the upper member, especially in strata of the uppermost Ludfordian and Pridoli. In general, the abundance of tests and the diversity of species increase up section in the upper member of the Henryhouse Formation as the lithology becomes less argillaceous and distance from the level of the Lau Event increases. *Tolypammina* becomes abundant, *Lagenammina* reappears, and smooth-walled *Psammosphaera*? appears. Stepwise changes in *Thurammina* and genera of colonial foraminifers such as *Sorostomasphaera*, *Webbinelloidea*? and *Thekammina* allow for a correlation of stratigraphic level and/or paleoecology within the upper member between studied sections. An interval of an impoverished fauna primarily composed of *Thuramminoides* and *Webbinelloidea*? is associated with the onset of the Klonk Event and corresponds to boundary strata of the Henryhouse and Haragan Formations. The third assemblage is characteristic of the lower part of the Haragan Formation with a lower abundance and diversity of species of *Sorostomasphaera* and *Webbinelloidea*? and features new species of *Thekammina*, *Amphitremoida*, and *Thuramminoides*.

Mass reproduction and multi-generation culture of planktonic foraminifera in laboratory

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Benthic foraminifera are known to follow a complex reproduction strategy involving various types of sexual and asexual reproductive modes. In contrast, planktonic foraminifera were long thought to be obligate sexual outbreeders. In a study on the polar species *Neogloboquadrina pachyderma*, we recently showed that this assumption, counter-intuitive for the maintenance of reproductive success at low population densities, is an observational artifact. The frequency of asexual reproduction in *N. pachyderma* is low (~ 3%), partly explaining why it had only been observed twice and serendipitously in the past. The survival of the asexually produced offspring is high and results in ~ 75% of the population renewal, suggesting that the vast majority of specimens deposited on the seafloor result from this reproductive mode. This discovery not only sheds light on planktonic foraminifera population ecology but also opens the possibility to maintain these organisms continually in culture and grow them entirely in controlled conditions.

In autumn 2022 we selected specimens of *N. pachyderma* from the Baffin Bay by traits, that I previously observed in specimens that reproduced asexually. We placed them in a culture setting designed to facilitate and track their reproduction. This increased the probability to obtain asexually produced offspring in the laboratory from 3% to 58.7%. Moreover, we showed that it was possible to raise the offspring to up to 400 µm in diameter, which constitute ideal material for shell geochemistry, whether it is for e.g., bulk shell analyses through dissolution or the use of microanalytical techniques for element-to-calcium ratio and/or stable isotopes. In the six months since the collection of the specimens we obtained three generations of *N. pachyderma* in the laboratory. This provides unequivocal evidence that like their benthic ancestors, planktonic foraminifera possess the ability to reproduce asexually across several generations.

Because *N. pachyderma* lives almost exclusively in polar environments and therefore might behave differently than tropical or subtropical species, we applied our sampling and culture methodology to the species *Globigerinita glutinata* from the Gulf of Aqaba in March 2023 and also observed events of asexual reproduction. The high number of asexual reproductive events we recorded, 37 in total, allowed the imaging of specimens before and during the events themselves, documenting the first steps of life and calcification of the offspring.

Planktonic foraminifera from cold and warm water environments are capable of reproducing asexually in vivo and vitro. This offers the tantalizing prospect of studying their geochemistry under controlled environmental conditions for their entire life cycle and will give new insights into their ecology. In a first of many applications, it will allow to quantify the so-called "vital effect" of planktonic foraminifera by comparing the geochemistry of clones raised in the exact same condition.

The significance of foraminifera in Southern Ocean: examples from the west-central Ross Sea

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The importance of planktic and benthic foraminifera in the study of current and past marine environments is well established. These microfossil groups are well-known as helpful proxies for decipher and time constrain environmental changes in polar areas documented in sedimentary facies ranging from sub-glacial to open marine conditions. Nevertheless, their presence, conservation and diversity in the polar region is limited by a number of several factors. One of the major problems is the calcite compensation depth (CCD) which fluctuates through time. On the Antarctic shelves, the CCD is usually forced to be between 350 and 1000 m due to low temperatures and extremely corrosive water masses. Additionally, the production and accumulation of biogenic carbonate are restricted by significant quantities of siliciclastic sediments associated with glacial activities. Consequently, biogenic carbonate accumulations on the Antarctic shelves are very limited in time and in space and the presence of calcareous foraminifera is regarded as a chance.

Furthermore, as demonstrated by researches conducted in the Ross Sea, the availability of well-preserved calcareous material offers an excellent possibility to build a more accurate age model respect the use of acid-insoluble organic matter (AIOM). Several investigations report that the ages determined by AIOM are frequently anomalously old, with an overestimated age of glacial retreat.

Insufficient data exist on the ecological requirements of foraminifera and their present-day distribution. Studies performed on core-top samples from different oceanographic areas of the Ross Sea document that diversity and abundances of the taxa are strongly influenced by the regional differences in water mass properties. The exclusively occurrence of agglutinants observed in sediments from the Drygalski and Lewis Basins may be attributed to cold, saline, CO_2-rich bottom waters and to the presence of a shallow CCD, conditions unfavourable to carbonate precipitation and preservation. Instead, samples from the JOIDES Basin and from the Pennell Trough are characterised by a higher species richness and by the presence of calcareous as a result of the intrusion of the relatively warm, salty and rich in nutrients Modified Circumpolar Deep Waters.

The recovery of foraminifera in the late Quaternary sediments in various sectors of the west-central Ross Sea allow to interpret the climatic phases that determined the advances and retreats of the Ross Sea Ice Shelf. The dynamics of the RIS, the largest in Antarctica, has been investigated by several researchers, however, the timing of its retreat from the Last Glacial Maximum (LGM) is still under debate, mainly due to a lack of robust marine chronostratigraphy. From inner continental shelf to the shelf break, the Drygalski and JOIDES Basins together with the Pennell Trough and Central Basin were investigated. In the inner continental shelf, the strong glacial influence together with the occasionally occurrence of tephra and cryptotephra limit the diversity of the foraminifer associations.

In contrast, towards the outer part of the continental shelf, the particular oceanographic conditions favour a greater availability of carbonate and thus a greater richness of foraminifera.

In the outer basins, of particular importance is the presence of *Neogloboquadrina pachyderma*, the only calcareous planktic foraminifer able to live in polar areas, surviving in brine channels within sea-ice under hyper-saline and low temperature conditions. We document intervals with an abundant occurrence of well-preserved *N. pachyderma* (juveniles and adult forms) from deglacial sedimentary sequences of northern Drygalski Basin and Hallett Ridge (Western Ross Sea), reflecting situations of open water conditions and/or variation in the length and intensity of seasonal sea ice.

Living Benthic foraminifera as ecological and biomonitoring tools in the Marano and Grado Lagoon (northern Adriatic Sea, Italy)

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Lagoons are distinctive naturalistic ecosystems with a delicate biological balance hosting a wide range of organisms. They represent the traditional paralic environment (sensu Guelorget & Perthuisot), along with fjords, deltas, and estuaries, where variations in salinity, oxygenation, nutrients, and other factors produce a complex degree of confinement that symbolizes the amount of time required for the renewal of marine waters. Lagoons and other coastal marine ecosystems have experienced heavy human-related use in recent decades, with negative effects on the aquatic ecosystem. Through the study of these biological consequences, which affect both animal and plant species, we can discover biological indicators (also known as bio-indicators) that can detect changes due to human activity.

The Marano and Grado Lagoon is a 160 km^2 coastal shallow coastal water system located along the northern Adriatic Sea (Italy), between the Tagliamento and Isonzo River deltas. This lagoon is typically regarded as a well-preserved place where natural environment conservation must coexist with a variety of human activities such as fishing, clam harvesting, shipping, and industry.

The Marano and Grado Lagoon, especially in the eastern Grado sector, is well known for being contaminated by mercury (Hg) released from the Idrija Hg mine (Slovenia) and transported by the Isonzo River and secondarily from the decommissioned chlor-alkali plant of Torviscosa (Italy). Inside the lagoon, Val Noghera is one of the greatest and most productive fish farms, where a semi-intensive farming approach is employed to mitigate the high Hg concentrations. It covers a surface of 220 ha and, in addition to a regulated water exchange through sluice gates and rainwaters, the fish farm receives limited freshwater inputs from several artesian wells (with temperatures up to 33°C).

This study presents the living foraminifera from several sites located in the Grado sector of the lagoon and in the Val Noghera. This survey represents one of the first study on the foraminiferal fauna in biocoenosis, since the data collected to date for the Marano and Grado Lagoon only consider the distribution of foraminifera in tanatocoenosis.

The main aims of this study are the following: i) to provide information on the distribution of the main foraminiferal species in lagoon areas with different degrees of confinement to understand how variations in environmental conditions, total organic carbon (TOC) and Hg concentrations might control the distribution, abundance of species, and the possible occurrence of deformations in foraminiferal tests; ii) provide a judgement of the ecological quality status (EcoQS) of the various environments examined based on the biotic indices inferred from the foraminifera in biocenosis.

Predicting deep-sea living (stained) benthic foraminifera from the continental slope and São Paulo Plateau, Santos Basin (SW Atlantic): Differences between genus and species data using machine learning

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The objectives of this work are to compare the use of genera and species data in environmental assessment and to predict the distribution of foraminifera, using abiotic data, in the sediments from the continental slope and São Paulo Plateau in the Santos Basin (SW Atlantic Ocean).

Four hundred and eleven sediment samples, including replicates, were collected (box corer) in 48 stations located on the continental slope and São Paulo Plateau, between 400 and 2,400 m of water depth, in the summer of 2019 and winter of 2021, from the Santos Project - Santos Basin Environmental Characterization, PETROBRAS. The upper 0-2 cm of each core was sliced for living foraminifera. The samples were stored in a solution of rose Bengal and 10% formaldehyde buffered with borax. The sedimentological parameters (gravel, sand, mud, and calcium carbonate- $CaCO_3$) and geochemical data (Cu/Zn, V/(V/Cr), organic phosphorus, total organic carbon, $\delta^{13}C$, $\delta^{15}N$, chlorophyll a, phaeopigments, lipids, carbohydrate, and biopolymers) were obtained in the Santos project. Machine learning analysis was performed by the iMesc application, and hierarchical clustering, and self-organizing maps (SOM) were used to separate the foraminifera genera and species into groups. The Random Forest (RF) was performed using the abiotic data as predictor of the foraminifera groups.

The cluster analysis on the SOM (Bray Curtis index) applied on the genera data recognized 4 different groups which followed the bathymetric gradient: upper slope stations (400 m depth -Group I), upper-middle slope stations (400 to 1,300 m -Group II), upper-middle slope stations (400 to 1,300 m -Group III), and lower slope and São Paulo Plateau stations (1,900-2,400 m -Group IV). The abiotic data that best predicted the 4 groups with 65% of accuracy were Cu/Zn, phaeopigment (phaeo), total organic matter (TOC), V/(V/Cr), and organic phosphorus (Porg). The most representative genera of each association were: *Globocassidulina, Reophax, Bolivina, Lagenammina*, and *Thurammina*. Applying the same analysis in a species matrix, the groups also showed a bathymetric arrangement. However, an additional group of the middle slope (1000 m and 1,300 m depth) was identified. The abiotic data that best predicted the 4 groups with 59% of accuracy were Cu/Zn, V/(V/Cr), phaeo, carbonate concentration ($CaCO_3$), lipids, and carbohydrate concentration. The most representative species were: *Globocassidulina subglobosa, Reophax* sp. 1, *Bolivina albatrossi, Trifarina bradyi, Epistominella exigua* and *Siphonina bradyana*. The model was based on 80% of foraminifera data that was used to predict the other 20% foraminifera distribution.

The comparison between the results obtained from analyses applied on both genera and species revealed that the foraminifera distribution in the Santos basin is mainly controlled by the availability/quality of food and oxygen. We also concluded that the genus data, which analysis is less time-consuming, can be applied in the environmental assessment of the basin. However, we cannot discard species data's contribution to understanding the oceanographic processes in the study area.

Recent foraminiferal assemblages in terrestrial salt ponds and meadows in Central Germany

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Benthic foraminifera are common and highly diverse in marine ecosystems. They have also been observed at low abundances and species numbers in terrestrial brackish lakes and salt ponds. First observations of benthic foraminifera in central Germany date back to 1939 and 1958 where single species of intertidal foraminifera have been reported from saline ponds and meadows in the states of Sachsen-Anhalt and Thüringen. The saline waters derive from late Paleozoic and early Mesozoic salt deposits under ground. In 2022, we took surface sediment samples along transects of vegetation zones from known and previously unexplored saline ponds and meadows at different locations in Sachsen-Anhalt and Thüringen to examine whether foraminifera are still living in these habitats. We found live (Rose Bengal stained) and dead foraminifera at all locations, partly with a higher species richness than in marginal marine ecosystems at the German North Sea coast. The modern, terrestrial assemblages are composed of typical salt-marsh foraminifera (*Entzia macrescens, Trochammina inflata, Trochamminita irregularis, Miliammina fusca, Haplophragmoides manilaensis*, and *Haplophragmoides wilberti*). We also found species that have not yet been reported from temperate salt marshes in northern Germany (*Trochamminita salsa* and *Gordiospira arctica*), and a species (*Entzia* sp.) which probably developed as an endemic species in the saline ponds and meadows in Central Germany. We assume that the foraminifera were transported to Central Germany via migrating birds. It is still unknown when and how often the terrestrial saline habitats have been colonized and whether the foraminifera originate from southern or northern Europe or from both regions. Future genetic analyses will clarify whether some of the inland salt-marsh foraminifera developed endemically and further field campaigns will provide insights into the population dynamics at various terrestrial saline ecosystems in Germany.

Reconstruction of calcification depths of Quaternary planktic foraminifera from the Espirito Santo Basin (southwestern Atlantic) using stable isotopes

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The oxygen isotope composition of foraminiferal tests is a well-established proxy to reconstruct seawater salinity, temperature and water masses distribution in the geological past. For example, the oxygen isotope analysis of planktic foraminifera calcifying at different depths can reveal changes in the structure of the thermocline. These reconstructions rely on the precise knowledge of the calcification depth of each species, which poses challenges, especially when dealing with fossil records. In this study we reconstruct the calcification depths of *Globigerinoides ruber* (white and pink), *Globigerinoides sacculifer, Globorotalia truncatulinoides*, and *Globorotalia menardii* by means of oxygen isotope analysis

of core top samples (size fraction > 150 μm) collected in the Espirito Santo Basin (southwestern Atlantic). The measured $\delta^{18}O$ values (vs. V-PDB) are as follows, *G. ruber* (white): –0.92 per mil, *G. ruber* (pink): –0.99 per mil, *G. sacculifer*: –0.61 per mil, *G. truncatulinoides*: +0.69 per mil, *G. menardii*: +0.43 per mil. Based on the present-day vertical salinity profile and on the linear relationship between salinity and seawater $\delta^{18}O$ value, we obtained a vertical profile of $\delta^{18}O$ values for foraminiferal calcite, under the assumption of isotopic equilibrium. Plotting the measured $\delta^{18}O$ values on top of the theoretical $\delta^{18}O$ profile yielded the following calcification depths, *G. ruber* pink: 85 m, *G. ruber* white: 95 m, *G. sacculifer*: 115 m, *G. menardii*: 190 m, *G. truncatulinoides*: 225 m. Since the $\delta^{18}O$ values of the tests reflect the long-term calcification period, our estimates represent average calcification depths, integrating the potential effect of vertical migration in the water column.

Vertical distribution of planktonic foraminifera and its controlling environmental factors in the eastern South Pacific

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Planktonic foraminifera play an essential role in the marine food web and biogeochemical cycles in pelagic ecosystems, so it is necessary to gain knowledge of their characteristics as living organisms. However, studies on modern planktonic foraminifera are still not enough to understand their ecology, distribution, and its limiting factors. For example, planktonic foraminiferal habitat depth has been studied and conceptualised mainly using stable oxygen isotope ratios preserved in their tests. Such generalized concepts of their living depth are useful when foraminifera are utilized as proxy careers. However, it is not necessarily the case that is observed in the real oceanic environment. It is also pointed out that planktonic foraminifera responds to various environmental factors irrespective of depth, which means that understanding their distribution in multivariate space is necessary. Here, as a case study, we aimed to investigate the relationship between marine environmental parameters and habitat depth of planktonic foraminifera in the eastern South Pacific. Such coupling of knowledge of modern planktonic foraminifera distribution and corresponding ocean environments can also contribute to understanding a more detailed picture of paleoenvironments reconstructed using planktonic foraminifera.

Planktonic foraminifera samples used in this study were collected during R/V Hakuho-maru Southern Pacific Cruise KH-19-6. Stations were located off the coast of Peru in the eastern South Pacific Ocean, St1 (10°S, 100°W), St3 (20°S, 90°W), and St5 (30°S, 90°W). Samples were collected from 7 intervals (0-20 m, 20-50 m, 50-100 m, 100-150 m, 150-200 m, 200-500 m, and 500-1000 m) using a Vertical Multiple Plankton Sampler. We picked up all planktonic foraminifera tests under a stereo microscope and recorded the number of individuals of each species in each interval. Then, we considered the number of individuals by species per 1 cubic meter as one community. For the vertical environmental parameters, we used five physicochemical data from CTD observations at the same station: water temperature, salinity, dissolved oxygen concentration, chlorophyll concentration, and density. We conducted a multivariate statistical analysis (dbRDA) to determine the correlation between the environmental parameters and the foraminiferal communities.

11,931 planktonic foraminiferal individuals were picked up and classified into 39 species in 19 genera. The community data were analyzed by hierarchical cluster analysis using Chao index as the distance, and each community was divided into four groups, reflected the location and depth. The dbRDA analysis revealed that all five parameters significantly affected the vertical distribution of the community, particularly seawater density, temperature, and salinity. Besides, differences between stations were related to dissolved oxygen concentrations. Since the eastern South Pacific Ocean has some water mass structures characterised mainly by water temperature, salinity, and dissolved oxygen concentration. It indicates that the characteristics of each water mass structure may be reflected in the community composition. Even though these physicochemical parameters could explain the compositional differences to some extent, the dbRDA analysis also highlighted that these five parameters alone could not sufficiently describe the differences. We presume that parameters related to biological factors, such as nutrient concentrations, and the density of other plankton that may interact with planktonic foraminifera, affect the foraminifera community composition. If these parameters can be obtained and considered in the analysis, it would allow us to better understand the role of planktonic foraminifera within marine ecosystems and interactions with other organisms that could not be observed directly.

Assessing the impact of different carbonate system parameters on benthic foraminifera from controlled growth experiments

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Insights into past marine carbon cycling and water mass properties can be obtained by means of geochemical proxies calibrated through controlled laboratory experiments with accurate seawater carbonate system (C-system) manipulations. Here, we explored the use of strontium/calcium ratio (Sr/Ca) of the calcite shells of benthic foraminifera as a potential seawater C-system proxy through a controlled growth experiment with two deep-sea species (*Bulimina marginata* and *Cassidulina laevigata*) and one intertidal species (*Ammonia* T6). To this aim, we used two experimental set-ups to decouple as much as possible the individual components of the carbonate system, i.e., changing pH at constant dissolved inorganic carbon (DIC) and changing DIC at constant pH. Four climatic chambers were used with different controlled concentrations of atmospheric pCO_2 (180 ppm, 410 ppm, 1000 ppm, 1500 ppm). Our results demonstrated that pH did not influence the survival and growth of the three species. However, low DIC conditions (879 µmol kg^{-1}) negatively affected *B. marginata* and *C. laevigata* through reduced growth, whereas no effect was observed for *Ammonia* T6. Our results also showed that Sr/Ca was positively correlated with total Alkalinity (TA), DIC and bicarbonate ion concentration ($[HCO_3^-]$) for *Ammonia* T6 and *B. marginata*; i.e., DIC and/or $[HCO_3^-]$ were the main controlling factors. For these two species, the regression models were coherent with published data (existing so far only for *Ammonia* T6) and showed overall similar slopes but different intercepts, implying species-specific effects. Furthermore, the Sr/Ca - C-system relationship was not impacted by ontogenetic trends between chamber stages, which is a considerable advantage for paleo-applications. This applied particularly to *Ammonia* T6 that calcified many chambers compared to the two other species. However, no correlation with any of the C-system parameters was observed for Sr/Ca in *C. laevigata*. This might imply either a strong species-specific effect and/or a low tolerance to laboratory conditions leading to a physiological stress, thereby impacting the Sr incorporation into the calcite lattice of *C. laevigata*.

Benthic foraminifera as tools to reconstruct past tidewater glacier dynamics: A case study from Kongsfjorden (Svalbard)

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Located at the interface between terrestrial and marine systems, high latitude glaciated fjords are sensitive spots to current and past climate change. Kongsfjorden is located on the western part of the Svalbard archipelago and is characterized by steep environmental gradients, due to the dynamics of the tidewater glaciers, and the inflow of warm Atlantic Water (AW). Here we analyze fossil benthic foraminiferal assemblages in two main sediment cores in order to reconstruct past environmental changes in link with these environmental gradients. Sediment core 10JM-GLACIBAR-GC01, located in front of a surge-type tidewater glacier (Kronebreen complex) in the inner Kongsfjorden, represents a historical record spanning the period from 1950 to 2010 AD. In this record, we tested relationships between taxonomic and functional diversity metrics and the reconstructed distance from the glacier front. We observed a general increase in foraminiferal fluxes and diversity with the progressive glacier retreat, confirming a positive benthic response to reduced glacier-induced disturbance through time. This historical record confirms therefore the successful use of diversity metrics as proxies for tidewater glacier retreat. A study of a second sediment core, NP07-13/58-GC, spanning the last 3000 years and located in the central Kongsfjorden, was initiated to reconstruct the two end-members relationship between AW inflow and glacier retreat using benthic foraminiferal assemblages and diversity metrics applied in the historical record. The preliminary results show that until 1.6 cal ka BP and between 800 and 500 yrs cal BP, a low diversity and high relative abundances of glacier proximal species characterized the assemblages. According to the developed diversity metrics models, this suggests that the glacier grounding line/ice sheet was advanced by about 10 km compared to its position during the mid 20th century. From 1.6 to 0.8 cal ka BP and between 500 and 200 yr cal BP, taxonomic diversity increased, suggesting decreased glacial influence at the core site (in the central Kongsfjorden). Additionally, the most recent part of the record (500 - 200 yr cal BP) recorded increased relative

abundance of the AW indicator *Adercotryma glomeratum*, suggesting increased influence of the AW carried by the West Spitsbergen Current in the central Kongsfjorden. These ecological observations need further investigations and comparison with published studies from Kongsfjorden and other Svalbard fjords. Investigations with multivariate analyses and Generalised Additive Models could help better interpret the patterns observed in term of species composition and general diversity.

From "source to sink" - a new perspective on the past dynamics of the Murray Canyon Group from benthic foraminiferal communities

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We present fossil benthic foraminiferal assemblage data from marine sediment core SS02/06-GC2 located in the abyssal plain of the Murray Canyon Group (offshore South Australia). The sedimentological characteristics indicate the presence of turbidite deposits showing classical Bouma-like sequences, dated between ~40 and 12 cal ka BP. These results confirm the previous interpretation of the observed large deep-water holes in the abyssal area where the core was sampled as being gouged by surges of high-energy turbidity currents. The presence of good indicator taxa and unique assemblages occupying specific bathymetric depths allows the determination of the source origin of the sediments making the turbidites. Three distinct faunal groups are found: 1) mostly shelf species, 2) mostly bathyal species and 3) mostly abyssal species. In the sediment core, these groups present a quasi-systematic succession, with nearly all Bouma-like sequences starting with the dominance of bathyal species in the coarse-grained base, followed by the dominance of shallow species in the silty part, and finally with abyssal species in the clays. To explain such phenomena, turbidites triggered by mixed hyperpycnal/hypopycnal flow processes and turbidity currents during periods of river floods are considered for the first time within the Murray Canyon Group. They are mostly related to periods of increased fluvial discharges during wet phases in the Murray-Darling Basin.

Paleoproductivity fluctuations at the seafloor in the Gulf of Cadiz during MIS 25-MIS 19: evidence from benthic foraminifera assemblages

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Benthic foraminifera assemblages can be used to trace trophic conditions and oxygen levels at the seafloor during the Early-Middle Pleistocene Transition (EMPT, 700-1250 kyr). The EMPT was an event that marked a change in how Earth's climate system responded to orbital forcing. Throughout the EMPT, the frequency of glacial-interglacial cycles shifted from ~ 41 kyr to ~100 kyr, which resulted in more intense and longer-lasting interglacial periods. While the EMPT has been studied worldwide, the impacts of those changes in the Gulf of Cadiz, a transition zone between the Mediterranean Sea and the Atlantic Ocean, are still mostly unknown. Reconstructing and understanding changes in environmental conditions under varying climatic conditions is fundamental to predict how ecosystems might react to the ongoing and future climate change. The present study aims to reconstruct productivity and oxygen levels based on benthic foraminifera across the EMPT interval from Marine Isotope Stage (MIS) 26 to MIS 19 (970-761 kyr). Our data come from sediment samples of IODP Site U1387 (36.8°N, 7.7°W; 559 m water depth), drilled into the Faro Drift and under the influence of the Mediterranean Outflow Water (MOW). Variations in MOW properties can affect the productivity, oxygen level, and bottom current velocity along the western Iberian margin and thus the benthic ecosystem. For the environmental interpretation, I am combining my faunal data with various other parameters, such as total organic carbon and total alkenone contents and planktonic foraminifera and diatom abundances. Organic matter availability and oxygen concentration are major factors controlling benthic foraminifera distribution, abundance, and diversity. The first analyses focus on the glacial/interglacial cycle of MIS 20 to MIS 19, and

interglacial MIS 25 as both experienced considerably different conditions in abiotic (e.g., insolation; sea-surface temperature) and biotic (e.g., productivity) factors. MIS 25 experienced warmer temperatures, a bloom in diatoms and a poorly ventilated water mass at the seafloor. The abundances of benthic foraminifera species *Bulimina aculeata* and *Sphaeroidina bulloides* reached more than 30% during the early MIS 25 period associated with seasonal upwelling as indicated by *Chaetoceros* spores. During interglacial MIS 19c, on the other hand, an increased flux of fresh phytoplankton food, as indicated by high concentrations of alkenones, possibly caused the increase in the *Hyalinea balthica* abundance. Relative high abundances of *Cassidulina laevigata* and *Globocassidulina subglobosa* throughout glacial MIS 20 point to changes in the quality of food. Finally, during the MIS 20/MIS 19 glacial-interglacial transition, we observe a rise in sub-oxic species abundances that might be linked to degraded organic matter, potentially exported from the Mediterranean Sea during sapropel formation. Those results highlight varying conditions, and we need to expand the analyses to include MIS 24 to MIS 21 and perform Principal Component Analysis to clarify the mechanisms driving the ecological preferences of the species under glacial and interglacial conditions.

The global genetic diversity of planktonic foraminifera

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The sequencing of the ribosomal RNA gene of planktonic foraminifera has challenged the morphological species concept since the 1990s when specimens of a single morphospecies showed large divergences among their sequences, indicating the presence of several biological but morphologically cryptic species. Almost three decades of single-cell sequencing carried out by multiple research teams resulted in the publication of ~40 papers and the generation of thousands of single-cell rRNA gene sequences. In addition, the onset of global metabarcoding surveys in the mid-2010s generated a profusion of genetic data that are challenging to align with the first generation data derived of single-cell sequencing. This ultimately renders the global biodiversity assessment of planktonic foraminifera difficult. Here we developed an approach to bring the single-cell and metabarcoding data under the same taxonomic umbrella to assess the worldwide diversity of planktonic foraminifera. We assembled an observational dataset of ~10,000 single-cell foraminifera genetically characterized and queried a global metabarcoding dataset of ~2,000 samples and 2.42 billion reads to retrieve planktonic foraminifera environmental sequences, resulting in ~1100 oceanic stations distributed worldwide. Globally, we identified 94 "biological" species, which nearly doubles the diversity assessment based on exclusively morphological traits. However, our analysis revealed that only 16 morphotaxa carry more than one genotype. This means that the majority of the ~50 morphologically defined species of planktonic foraminifera do not have cryptic diversity. Morphotaxa inhabiting mid to high-latitude environments have the highest degree of cryptic diversity while low-latitude taxa are moderately affected pointing to a non-random distribution of the phenomenon. Overall, our analysis shows that despite a profusion of genetic data, planktonic foraminifera diversity is modest and finite in contrast to other planktonic protists.

Renewal of planktonic foraminifera diversity after the Cretaceous Paleogene mass extinction by benthic colonizers

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The biotic crisis following the end-Cretaceous asteroid impact resulted in a dramatic renewal of pelagic biodiversity. Considering the severe and immediate effect of the asteroid impact on the pelagic environment, it is remarkable that some of the most affected pelagic groups, like the planktonic foraminifera, survived at all. Here we queried a surface ocean metabarcoding dataset to show that calcareous benthic foraminifera of the clade Globothalamea are able to disperse actively in the plankton, and we show using molecular clock phylogeny that the modern planktonic clades originated from different benthic ancestors that colonized the plankton after the end-Cretaceous crisis. We conclude that the diversity of planktonic foraminifera has been the result of a constant leakage of benthic foraminifera diversity into the plankton, continuously refueling the planktonic niche, and challenge the classical interpretation of the fossil record that suggests that Mesozoic planktonic foraminifera gave rise to the modern communities.

Response of *Ammonia confertitesta* (T6) to Triple Stressors: Ocean Acidification, Warming, and Deoxygenation

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Global changes lead to ocean acidification, warmer temperatures, and the expansion of hypoxic zones in coastal areas. These three stressors can have complex and poorly understood combined effects on calcifying marine microorganisms. In this study, we aimed to better understand the consequences of these threats on the survival and shell calcification of one of the most important marine calcium carbonate-secreting microorganisms - foraminifera. Our experiment was designed to culture benthic foraminifera under two temperatures, two different oxygen concentrations (oxic *versus* hypoxic), and three different pH (high and two low pH conditions based on the IPCC scenarios by 2100, -0.4 and -0.6 pH units). The experiment was performed at Kristineberg Centre for Marine Research and Innovation (Sweden).

In September 2022, benthic foraminifera were collected from the Gullmar Fjord (50 m station) and Fiskebäckskil's mudflat. Several species were identified, including *Nonionella* sp. T1, *Nonionellina labradorica*, *Bulimina marginata*, and the intertidal species *Ammonia confertitesta* (T6), and *Quinqueloculina* sp. Specimens were calcein-labeled before the experiment, to differentiate between pre-existing and newly formed chambers. After the experiment, the specimens were then CellTracker Blue-labeled to determine live individuals. Specimens were cultured for 48 days in Petri dishes maintained in aquaria and fed weekly with a mixture of freeze-dried algae. Ten different environmental conditions were tested. Two thermoregulated rooms were set at 9°C (*in situ*) and 13°C, respectively. In each room, we had controls (normal pH 8.0, oxic), pH 7.6 (medium pH, oxic), pH 7.4 (low pH, oxic), hypoxic high pH (pH 8.0, $[O_2]$< 63 µmol L^{-1}), and hypoxic low pH (pH 7.4, $[O_2]$< 63 µmol L^{-1}). Aquaria were duplicated for the controls and the two lower pH conditions run at both temperatures. We monitored the temperature, salinity, alkalinity, pH, and $[O_2]$ in hypoxic aquaria weekly to ensure stable water conditions. Survival and growth were estimated, and newly formed chambers were analyzed by laser ablation.

Here, we focus on *Ammonia confertitesta* (T6) which calcified more chambers than other species. Our preliminary results showed no statistical difference between replicated aquaria for the seawater chemistry. However, we observed that the survival rate varied by up to a factor of two between replicates for all conditions, suggesting that survival is not only dependent on environmental conditions but also on internal or confounding factors (e.g., physiological stress). A total of 60 newly formed chambers were analyzed coming from the different experimental conditions, however, no calcification occurred for the most severe combination of stressors (i.e., warm + hypoxic + low pH). Furthermore, the ratios of Mg/Ca,

Mn/Ca, Ba/Ca, and Sr/Ca were not impacted by ontogenetic trends between chamber stages, making it advantageous for environmental reconstructions. Although few chambers were analyzed by laser ablation, a larger variability in the TE/Ca values is observed at the low pH. Because laser ablation is a destructive method, new geochemical analyses will be performed on specimens after μCT reconstructions.

The "glacial" sapropel S6 (172 ka; MIS 6): a multiproxy approach to solve a Mediterranean "cold case"

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Sequences of dark colored, organic-rich sediment layers, called sapropels have been observed throughout the geological archive of the Mediterranean Sea, but the mechanisms behind their cyclical deposition are not yet fully understood by the scientific community. They are representative of large-scale bottom water deoxygenation and have been found to correspond with times of high-amplitude precession minima and insolation maxima. As a result of this specific orbital configuration the NH monsoon systems are intensified, heavily increasing precipitation over North Africa causing significant changes in the freshwater and heat budgets of the Mediterranean basin, limiting bottom water ventilation and leading to basin-wide bottom water anoxia. For these reasons, most sapropels are deposited during warm interglacial periods, as glacial conditions are theoretically less suitable for sapropel events. However, glacial sapropels have been recorded, such as sapropel S6, which was deposited during the penultimate glaciation of Marine Isotopic Stage 6 (MIS 6; 191 – 130 ka) responsible for the largest Quaternary Eurasian ice sheet to exist. With the use of high-resolution foraminiferal isotope, speleothem, and pollen records, previous literature pertaining to MIS 6 has evidenced the presence of millennial scale climate variability (sequences of interstadial-stadial episodes) controlled by the interactions between ocean-atmosphere-ice sheets impacting the North Atlantic and the Mediterranean Sea. Therefore, in addition to the monsoon sourced freshwater input being added to the Mediterranean at the time of S6, the interstadial warming events within this abrupt climate variability result in the melting of the surrounding ice sheets, acting as a second source of freshwater input. It is therefore argued that this combination of freshwater input is the mechanism behind the decreased rates of eastern Mediterranean (EMED) deep water formation causing bottom water anoxia, and, ultimately, the deposition of sapropel S6.

Here, we present a multiproxy paleoecological and geochemical study of the sapropel S6 sedimentation layer found in piston core M25/4-12 retrieved from the Ionian Sea of the EMED basin. Results from the analyses of planktonic foraminifers, calcareous nannofossils, pollen, dinocysts, and foraminiferal $\delta^{18}O$ were compiled, and compared to the findings of the previously mentioned published literature on MIS 6 and sapropel S6. Because of our high-resolution sampling effort, we were able to recognize within our multiproxy results the proposed millennial scale climate variability that impacted sapropel S6. This palaeoecological evidence, therefore, offers a new level of confirmation regarding the mechanisms behind the deposition of S6. Additionally, in agreement with the consensus of sapropel S6, our results also suggest that this period within MIS 6 experienced more mild/temperate and humid conditions than expected for a glacial period.

Ultrafine structure observation and pH imaging of site of calcification in *Sorites orbiculus*

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Foraminifera are unicellular organisms with calcareous shells. As the elemental composition of foraminiferal shells reflects the paleoenvironmental conditions, it can be used as a paleoceanographic proxy. However, our knowledge of the biological processes of elemental uptake associated with calcification is still limited. In particular, the full details of the role of pseudopodia and organic sheet structures of the shell during calcification remain unclear. In order to reveal the process of shell formation in hyaline-shelled rotallids (*Ammonia confertetista*), one of the two types of calcareous foraminifera, we performed ultrafine structural observations of individuals during shell formation. From these observations, we have shown

that calcification site is separated from an outer environment by an organic sheet structure where calcium carbonate is deposited. We also studied using intracellular and extracellular pH observations on living individuals in the process of chamber formation. These observations revealed that a high pH microenvironment was created at the site of calcification, where calcium carbonate is easily deposited. Conversely, a low pH microenvironment was created at the outside of the test, which facilitates the uptake of carbonate/bicarbonate ions as a carbon dioxide.

On the other hand, the formation process of porcelain-shelled miliolids, another type of calcareous foraminifera, have not been well studied since Hemleben's previous study revealed the formation of needle-like calcite crystals in the intracellular vesicles. Parker's study focused on the shell structure of diverse miliolid species, but there is still limited knowledge on how their shells are organised with long, elongated calcium carbonate crystals. If the long, thin crystals are secreted from the vesicles and intertwined each other, it is necessary to observe how they are arranged into the test wall. To clarify the detailed process of chamber formation in the porcelain-shelled miliolid foraminifera, we observed the ultrafine structure of the calcification site and pH imaging during calcification of *Sorites orbiculus*.

A focused ion beam scanning electron microscope (FIB-SEM) was used to make smooth transverse sections of the chamber wall during the process of calcification. The FIB-SEM images showed that a highly porous cotton candy-like structure was formed in the calcification site. structure was highly branched and fibrous. On the other hand, the shell structure of the penultimate chamber was packed with crystals and denser than the newly calcifying chamber. In addition, no crystal-like morphology has so far been observed in the intracellular vesicles.

The series of intracellular pH observation showed an increase in pH at the place of a newly forming chamber (i.e. 0) in *S. orbiculus*. However, in *S. orbiculus*, the increase in pH is also observed in the penultimate chamber (i.e. -1) and the chamber before the penultimate chamber (i.e. -2).

These results suggest that calcification of *Sorites orbiculus* does not occur in the manner proposed by Hemleben's previous study, in which the intracellular vesicles form needle-like crystals to construct the shell wall. This observation may reveal a novel and unknown mode of biomineralization in foraminifera and also be a key to understanding elemental partitioning and isotopic fractionation in foraminiferal shells.

Documentation of the native shallow water benthic foraminiferal assemblage in a sediment core from the coastal region of Northern Israel

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The opening of the Suez Canal in 1869 created a renewed direct connection between the Red Sea and the Mediterranean Sea. This enabled hundreds of species (Lessepsian invaders) to overcome a long-standing biogeographical barrier between these two seas that had previously existed since the Miocene. There has been an increasing number of publications that reported the presence of invasive and non-native species in the Mediterranean Sea among which foraminifera can be found. The focus of these studies lies on the most recent part of the invasion process, the establishment success and possible harm to the ecosystem by invasive species. However, the sensitivity to microhabitats and spatial microdistribution of foraminiferal community structures in the Eastern Mediterranean Sea makes it important to understand the local native communities and their natural changes through time first, so later studies can assess the impact of non-native foraminifera species better.

To address this research need, a sediment core of ~80 cm length and 7 cm in diameter was taken in 40 m water depth on the coast of Israel, near Atlit. The total assemblage of foraminifera (>63 μm) was determined for every 5 cm and their biodiversity indices were calculated (Shannon-Wiener index, Dominance, Evenness, Fisher's alpha index).

The majority of it provides an archive of native foraminiferal communities that predates the opening of the Suez Canal. The most recent part of the core shows the progression of the migration process. The sediment composition was characterized by a change to coarser sediment in the top 10 cm.

We found 244 species in total and calculating biodiversity indices showed a high biodiversity (e.g. maximum Shannon-Wiener index of 3.95 at 65 cm, extrapolated age of ~7050 years), which is typical for the Eastern Mediterranean Sea. Calcareous (49.6%) and porcellaneous (44%) species showed a high species richness throughout the core while there were only a few agglutinated species present (5.7%). Regarding the number of individuals, *Asterigerinata mamilla* (13.35% of all individuals) was the most dominant species, followed by *Textularia bocki* (4.75% of all individuals) and *Tretomphalus* sp. (4.0% of all individuals). Graphical analysing methods (Detrended Correspondence Analysis and Non Metric Multidimensional Scaling Analysis) showed a dissimilarity between the older part of the core (70 – 8 cm) and the recent part of the core (7 – 1 cm).

The top 7 cm of the core showed an altered community structure, higher total abundances and the presence of most non-native species (11 species in total). The most abundant non-native foraminifera species was *Heterostegina depressa.* Correlating the grain sizes with the number of species and number of individuals showed a positive and significant

relationship between grain sizes and foraminifera. Analysing lifestyle proportions showed that throughout the core epifaunal living foraminifera species dominated over infaunal living species.

The introduction of Lessepsian species and the changes in substrate drove an overall shift of the foraminiferal assemblage.

Automation adventures: First steps in the automatic identification of benthic foraminifera from high resolution 3D images of sediment cores

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X-ray CT scanning, or microtomography, is a non-destructive analysing technique that allows the visualization of the inner structure of materials. It is based on the differential attenuation of an x-ray beam transmitted through a sample. Depending on the local density and the atomic number of the material, the x-rays are more or less absorbed, producing a radiographic projection very similar to medical radiography. Provided that the sample under investigation is imaged from different angles, the radiographic projections can be combined to produce a 3D image in which the intensity values carried by the unit cells (voxels) correspond to the local density of the material.

In our study, we used this technique to investigate the 3D distribution of benthic foraminiferal individuals in a sediment core, previously embedded with resin following the FLEC (Fluorescently Labeled Embedded Core) protocol. Due to their dense shell, the foraminifera appeared slightly brighter than most of the surrounding sediment, with the notable exception of scattered dense grains and other shell fragments.

After image acquisition, we manually pointed the benthic foraminifera present in the core and obtained the 3D coordinates of their exact position in the sediment with a resolution of 13 µm respectively in the x, y and z axes. A correction was applied to these coordinates to account for the inclined sediment surface. This allowed us to count and spatially locate benthic foraminifera within their actual life position. The results allowed us to observe a general preference for sub-superficial (100-300 µm depth) microhabitats for species generally considered as "epifaunal".

In parallel, at a first attempt to automatically identify foraminifera in the matrix, we applied a successive series of filters on the original images to minimize noise and then let the software count the foraminifera with the ImageJ program. However, comparison between manually pointed specimens and automatically identified specimens revealed a high proportion of false positives for the latter, i.e., a bias towards selection of non-significant fragments, sediment grains, etc.

Ongoing investigations are therefore oriented towards the application of Convolutional Neural Networks to CT scan images. Preliminary results are highly encouraging, with a high accuracy in the identification of benthic foraminifera in their natural position within a sedimentary matrix.

Future work will improve the model on other independent samples and enlarge the spectrum of species, with different test composition and preferential microhabitats, that can be analysed and recognised using this technique. Distinction between living and dead specimens will be an additional challenge. The optimisation of this kind of technique will finally allow to study benthic foraminifera directly in their natural microhabitat and at high spatial resolution, which could be particularly useful to investigate fine scale processes inducing for example patchiness or migrations.

Roadian foraminifers of the Williams Ranch Member of the Cutoff Formation (Guadalupian, Middle Permian), Delaware Basin, West Texas (USA)

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In West Texas, Middle Permian rocks of the Delaware Basin outcrop in the Guadalupe and Apache Mountains. The World stratotype area for the Middle Permian, Guadalupian Series and the GSSP's for the Roadian, Wordian and Capitanian stages are located within Guadalupe Mountains National Park. The Guadalupe Mountains area contains a unique Middle Permian Reef Complex with strata of various paleoenvironments ranging from back reef, reef, fore reef to basinal. Guadalupian strata in the Delaware Basin are divided (in ascending order) into the Cutoff, Brushy Canyon, Cherry Canyon,

and Bell Canyon Formations. In the Guadalupe Mountains each formation is divided into several members characterized by distinctive lithofacies. The Roadian part of the Cutoff Formation is subdivided into four members (in ascending order): El Centro, Butterfield, Rest Area, and Williams Ranch. The first appearance of the conodont species *Jinogondolella nankingensis* marks the lower boundary of the Roadian stage, which is placed in the middle part of the El Centro Member of the Cutoff Formation.

In the Guadalupe Mountains area, the Guadalupian small foraminifers have not been extensively studied and are known mostly from the Capitanian strata. Roadian small foraminifers have not been monographically studied at all, their presence in this interval only mentioned in one abstract. A diverse assemblage of Roadian foraminifers is present in strata of the Williams Ranch Member in the Quarry section that outcrops along U.S. Highway 62/180 in the Guadalupe Mountains area. The strata of the Quarry section are represented in the lower part by thin-bedded black carbonate mudstone with small black pebbles of packstone. In this part of the section can be seen soft sediment deformation. Above this unit is a zone of debris associated with thin- to medium-bedded black carbonate mudstone with lenses of mollusc-bearing packstone. Some beds of the carbonate mudstone are laminated and contain a rich assemblage of radiolarians. The packstone lenses contain a very diverse fauna consisting of ammonoids, a fish assemblage of microremains of chondrichthyans and actinopterygians, some radiolarians, ostracodes, scolecodonts, holothurian sclerites, conodonts, and a rich assemblage of mostly small foraminifers and some fusulinids.

Conodonts are represented by the species *Jinogondolella nankingensis* with three subspecies (*J. nankingensis nankingensis*, *J. nankingensis tenuis*, and *J. nankingensis behnkeni*), elements of *Sweetina*, and elements of the apparatus of *Hindeodus wordensis*.

Small foraminifers are abundant and represented by agglutinated and calcareous genera. Among the agglutinated forms are species of the genera *Ammobaculites* and rare biserial "*Textularia*". Calcareous forms are dominant and are represented by genera such as *Pseudoammodiscus*, *Multidiscus*, *Hemigordius*, *Nodosaria*, rare *Tristix*, *Lingulonodosaria*, *Ichthyolaria*, rare *Howchinella*, *Geinitzina*, *Neoendothyranella*, *Globivalvulina*, *Tetrataxis*, and attached forms of the genera *Calcitornella* and *Calcivertella*. Some species such as *Ichthyolaria longissima, Tristix tcherdynzevi*, and *Geinitzina spandeli* are known from Kazanian strata of the Volga River area in the East-European Platform.

Fusulinaceans are represented by rare broken tests of the genus *Parafusulina* and abundant smaller forms of an ozawainellid type reported mostly from China and Japan and called *Chenella*.

Amphistegina lobifera as a sink for H_2O_2 in coral reef sediments from the Gulf of Aqaba

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Large benthic foraminifera (LBF) have been recognized as prolific ecosystem engineers due to their contribution to sediment production and reef framework stabilization. A largely unexplored way in which LBF might further shape their surroundings is through influencing reactive oxygen species (ROS) concentrations. Various marine organisms were found to impact concentrations of ROS such as hydrogen peroxide (H_2O_2) in their environment, potentially resulting in wide-reaching effects on redox states, bioavailability of trace metals and biogeochemical cycles linked to ROS.

In order to better understand the functional role of LBF in the microenvironment of marine sediments and their benthic habitats at large, we therefore assessed if the common diatom-bearing LBF *Amphistegina lobifera* impacts H_2O_2 concentrations in coral reef sediments from the Gulf of Aqaba (GoA). We hypothesized a) high H_2O_2 concentrations in the iron-rich GoA sediment, since reactions involving iron can generate various ROS, and b) that LBF can protect themselves against high environmental H_2O_2 levels by lowering H_2O_2 concentrations in their microenvironment, for example through enzymatic scavenging.

Combining H_2O_2 and O_2 microsensors in a laboratory set-up, we recorded H_2O_2 and O_2 depth profiles across the sediment-water interface and in the upper millimetres of GoA sediment samples with and without *A. lobifera*. We found that H_2O_2 concentrations in LBF-free sediment samples with minimal biotic activity reached up to 13 µM in the deeper anoxic layers, from which H_2O_2 seeped into the water column. Addition of *A. lobifera*, which was the dominant LBF species in the

sampled sediment, caused rapid depletion of H_2O_2 in surrounding sediment and stopped its release into the water column. High rates of foraminifera-driven H_2O_2 consumption were confirmed by measuring H_2O_2 and O_2 fluxes across the diffusive boundary layer of *A. lobifera* individuals under different concentrations of experimentally added H_2O_2 (up to 167 µM) and different light regimes. Our results showed that all measured specimen continuously consumed added H_2O_2 regardless of concentration and irradiance. In the presence of H_2O_2, a release of O_2 by the foraminifer was observed in darkness, which shows that catalase plays an important part in the scavenging process.

Overall, our findings indicate that *A. lobifera* act as a potent sink for H_2O_2 in shallow (sub)tropical benthic ecosystems. We suggest that accumulative scavenging of sedimentary H_2O_2 by *A. lobifera* and potentially other (large) benthic foraminifera species represents a yet unrecognized ecological function with potential implications for elemental cycles connected to H_2O_2, such as the oxygen and the iron cycle. As LBF are susceptible to environmental stressors, our study highlights the importance of investigating mechanisms underlying LBF-mediated biogeochemical processes and their response to environmental change.

Foraminifera diversity from the ocean surface to the surface layer of sediments in Nordic Sea

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Foraminifera are single-celled organisms that play a significant role in the marine ecosystem and are important for reconstructing past environmental conditions due to their sensitivity to environmental changes. However, there is a lack of understanding regarding the transportation and deposition of DNA that originates from foraminifera, from the ocean surface to the seafloor, and its eventual inclusion in the sedimentary records of marine environments. Recently, metabarcoding is a powerful tool for studying biodiversity and ecosystem function, as it can provide rapid and accurate information on the composition of complex communities. The use of metabarcoding has become increasingly popular in recent years, particularly in the study of microbial ecology and biodiversity. Here, we present results from a study that examines the diversity of foraminifera, from the ocean surface to the surface layer of sediments in the Nordic Seas by metabarcoding approach. In brief, seawater and sediment samples from twenty-five stations were collected from the water column (5 m, 100 m and bottom) and the seafloor (surface sediment) and analysed using molecular techniques. The study revealed a diverse assemblage of foraminifera species, with variations in community structure and abundance between different water depths and sediment layers. The results also suggest that environmental factors, such as water temperature and salinity, play a crucial role in shaping foraminifera communities. This study provides new insights into the distribution and diversity of foraminifera in the Nordic Sea and their potential use as indicators of environmental changes in the region. The findings have implications for understanding past and present marine ecosystems and their responses to climate change.

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Bio-erosional traces on the foraminiferal test

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Previous studies have shown that bio-erosional traces on the Benthic foraminiferal test are quite common in many modern and fossil environments. A few of the trace makers are known, but most traces are made by unknown organisms. Likewise, it is also unknown why such organisms make these traces. Some species of foraminifera are known to excavate pits or borings in different substrates such as the tests of dead as well as living organisms or limestone rock. Some of these traces have been attributed to predatory or parasitic behavior in both modern and fossil environments. Several species of benthic foraminifera have been observed to demonstrate what seems to be a parasitic or predatory mode of life. However, many more species are believed to have a similar behavior due to their ability to bore into different substrates and tests of calcareous organisms, including other foraminifera. In this study I will show that the morphological variety of the traces found in foraminiferal test is in general caused by unknown organisms.

The High-Low: combined analytical approaches yield both high and low past ocean temperatures from the equatorial Indian Ocean across the Cenozoic

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Our ability to accurately reconstruct ocean temperatures in the geological past has inherent weaknesses with traditionally applied proxies for temperature reconstruction (e.g., Mg/Ca) having both biological and geochemical caveats. The recent decade has seen the increased development and application of clumped isotope thermometry (Δ_{47}) as a viable approach for temperature reconstruction from foraminifera. The clumped isotope (Δ_{47}) approach is thought to be outwith biological vital effects and the requisite assumptions regarding past seawater chemistry due to the clumping of ^{13}C-^{18}O bonds being dictated, in isolation of seawater chemistry, by thermodynamics.

We present paired Mg/Ca-temperatures and Δ_{47}-temperatures from inferred mixed-layer dwelling planktic foraminifera spanning the Cenozoic (0-58 Ma) from IODP Site U1443 in the southern Bay of Bengal. There is good agreement between the two analytical approaches across the Pliocene-Pleistocene. However, this relationship breaks down with a divergence between Mg/Ca-temperatures with Δ_{47}-temperatures in the late Miocene, with the latter recording cooler than expected temperatures. The cooler than expected temperatures recorded by the Δ_{47} suggests a sensitivity to post-depositional diagenetic effects greater than that of the Mg/Ca-temperatures. In order to help constrain the degree of diagenetic overprinting we present Δ_{47}-bottom water temperatures reconstructed from benthic foraminifera to assess the differences in carbonate precipitation settings, between the upper mixed layer with bottom waters, at the site across the studied interval.

Abundant chitinous structures in cytoplasm of *Chilostomella* and their potential functions

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Benthic foraminifers inhabit a broad range of marine environments and are particularly common in hypoxic sediments. The biology of benthic foraminifera is a key to understanding benthic ecosystems and relevant biogeochemical cycles. *Chilostomella* is a foraminiferal genus commonly found in hypoxic deep-sea sediments and has poorly understood ecological and biogeochemical characteristics. The carbon isotopic compositions of their lipids and calcite test are substantially different from other co-occurring genera, probably reflecting unique features of its metabolism. Here, we investigated the cytoplasmic and ultrastructural features of *Chilostomella ovoidea* from bathyal sediments of Sagami Bay, Japan based on serial semi-thin sections examined using an optical microscope followed by a three-dimensional reconstruction, combined with TEM observations of ultra-thin sections. Observations by TEM revealed abundant electron-dense structures dividing the cytoplasm. Based on histochemical staining, these structures are shown to be composed of chitin. Our 3D reconstruction revealed chitinous structures in all chambers and particularly abundant in last few chambers. These had a plate-like form in the final chambers but became rolled up in earlier chambers (towards the proloculus). These chitin-plate structures may function to partition the cytoplasm in a chamber to increase the surface/volume ratio, and/or act as a reactive site for some metabolic functions. They co-occur with putative chloroplasts, suggesting these two unique features likely play significant roles on *Chilostomella*'s metabolic adaptations to the hypoxic environments and distinct isotopic compositions.

Assessing the environmental quality of a historically-polluted fjord: a comparison of benthic foraminiferal eDNA and morphospecies proxy approaches

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Transitional environments present a unique challenge to Ecosystem Quality Status (EcoQS) assessment due to highly heterogenous conditions within the system, resulting in the "estuarine quality paradox". Benthic foraminiferal assemblages provide high resolution environmental proxy records of the interaction between abiotic and biotic parameters in aqueous ecosystems. Fjords particularly have complex seabed topography which limits bottom water exchange and can result in hypoxia, and Idefjord on the Swedish Norwegian boarder is no exception. Although this oxygen decline is a natural occurrence which impairs fjord's EcoQS, these 'naturally stressed conditions' complicate the definition of in-situ reference conditions if the system becomes subject to anthropogenic impact. At Idefjord the prolonged dumping of waste products from the paper and pulp manufacturing and bleaching industry, situated at the city of Halden, into the river Tista which feeds the fjord system, has led to a build-up of organic matter, sewage effluent and pollutant accumulation in the sediments. This study is the first assessment of foraminiferal diversity using sedimentary eDNA from one of the most polluted and anoxic fjords in Scandinavia, comparing the assemblage response reported by morphology-based and molecular ecosystem assessment techniques.

Although index thresholds and genetic data processing decisions influence the EcoQS assessment category determined by each technique, both datasets report congruous responses in the benthic foraminiferal assemblages to pollution and environmental stress factors. Genetic methods tend to overestimate EcoQS at highly anoxic sites probably due to a presence of dormant propagules or extraorganismal DNA and suggesting that morphological methods are more suited to assessment in such conditions.

Patterns of foraminiferal diversity and species composition from a three-year time series in the Southeastern Clarion-Clipperton Zone, an area designated for deep sea mining

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The Clarion-Clipperton Zone (CCZ) in the eastern equatorial Pacific is a target of commercial deep-sea mining (DSM) due to its extensive deposits of high-grade polymetallic nodules. Benthic foraminifera play a crucial role in the ecological balance of oligotrophic abyssal plain communities, where they are the dominant eukaryotes across all size classes (meio-, macro-, mega-) and contribute significantly to the deep-sea food web. Effects of DSM include the generation of sediment plumes, the redeposition of sediment and organic matter, sediment compaction, as well as the loss of hard substrate as habitat heterogeneity in an otherwise homogeneous environment. In order to establish a baseline prior to test mining, this study investigated patterns of foraminiferal diversity, species composition, and density (>63 µm; stained and total) from the top 5 centimetres of 80 multicores across three timestamps (Oct 2020, May 2021, Aug 2022) from the NORI-D exploration lease area. All samples were stained with rose bengal, sieved to 63-µm, wet-picked, and identified to the lowest possible taxon. Nearly 60% of morphospecies found were undescribed. Morphospecies that could not be identified as a described species were preserved, photographed, and given a unique identifier using the lowest identified taxonomic level and a serialized voucher code. All voucher specimens were preserved and will be sequenced for future species description. As the largest quantitative foraminiferal study from the CCZ with over 700 distinct morphospecies found and over 100,000 individuals identified (stained and unstained), this research reinforced the previously documented high species richness and diversity found in polymetallic nodule fields as well as the dominance of monothalamous foraminifera. Additionally, this analysis unveiled a connection between nodule presence/size and its effect on foraminiferal species composition.

The effect of $[Mg^{2+}]_{sw}$, $[SO_4^{2-}]_{sw}$, and temperature on Mg incorporation in cultured benthic foraminifera

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Element incorporation into foraminifera has proven essential to many palaeoceanographic and environmental reconstruction studies. One of the most applied proxies to reconstruct past temperature is the Mg/Ca ratio. As happens with most of the proxies, Mg/Ca doesn't work perfectly and the accuracy, precision, and sensitivity of the reconstructions are affected by the influence of other environmental parameters. Besides temperature, seawater [Mg^{2+}], the marine inorganic carbon system, and salinity also affect foraminiferal Mg/Ca. Moreover, different species can have vastly different Mg/Ca even when grown under identical conditions.

To understand how Mg incorporation is affected by these conditions, we applied a systematic approach by testing the effect of $[Mg^{2+}]_{sw}$, $[SO_4^{2-}]_{sw,}$ and temperature on species of foraminifera with different biomineralization mechanisms (i.e. species with contrasting calcite chemistries and shells that have different microstructures). Results will allow us to 1) apply Mg/Ca as a paleothermometer with greater accuracy, 2) investigate the use of Mg/Ca and how it could be influenced by other environmental parameters, and 3) investigate phylogenetic relation in Mg incorporation.

Laboratory feeding experiments - investigating respiration rates of the benthic foraminifer *Nonionella* sp. T1

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Benthic foraminifera are important components of marine ecosystems, contributing to biogeochemical cycling and serving as indicators of environmental change. Their behaviour under different environmental conditions is of importance for the study of paleoclimate due to their extensive use as paleoproxies. Gaining knowledge of their role in energy and nutrient flows leads to a better understanding of ecosystem functioning. In this study we investigated respiration rates of the potentially invasive benthic foraminifer *Nonionella* sp. T1 originating from sediments within the Gullmar Fjord and cultivated in artificial sea water (ASW) in the laboratory at the University of Vienna. In order to assess the flux of organic carbon within an organism both oxygen respiration and carbon assimilation need to be considered. A non-invasive method was used to analyze oxygen respiration rates. The method involved placing an Oxygen Sensor Spot in a small, 2.5 ml airtight glass vial alongside the foraminifera. Oxygen concentrations under dark and light conditions were documented using an Oxygen Microsensor. We used a large number (n = 100 per sample, triplicates measured) of cleaned, living specimen. Respiration rates are given in nl O_2/h calculated for biovolume (µm³) which was assessed for each individual using photo microscopy. For the purpose of quantifying CO_2 production from foraminiferal respiration samples were additionally analysed via Cavity Ring-Down Spectroscopy (CRDS) which detects trace metals and measures isotopic ratios from a gas phase. In order to more clearly trace the carbon signal from the foraminifera within this experimental setup they were fed with freeze-dried ^{13}C-labelled diatoms (*Phaeodactylum tricornutum*) prior to the CO_2 measurements. Our results from the Oxygen Microsensor show a consistent respiratory activity for *Nonionella* sp. T1 by a significant ($r^2 \geq 0.98$) linear decrease in oxygen content over time (~ 7 h). The oxygen respiration rates measured at 7.37×10^{-7} to 3.32×10^{-6} nl O_2/µm³/h under dark conditions fall within the upper range of previously observed foraminiferal respiration rates. With most other studies using much less specimen for measurements due to their focus on the relation between respiration rates and individual biovolume a direct comparison is difficult. Further, first results from CRDS analysis show detectable amounts of CO_2 release from foraminiferal respiration and more results are needed. Combining these findings our research contributes to a better understanding of the metabolic processes and the ecological role of the potentially invasive foraminifer *Nonionella* sp. T1. Quantifying respiration rates using significant sample sizes supports the continuous evaluation of the contribution of benthic foraminifera to O_2 consumption and CO_2 production within benthic communities.

Composition of Foraminifera test bound organic matter and proxy potential

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Foraminiferal shells are extensively used to reconstruct the marine environment in the geological past. The foraminifera test-bound organic material (FBOM) has been used as a proxy for past atmospheric CO_2 concentrations, past nitrogen cycling and has the potential to provide information on water mass circulation and carbon cycling. Additionally, unlike particulate organic matter, FBOM has the advantage of being sheltered by the foraminifera test from diagenetic alteration and potential contamination. However, to fully exploit the proxy potential of FBOM, its molecular composition must be clearly assessed. Recent work suggests that FBOM may be characterized by a substantial lipid content and that this would justify depleted FBOM $\delta^{13}C$ values. To assess this hypothesis and provide further information on the FBOM chemical composition, we carried out analyses using gas chromatography-mass spectrometry and flame ionization detection (GC-MS/FID) together with liquid chromatography organic carbon and nitrogen detection (LC-OCD/OND). Our results show no evidence of a sizeable lipid component. Instead, they indicate that polysaccharides and proteins dominate the FBOM, as proposed by earlier studies. Furthermore, our study explored for the first time the potential of LC-OCD/OND analyses on FBOM and the impact on this proxy of the methodology used.

Larger foraminiferal biodiversity from Paleocene to Miocene: possible relationships with climate changes

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A list of over 1,300 species belonging to 215 genera spanning Danian to Langhian, and including 26 Shallow Benthic Zones (SBZ) was used to obtain a biodiversity analysis based on a comprehensive and critical review of the scientific literature on larger foraminifera (LF) and other accompanying shallow-water foraminifera of the Mediterranean Neotethys.

This large dataset allows us to recognize a quick evolutionary radiation shortly after the abrupt extinction of LF occurred at the end of the Cretaceous period: high origination rates are recorded at both genus and species level in the early Danian, followed by a rather constant biodiversity throughout the rest of the Paleocene.

A tipping point is represented by the Paleocene-Eocene Thermal Maximum (PETM), which is followed by a startling radiation of K-strategists species, giving rise to an exceptionally high number of species belonging to the genera *Alveolina*, *Nummulites*, *Assilina*, *Discocyclina*, and *Orbitoclypeus*.

Similarly, even if to a lesser extent, a second minor turnover occurred in SBZ12, right after the Early Eocene Climatic Optimum (EECO).

Lutetian and Bartonian times were subjected to a general cooling trend, shortly interrupted by the Middle Eocene Climatic Optimum (MECO), which however seems having no significant influence on the general demise of several Eocene LF groups such as nummulitids.

The Eocene/Oligocene transition (EOT), known as contemporary with a major cooling event, also coincide with the extinction of major groups of LF such as the orthophragmines (= discocyclinids + orbitoclypeids).

During the Oligocene, lepidocyclinids and miogypsinids flourished in the Neotethys but already in the Late Oligocene, at the end of the SBZ23, which roughly coincides with the end of the Late Oligocene Warming Event (LOWE), the biodiversity dropped to low values.

Unfortunately, during the Miocene the diversity became so low that it's very hard to precisely detect the influence of the Middle Miocene Climatic Optimum (MMCO) on the LF communities.

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A new proposal for biozonation of the Paleocene: Shallow Benthic Zones (SBP) calibrated with calcareous nannofossils

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The Danian-Thanetian interval has been investigated in three sites from northern Italy, i.e., Tabiago and Monte Giglio in Lombardy and Ardo in Veneto. All these are deep-sea sections with abundant content in calcareous nannofossils, but they contain intercalations as well of calciturbiditic, larger foraminifera-bearing beds derived from shallow-water environments, making them suitable for a direct correlation of different biozonation tools. The analysis of both larger foraminifera and calcareous nannofossils allowed us to reconstruct with sufficient detail the Southern Alps record, which could be considered as a starting point to obtain a new biozonation integrated scale. The shallow benthic (SB) zones, calibrated with the calcareous nannofossils (CN) zones, provided new data about the biozonation of the Paleocene. Accordingly, we propose to introduce four new SBP (Shallow Benthic Paleocene) Zones (SBP1-4), partly coincident with the former SB Zones of the standard biozonation but defined following an innovative biostratigraphic approach for larger foraminiferal, which is based on biohorizons instead of marker species as in the traditional approach used since the introduction of the SB Zones. One of our main results is that the SBP1/SBP2 boundary, coincident with the recovery of the complexity among foraminifera, turns out to occur only 2 Ma after the K/Pg crisis, faster than previously retained.

Unexpected high records of non-indigenous foraminiferal species in the eastern English Channel

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The English Channel is known as a hotspot of Non-Indigenous Species (NIS). Besides aquaculture, their other main entry is commercial harbours due to globalised shipping through ballast waters and fouling. Recently, we witnessed the emergence of foraminiferal species originating from Asia yet unrecorded in the English Channel i.e. *Trochammina hadai*, *Virgulinella fragilis*, *Spirobolivina* sp. and to a lesser extent *Ammonia confertitesta*. After presenting some general statements on these newcomers in the eastern English Channel, and potential impacts of these species on their new ecosystems, we will illustrate the arrival of NIS species based on the *Ammonia tepida* morphogroup that includes the three pseudo-cryptic species, *A. aberdoveyensis*, *A. confertitesta* and *A. veneta*. The morphological discrimination of the latter three species has been recently established, but information on their ecology and habitats is still relatively scarce. This study aims to define distribution patterns of these species at eight sites scattered along the French coasts of the English Channel, covering a total of 39 stations. These sites were classified into two contrasted habitats based on the intensity of anthropogenic influence, either harbours (heavily modified habitat) or less impacted (moderately influenced habitat). The use of *IndVal* index (measuring the specificity of a species to a given habitat) clearly indicates that *A. confertitesta* is preferentially recorded in or close to harbours. We then compiled previously reported occurrences of *A. confertitesta* from literature and compared it with harbour locations in Europe, showing that the species almost always occurs in the vicinity of major commercial harbours. In some cases, *A. confertitesta* occurs relatively far away from these harbours, suggesting a secondary spread. Our results confirm that *A. confertitesta* is a NIS in the eastern English Channel, outnumbering it congeneric indigenous species *A. aberdoveyensis* and *A. veneta* and becoming the dominant *Ammonia* species in these heavily modified habitats.

Foraminiferal diversity uncovered by *seda*DNA metabarcoding

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The Arctic marine biodiversity undergoes rapid changes due to global warming. These changes have been demonstrated in the case of macroorganisms, but little is known about their impact on the biodiversity of small, single-celled organisms,

such as foraminifera. Furthermore, our knowledge of the impact of climate changes on marine biodiversity across geological times is limited to a few taxa that leave fossilized remains. Recent advances in environmental genomics can change this situation radically. In particular, environmental DNA analysis is an effective method for tracking the evolution of biodiversity over time and space in a holistic manner. Evidence that DNA can be preserved in marine sediments at geological time scales has opened up new avenues for the use of sedimentary ancient DNA (*seda*DNA) in paleoenvironmental research.

Our research indicates the existence of foraminiferal *seda*DNA in the Late Quaternary sediments in the Nordic Seas and revealed foraminiferal assemblages much more diverse than those inferred from the fossil records. In particular, *seda*DNA studies have revealed a vast diversity of non-fossilizing monothalamous foraminifera, including several new potential indicator species. Although microfossil and *seda*DNA records complement each other rather than overlap, combined together they reveal more detailed information than may be derived from each approach individually. Furthermore, our results show that a finer molecular analysis can provide valuable information about the occurrence of different foraminiferal genetic variants over time. These changes at the genotype level are associated with environmental conditions, indicating that genotypes have different ecological preferences and can be used as alternative paleoceanographic proxies in the future.

Despite the limitations of the *seda*DNA approach, resulting from the degraded nature of *seda*DNA or potential technical biases, it may provide a powerful mean to reconstruct paleoenvironments more comprehensively and to better understand what drives past Arctic environmental changes. However, to fully exploit the potential of *seda*DNA as a proxy, it is essential to increase our knowledge about the molecular ecology of modern foraminifera. As the present is the key to the past, metabarcoding data on living-species distributions and their population structures are indispensable to the accurate interpretation of paleometabarcoding data and the use of foraminiferal genomic variants as indicators of changing environmental conditions.

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Monothalamous foraminifera: mapping the unknown diversity revealed by environmental genomics

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The diversity of forams is usually associated with the morphological complexity of their external skeletons. However, with the advances of molecular research it became clear that there is a parallel world of non-skeletonized monothalamous foraminifera that might be as diverse, or even more diverse, than their multichambered calcareous or agglutinated cousins. These monothalamids dominate in practically all metabarcoding studies. Some of them could be assigned to a few described species or genera, but the majority remain unidentified. Great efforts have been made in recent years to describe morphologically and genetically at least some of the most common monothalamids. Yet, given the continuous flood of new sequences being produced by metabarcoding studies, these newly described species are like a drop of water in an ocean of unseen biodiversity. Here, we report the first attempts to classify these unknown monothalamids based on their molecular signatures. Numerous novel lineages have been revealed, and their distributions have been tentatively assessed. Further efforts are needed to characterize these new lineages morphologically. Nevertheless, the lack of morphological taxonomy should not be viewed as an impediment to the future development of foraminiferal metabarcoding. Our work is the first step towards making ecological sense of the huge unknown diversity of monothalamids and testing their potential use as bioindicators of environmental impacts.

Morphological variations in *Pseudohastigerina micra* from the upper Eocene flysch sediments of the island of Hvar, Croatia

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Upper Eocene flysch sediments are an important unit of Dinaric foreland basin deposits. At the island of Hvar, Croatia, two outcrops where these sediments are well exposed were selected and sampled for micropaleontological studies. These are Zaraće and Podstine coves sections.

Taxonomic identification of foraminifera revealed that the flysch sediments at both sections contain an abundance of planktonic foraminifera, with P/B ratio being rather uniform across both sections, ranging from 0.83 to 0.93. Planktonic

foraminifera assemblage is very similar at both sections. It is dominated by small (*Globoturborotalita*) and large (*Subbotina*, *Dentoglobigerina*) representatives of fam. Globigerinidae. Members of smooth-walled *Turborotalia cerroazulenzis* lineage are also present and were used to correlate the samples to planktonic zonal schemes in the absence of index taxa. The samples collected at the Zaraće section correspond to planktonic foraminiferal zone E15, while Podstine section ranges across the E15 and E16 zones, placing both within the upper Eocene age of deposition. There is a notable abundance of small-size, 'opportunist' species belonging to genera *Tenuitella*, *Streptochilus* and *Pseudohastigerina.* The latter, largely represented by its species *Pseudohastigerina micra*, is consistently present throughout both sections. This research aims to determine whether any biometric changes can be detected in tests of *P. micra* specimens.

P. micra is considered to have been a surface dweller lacking algal symbionts, the latter being a common trait among small-sized species. It was common in low to high latitudes and tolerant of eutrophic environments. In samples from both studied sections *P. micra* was mostly limited to the 63-125 μm size fraction and in seven samples (five from Zaraće section and two from Podstine section) it was both sufficiently abundant and well-preserved to allow accurate biometric measuring of their tests. For each sample 50 *P. micra* tests from the 63-500 μm size fraction were randomly picked, observed under a stereoscopic microscope and photographed in side and aperture views. The measured parameters were the maximum test diameter, the dimensions of the ultimate chamber and the number of chambers in the final whorl. Aperture type of each specimen was identified to determine the frequency of bipartite aperture configuration among the specimens.

Across both sections, the average test size of *P. micra* ranges from 140.3 to 159.9 μm, placing the specimens in the lower size range for this species during the Eocene. The lowest average test size was recorded within the lower part of zone E15 in a sample taken at Zaraće section. This sample also stands out by having the largest abundance of small species as well as the record abundance of *P. micra* where it makes up for 11.3 % of the entire foraminiferal assemblage. The size and shape of the final chamber is highly varied even among specimens within individual samples, with no discernible rules or patterns to their variations. Lastly, the frequency of bipartite aperture is very low among the studied specimens, with only up to 4 % of tests exhibiting this aperture configuration in any given sample.

This research indicates that in subtropical to temperate latitudes during upper Eocene, *P. micra* could exhibit particularly small test sizes. This is notable, as the disappearance of large-sized *P. micra* specimens is in some cases used to distinguish the Eocene/Oligocene boundary when warm-water index taxa are absent. Further investigation is required to compare these measurements with specimens from other nearby Eocene and Oligocene sites.

First record of deep-sea benthic foraminiferal response to the Late Lutetian Thermal Maximum in the Tasman Sea (IODP Site U1508, Southwest Pacific)

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Transient global warming events, called hyperthermals, occasionally interrupted the gradual cooling trend of the middle Eocene. Like early Eocene warming events, they are characterised by increased pCO_2 levels, a paired negative excursion in carbon and oxygen stable isotopes (measured on bulk sediment and benthic foraminifera) and marine carbonate dissolution. Understanding how these events affected deep-sea ecosystems in the past is essential to unravel disruption of climate system dynamics during periods of increased pCO_2 levels. Here we analyse the effects of the Late Lutetian Thermal Maximum (LLTM, also known as the C19r event), in the Reinga Basin of the Tasman Sea (Southwest Pacific). The short duration of the LLTM, ~ 30 kyr in the Atlantic Ocean records, poses a challenge to identify this event in deep-sea sediments, and so far only three studies have dealt with its paleoecological consequences in the deep sea, all of them in the Atlantic Ocean.

This study is the first record of the deep-sea benthic foraminiferal response to the LLTM in the Tasman Sea. The magneto- and biostratigraphic shipboard age model was refined in order to locate the event in the International Ocean Discovery Program Hole U1508C. Assuming linear sedimentation rates between tie points, using GPTS2012, the age of 41.38 Ma for the studied event identifies it as the LLTM.

No evidence for carbonate dissolution was observed across the study interval. Quantitative analyses of benthic foraminifera show changes in the relative abundance of species across the LLTM, but no extinctions. The dominance of dysoxic taxa (such as *Lenticulina* sp. or *Uvigerina peregrina*) and species of the Superfamily Buliminacea (e.g. *Bulimina*

tuxpamensis and *Turrilina brevispira*) suggest oxygen deficiency associated with eutrophic conditions during the LLTM. This hypothesis is supported by the decrease in relative abundance of the oxic indicator *Globocassidulina subglobosa.*

Our preliminary results reveal enhanced export productivity in the Tasman Sea during the short-lived LLTM. This research, combined with on-going studies of paleotemperature estimates based on organic biomarkers, will contribute to evaluate how rapid hyperthermal events affect marine ecosystems.

Benthic foraminiferal response to the Middle Eocene Climate Optimum in the Tasman Sea (IODP Site U1511, Southwest Pacific)

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The gradual cooling trend of the Eocene was interrupted at ~40 Ma by a global warming event, the Middle Eocene Climatic Optimum (MECO). This long duration event (~500 ka) is marked by a negative $\delta^{18}O$ excursion associated with a 3–6 °C global warming, an increase in atmospheric pCO_2, and shallowing of the carbonate compensation depth (CCD). Furthermore, using mineralogical and chemical analyses, significant changes in atmospheric and oceanic circulation dynamics are identified during the event.

Although the MECO is sometimes referred to as a hyperthermal event, it is an enigmatic case due to its differences with other Eocene hyperthermals, which normally display a rapid onset followed by a gradual return to roughly pre-event temperatures. In contrast, the onset of the MECO was gradual and it was followed by a rapid return to pre-event conditions. In addition, the onset of the MECO does not coincide with a global negative carbon isotope excursion in marine carbonates, and carbonate dissolution in the deep sea was greater than expected, raising questions about the carbon cycle dynamics during this warming event. Despite being key to unravel the relative role of changes in carbon flux vs. warming on the ocean floor, there are only a few studies focused on the MECO effects.

The MECO was recovered at Site U1511 during International Ocean Discovery Program Expedition 371 in the Tasman Sea. The site lies in the Tasman abyssal plain (at 4,858 m water depth), and Eocene sediments were deposited below the CCD. Calcareous microfossils are absent, but agglutinated benthic foraminifera are well preserved and the study of their assemblages allows us to investigate for the first time the assemblage turnover and paleoenvironmental changes across the MECO at abyssal depths.

Diversity of the assemblages is low throughout the study interval (<20 species identified), and the opportunist species *Spiroplectammina spectabilis* peaked during the MECO. This species is interpreted as indicative of an elevated organic flux to the seafloor and/or high siliciclastic flux. The proliferation of this opportunistic species indicates environmental instability at the seafloor during the MECO. The combination of our results with published litho- and magnetostratigraphic studies and multi-elemental XRF data analyses will contribute to understand the effects of the MECO at abyssal depths. Furthermore, the comparison of our results with those observed across other events characterized by high temperatures and elevated pCO_2 levels will help understand how global changes affect the deep ocean and ecosystems.

Response of foraminifera to anthropic changes in tidal channels from a tropical lagoonal system: Maricá-Guarapina Lagoonal System, Brazil

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Coastal lagoons show a high vulnerability to the effects of climate change and most of them are under accelerated process of environmental degradation promoted by several human activities. In order to mitigate these impacts, public agencies have implemented the dredging and opening of channels to increase the circulation of marine waters in the environment aiming to improve the system health. In southeastern Brazil, the Maricá-Guarapina Lagoonal System (MGLS) constituted by four interconnected lagoons (Maricá, Barra, Padre, and Guarapina) provides essential ecosystem services but it's under accelerated process of pollution and silting. Benthic foraminifera have shown great potential for biomonitoring

studies due to their high biodiversity, preservation in the substrate, and quick response to changes in the environment that can reflect at both the population and community level. In this context, this study investigated the effects of opening and dredging of artificial channels on the environmental quality in SLMG using the relationship between foraminifera and environmental parameters before and after innervations.

The sampling was carried out in March 2013 (before dredging) and in July 2019 (after dredging) along the 29 stations. The physical-chemical parameters were measured in the sediment-water layer with a portable probe. For foraminifera analyses, the 50 ml of sediment was collected in three different grab throws from the first (1 cm) of sediment, which was subjected to a rose Bengal solution for living organism identification. Detrended Correspondence Analyses (DCA) were applied for correlating the species with the abiotic parameters and cluster analysis (CA) was used with the objective of identifying the similarity between stations and assemblages in both sampling periods.

The data indicated a significant increase in marine influence on the system between 2013 and 2019 due to the opening the Barra Channel and the dredging of Itaipuaçu Channel. In addition, the year 2019 recorded lower values of rainfall. Between the periods there was an increase in the silt-clay indicating a decrease in the fluvial flow to the system. The average richness/station increased from 4 in 2013 to 6 in 2019 as a result of greater efficiency in renewing water by the channels. *Ammonia tepida*, *Ammonia parkinsoniana*, *Elphidium excavatum* and *Quinqueloculina seminulum* were the most constant species in 2013. In 2019, the dominance was similar except for the reduction of *Q. seminulum* representativeness and by the increase in the agglutinated species especially *Ammotium morenoi* and *Ammotium cassis*. DCA analysis showed more influence of water parameters in the distribution of species in 2013 while in 2019 were clay and salinity. The CA identified 6 different groups: Group I was composed predominantly of *A. dilatatus* and *A. morenoi* indicated areas with high values of clay in 2019; Group II was composed mainly of *E. excavatum* which was correlated to higher salinity values. This group was very restricted in 2013 and had a wider dispersion in 2019 in the lagoons; Group III was characterized by *A. parkinsonian*a, limited to a few stations around the river's mouth and channels; Group IV was an isolated station in Ponta Negra Channel in 2013 with the occurrence of *Warrenita palustris* and *Textularia earlandi*; Group V represented by *Paratrochammina guaratibaensis* was the area with higher salinity values and more hydrodynamic energy. This group expanded to the innermost regions in 2019 demonstrating increased circulation in MGLS; Group VI was represented by stations located in regions with greater environmental stress with a higher abundance of *A. tepida*. In 2013 this group was distributed in all innermost lagoons and in 2019 it occurred in two isolation points. The foraminifera proved to be an effective proxy to identify quickly changes in the ecosystem and should be included as an essential analysis in environmental monitoring programs in coastal lagoons.

Barium incorporation of benthic foraminifera – high resolution proxy calibration from the natural laboratory of the Northern Aegean Sea

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The barium cycle of the ocean is thought to be coupled to the marine carbon cycle; therefore, allowing the reconstruction of export productivity through the assessment of the Ba content in the geological record. In the upper water column of marginal marine settings, riverine input provides a source of Ba for the uptake in organic matter and the subsequent downward flux of particulate Ba, in addition to upwelled Ba. Thus, not only export productivity, but also riverine input can potentially be reconstructed from Ba in the (shallow) benthic realm. In this context, we want to address the specific question how the barium/calcium signal of a benthic foraminiferal test (Ba/Ca_{foram}) is formed. Benthic foraminifera colonize the sediment surface and precipitate their shell with an elemental and isotopic composition (e.g., $\delta^{13}C$) reflecting the surrounding bottom and pore water composition. We analysed, at high vertical resolution, the Ba/Ca ratios of live and dead specimens of *Uvigerina mediterranea* and *Melonis affinis* of seven core tops from several basins (water depths of 600-1500 m) within the Northern Aegean Sea (NAS). The transect spanning the different basins of the NAS shows a south to north gradient of increasing surface productivity and riverine input, setting the frame for the proxy calibration approach. In the Sporades Basin, the water column shows a vertically increasing gradient of dissolved Ba, which allows for the comparison to models

and data of the Ba cycle from other regions with similar trends. Our strategy is to investigate external (sediment geochemistry, early diagenesis) and internal (ecology, biomineralization) aspects leading to the formation of Ba/Ca_{foram} in the complex present day situation of the NAS. We intend to refine and strengthen calibrations needed for the application of this proxy in the sedimentary record to reconstruct paleoenvironmental changes, and specifically export productivity, in this region. Novel high resolution Laser Ablation ICP-MS results show that besides biological factors (vital effects assessed from chamber-to-chamber variability), combined ecological-geochemical factors (the specific microhabitat depth of different foraminiferal species in relation to pore water redox zones assessed from inter-species comparison) can significantly influence the Ba/Ca_{foram} signal. This calls for species-specific calibrations, for which we show an example, and downcore applications.

Planktonic foraminifera and paleoceanographic changes across the middle Cenomanian carbon-isotope excursion (MCE 1) in south-east England, UK

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Planktonic foraminifera were studied across the Mid-Cenomanian Event 1 (MCE 1, identified by a positive $\delta^{13}C$ excursion) at Lydden Spout, near Folkestone (Kent, south-east England, UK), the reference section of the middle Cenomanian Event 1 (MCE 1) characterized by a prominent double-peak $\delta^{13}C$ excursion of 1‰ identified in different ocean basins and considered a global event. Biostratigraphic and quantitative analysis of planktonic foraminifera are correlated to the carbon cycle perturbation that identifies the MCE 1, to the positive $\delta^{18}O$ shifts identified within the MCE 1, and to the occurrence of Boreal macrofossils (*Chlamys arlesiensis*, *Oxytoma seminudum*, and *Praectinocamax primus*).

Planktonic foraminifera show moderate preservation, are common throughout the section and comprise 40-50% of total foraminiferal abundance, although the population is mainly composed by small-sized specimens (< 250 mm). Large-sized specimens become more common and show a continuous occurrence up-section after the termination of MCE 1. The stratigraphic interval studied is assigned to the *Thalmanninella greenhornensis* and *Rotalipora cushmani* Zones. Variations in abundance and species richness of the planktonic foraminifera are correlated with the inferred palaeoecological preferences of taxa and permit the identification of distinct palaeoenvironmental settings across the MCE 1.

The stratigraphic interval corresponding to the MCE 1 is characterized by the absence of single keeled oligotrophic rotaliporids, by the evolutionary appearance of double keeled meso-eutrophic dicarinellids, and by the appearance of *Muricohedbergella portsdownensis*, a species interpreted as a cold-water taxon that first appears at the same level of Boreal macrofossils, and a positive $\delta^{18}O$ excursion of bulk carbonate within the lower part of MCE 1. These observations point to a palaeoceanographic scenario characterized by reduced stratification of surface waters and absence/disruption of the thermocline in a dominantly eutrophic regime during MCE 1.

Evidence provided by planktonic foraminifera, Boreal macrofossils and oxygen isotope records documented for the late Cenomanian Plenus Cold Event (PCE) at Eastbourne (UK) reveal similarities that confirm the periodic inflow of cold Boreal seawater originating in the Norwegian Sea as previously postulated to explain the occurrence of Boreal fauna in the Anglo-Paris Basin. The southerly extension of this water mass may be related to the re-organization of circulation driven by the long eccentricity cycle.

Turonian - Santonian paleoceanographic changes registered by planktonic foraminifera and stable isotopes at southern high latitudes

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The Turonian to Santonian sedimentary record recovered at IODP Expedition 369 Site U1513 in the Mentelle Basin (eastern flank of the Naturaliste Plateau, SE Indian Ocean, paleolatitude 60°S at 85 Ma) is studied to interpret the

paleoceanographic 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 U1513 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 paleotemperatures 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 paleotemperature 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.

The Middle Miocene benthic foraminiferal assemblages from Krndija Mt. (Našice quarry, Croatia)

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On the northern slopes of the Krndija Mt., near the Našice town, there is a large active quarry where the Middle and the Upper Miocene deposits are intensively excavated for cement production. During the Middle Miocene, this area of the North Croatian Basin was located on the southwestern margin of the Central Paratethys Sea and was part of the Pannonian Basin System. In the southern part of the quarry, the 100 m thick BG section consists of four lithofacies: algal limestones, bioclastic limestones, marls and pyroclastics. Due to the exploitation in the quarry, the new upper floors were opened, and the BGM5 section cropped out. In 58 m thick section, marls alternate with tuffs and bioclastic limestones, with rare interlayers of clay. The marls are laminated and form beds ranging in thickness from a few cm up to 7 m. Alternation of dark beds with great amount of organic matter and light beds rich in carbonates can be observed at BGM5 section. Marl samples were processed by the standard wet sieving method, and micropaleontological analysis was made on standardized samples (of about 300 foraminiferal specimens). The analysis included study of taphonomic conditions of foraminiferal tests, quantification of planktonic vs benthic foraminifera (P/B ratio) and detailed analysis of small benthic foraminiferal assemblages.

Study of benthic foraminifera revealed continuity of sedimentation from the Badenian to the Sarmatian at BG section. The Late Badenian age of middle part of the section has been proven with index species *Pappina neudorfensis* (TOULA), *Uvigerina brunnensis* KARRER and *Bulimina insignis* LUCZKOWSKA that are characteristic for the *Bulimina-Bolivina* zone. This part of section shows middle to outer shelf depositional settings with *Valvulineria-Bolivina* and *Cassidulina-Bolivina* assemblages The P/B ratio range is 41-81%, BFOI values vary between medium and low oxic conditions and benthic foraminifera assemblages reflect changes in nutrient input that triggers the fluctuation of oxygen content at the sea bottom. The upper part of succession, points to a shallowing upwards trend and sea-level fall at the end of the Late Badenian.

According to benthic foraminiferal assemblages the marls from top of the BG section and lower part of BGM5 section are attributed to the *Anomalinoides dividens* zone/ecozone of the Lower Sarmatian. The age determination is based on the findings of the species *Anomalinoides dividens* (LUCZKOWSKA), *Elphidium hauerinum* (d`ORBIGNY) and *Bolivina sarmatica* (DIDKOVSKY). The low values of P/B ratio (5-12%) indicate a shallow-water, inner shelf depositional setting, whereas greater values of the ratio (up to 49 %), found in some parts of the BGM5 section, suggest deepening of the Sarmatian paleoenvironment. *Elphidium* assemblage, typical for light marls, is dominated by epifaunal forms and herbivores. That benthic foraminiferal assemblage inhabited a normal marine highly oxic environment with lush vegetation on the sea floor. *Bolivina* assemblage is characteristic of dark marly beds and indicates a change in environmental conditions. Infaunal forms and detritivores dominate this assemblage being adapted to an environment with a lower oxygen content at the seafloor (moderate to low condition). Such alternation of benthic foraminiferal assemblages may indicate local sea level oscillations and/or changes in terrigenous input caused by different rate of weathering.

Trimorphism in *Orbitolites complanata* Lamarck, 1801 from the Lutetian of the Paris Basin (France)

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Despite being one of the earliest described Eocene larger foraminifera, *Orbitolites* is a little investigated genus. Herein, we provide new evidence from three classical outcrops of the Paris Basin (Grignon, Chaussy and Villiers) where the preservation of matrix-free specimens is exceptional. First, a comment is needed on why we do not refer to this species as *O. complanatus*, as in current practice. In 1801, Lamarck unambiguously considered as feminine the gender of the genus of *Orbitolites*, describing both *O. complanata* and *O. concava*. Thus, *Orbitolites complanata* is not a typographical error, it is the correct form according to the current Code of Zoological Nomenclature (Art. 30.1.4.4). For over two decades, this is a serious avoidance issue in foraminiferal nomenclature: a feminine gender is correct for about 12% of the foraminiferal genus-group names ending in *-ites,* and about 18% of those ending in *-oides*.

In our material, we did not find any microspheric (B) forms. In contrast, the large number of sectioned megalospheric (A) forms from the three localities shows two groups of embryos, small-sized (mostly < 200 μm) and large-sized (> 300 μm). Normality tests confirm two A generations. Among the large-sized forms, both dumbbell-shaped and subspherical protoconchs occur, followed by an annular deuteroconch and auxiliary camberlets. Our data indicate unambiguously that in *O. complanata* from the Paris Basin two megalospheric generations are present. This trimorphism is interpreted as a simplesiomorphy of the Soritidae.

Insights into the benthic foraminiferal response to precessional forcing and environmental changes across the Messinian Salinity Crisis onset in the Sorbas Basin (SE Spain)

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The Messinian Salinity Crisis (MSC) is a geological event that occurred at the end of the Miocene epoch, resulting in the deposition of large volumes of evaporite sediments after 5.97 Ma in the Mediterranean region. Before the onset of the MSC, long-term tectonic processes and orbital variations triggered the step-wise restriction, finally resulting in extreme paleoenvironmental conditions with periodic changes in the marine realm.

The Perales section in the Sorbas Basin (SE Spain), provides an astronomically tuned sedimentary record that precisely documents these changes up to the onset of the MSC. This record displays alternating layers of sapropels, deposited during insolation maxima, and (brown) marls deposited during insolation minima, sometimes intercalated by diatom rich deposits. The uppermost 23 lithological cycles prior to the MSC onset (6.22 – 5.97 Ma) were investigated.

We conducted a detailed quantitative analysis of the benthic foraminifera (BF) combined with morphometric measurements of *Bolivina* specimens. Quantitative data were used to calculate the BF Oxygen Index (EBFOI), which estimates the dissolved bottom water oxygen content. These proxies were compared to previously published calcareous nannofossils and planktic foraminifer data to study the paleoenvironmental evolution at the sea floor and the planktic-benthic coupling.

High export productivity is linked to organic matter preservation and abundance of the *Rectuvigerina* spp. gr. during insolation minima in the lowermost cycles. The same mechanism is thought to trigger the deposition of sapropels, which is then maintained by water column stratification. The *Rectuvigerina* gr. becomes very rare after 6.145 Ma following a long-term decline, and finally disappears at 6.033 Ma, which reflects a significant reduction in oxygen content (EBFOI). Following the *Rectuvigerina* disappearance, buliminds and bolvinids alternate within the cycles. The latter taxa show statistically significant cyclical size variations in phase with oxygen changes, which should reflect also NO_3^- and food availability in the infaunal niches, all related to export productivity and water column stratification.

The MSC onset is preceded by a prolonged organic matter accumulation and sea-floor oxygen depletion, in an anomalous sedimentary cycle deposited during a phase of low eccentricity and reduced oscillation of the insolation index. The deposition of this anomalous cycle is triggered by a strong restriction of the Sorbas Basin, which received a large amount of nutrients from terrestrial runoff strongly impact the marine biota.

Shared ancestry of algal symbiosis and chloroplast sequestration in foraminifera

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The mixotrophic benthic foraminifera have repeatedly established symbioses with various groups of algae and can engage in the sequestration of chloroplasts, known as kleptoplasty. So far, kleptoplasty has been documented exclusively in rotaliid foraminifera. Here, we report the discovery of kleptoplasty in the species *Hauerina diversa*, which belongs to miliolid foraminifera. The discovery of kleptoplasty in the two main clades of foraminifera suggests that this phenomenon is more widespread than previously documented. We observed intact chloroplasts in clustered structures within the foraminiferal cytoplasm and estimated the phototrophic activity using an isotopically labeled carbon source that confirmed the photosynthetic activity of the 'stolen' chloroplasts inside the host cell. Phylogenetic analysis of 18S rRNA gene sequences showed that *H. diversa* branches as sister to symbiont bearing Alveolinidae. This is the first time a close relationship between kleptoplastic and symbiotic species has been documented. Analysis of ribosomal SSU rDNA and metagenomics revealed that alveolinid symbionts and kleptoplasts both belong to the same clade within Coscinodiscophycea, a group of centric diatoms. This evolutionary linkage suggests a common ancestry of kleptoplasts and algal symbionts in foraminifera.

Identification of environmentally relevant benthic foraminifera from the Skagerrak fjords by deep learning image modelling

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Over the several past decades there has been increasing interest in using foraminifera as environmental indicators for coastal marine environments. As compared to macrofauna, which are currently used in environmental studies, foraminifera offer several distinct advantages as bioindicators, including short generation times, high number of individuals per small sample volume, hard and durable tests with high preservation potential, and low cost of sample extraction. One of the main problems with foraminifera identification is reliance on manual identification and expert judgement, which is a tedious and slow process prone to errors and subjectivity. Deep learning, a subfield of machine learning, has emerged as a promising solution to this challenge, since a neural network can learn to recognize subtle differences in shell morphology that may be difficult for the human eye to distinguish. Benthic foraminifera mounted on microslides from several Skagerrak fjords including Gullmar Fjord, Hakefjord and Idefjord were imaged using a Nikon SMZ-10 stereomicroscope and DeltaPix DP450 microscope camera. Images were then processed in Roboflow API, where individual foraminifera were labelled and classified. This resulted in 3003 images and 22,138 labelled individuals. Using the labeled images, a dataset was created to be used for deep learning training. We used the YOLO (You Only Look Once) v7 model implemented in the PyTorch framework, which has demonstrated state-of-the-art speed and performance for object detection as of the time of writing. Models were trained using a Nvidia RTX A4000 GPU (graphical processing unit). Preliminary results show a 90,3% mAP (mean average precision) and 78,8% mAP on the best and the worst performing models, respectively. Even though the imaging and labelling was done in a short amount of time, the results look promising and show that even a relatively small dataset can be used for training a reliable deep learning species identification model.

Assessing the impact of diagenetic bias on sea-level reconstructions spanning the last full glacial cycle based on deep-sea benthic foraminiferal stable isotope records

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One of the emerging debates regarding past sea-level variability and its relevance to future change involves discrepancies between reconstructions based on deep-sea proxies and those based on modeling simulations and geologic data from land-based deposits during the last full glacial cycle (i.e., Marine Isotope Stage [MIS] 6-1, ~150-11 ka). For example, sea-level estimates derived from deep-sea benthic foraminiferal stable isotope records indicate a range of sea level between approximately 60 m and 90 m below present during MIS 3. In contrast, glacio-isostatic modeling and ice sheet reconstructions based on land-based geochronology range from ~30 m to 50 m below present. Similar offsets between proxy-based reconstructions and models exist throughout the record, with specific interest in MIS 5a, 5c, and 5e. We focus on the extent to which diagenetic alteration may have biased deep-sea benthic foraminiferal stable isotope records. Specifically, we generated new single-test stable isotope records on specimens of the genus *Cibicidoides* from Ocean Drilling Program Sites 846 (deep equatorial Pacific) and 929 (deep equatorial North Atlantic) spanning the last full interglacial cycle. We measured the stable oxygen and carbon isotope ratios of ideally-preserved specimens (i.e., glassy), in addition to those being moderately- (i.e., pseudo-glassy) and poorly-preserved (i.e., frosty) to determine the extent to which inclusion of diagenetically altered specimens in pooled-test records may affect sea-level estimates. Using the results from only ideally-preserved specimens, as well as paired LA-ICPMS Mg/Ca measurements, we apply an ocean basin water mass mass-balance to calculate new sea-level estimates and compare them to land-based records.

Spreading of an alien benthic foraminifer in the North Sea: a reason to be worried?

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In the Skagerrak-Kattegat (eastern North Sea), the alien benthic foraminifer *Nonionella* sp. T1 (previously referred to as "*Nonionella stella*") was reported for the first time in 2011 and 2012 in the Swedish and southern Norwegian fjords, respectively. Based on dated sediment cores its first occurrence can be traced back to the 1980s in the Gullmar Fjord, to the 2000s in the Öresund and to 2010 in the Oslofjord. Since then, *Nonionella* sp T1 has spread all over the Kattegat and coastal Skagerrak, according to sampling campaigns performed between 2016 and 2022.

The species is now highly abundant in the entire Kattegat, including the Öresund, as well as in fjord mouths of the seasonally hypoxic Gullmar Fjord, the oxic Hakefjord and the long-term polluted Idefjord as demonstrated by molecular and morphospecies data. At the same time, *Nonionella* sp T1 is rare to absent in the Baltic Sea, Skagerrak deep basin and in deep fjords of western and northern Norway. This study shows some preliminary results on the species' present distribution in the study area and raises questions about the driving factors and potential effects on the local biodiversity.

Distribution of the putative invasive species *Nonionella* sp. T1 in the Gullmar Fjord – What is its potential contribution to biogeochemical cycles?

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Benthic foraminifera, both fossil and living, have been extensively studied in the seasonally hypoxic Gullmar Fjord (Sweden) for decades to decipher hydrographic changes and ecological status. In 2011, a non-indigenous species named *Nonionella* sp. T1 was discovered in the fjord for the first time. Here, we aim at evaluating its putative invasive behavior and life strategies by combining assemblage analyses of living foraminifera along a fjord transect of surface sediment (0-3 cm) together with four longer sediment cores (0-5 cm) from two stations at 51 m and 117 m water depth.

Our results showed that *Nonionella* sp. T1 collected in the surface sediment in September 2021 and 2022, was present in almost all the transect samples. This species dominated the living foraminiferal assemblages with an abundance between 15 and 72 %, at seven of the eight sites visited. The highest relative and absolute abundances were noted between 39 and 78 m water depth, proximal to the fjord mouth, with a reduced presence towards the deepest station and the fjord head. However, *Nonionella* sp. T1 was completely absent in the sandy sediments at the shallowest station (1 m water depth).

Sediment cores collected in November 2017 and May 2022 revealed that *Nonionella* sp. T1 exhibited higher abundance at 51 m water depth compared to 117 m. In a previous study, higher densities were observed at the station 51 m below the oxygenated sediment zone (< 2 mm depth), where high nitrate concentrations in pore waters were measured (2017 data). The authors demonstrated that *Nonionella* sp. T1 respires nitrate and the pool of specimens denitrifies up to 50 % – 100 % of the nitrate in sediment porewaters, revealing its non-negligible contribution to benthic denitrification. The 10-fold higher abundance of *Nonionella* sp. T1 recorded in 2022 (compared to 2017) supports previous hypotheses about their invasive character and alerts about their important role in the nitrogen cycle of the Gullmar Fjord. The results of this study highlight the need for continued monitoring of this invasive species, its spreading dynamics and ecological/biogeochemical impacts.

Exploring the Larger Benthic Foraminifera Diversity and Deformities in the Hypersaline Arabian Gulf: An Update on the Ecological Aspects

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In the 1960s and 1970s, Professor John Murray conducted several studies on foraminifera in the hypersaline coastal and shallow marine environment of the Arabian Gulf. Murray focused mainly on the United Arab Emirates region, examining the variety of benthic foraminifera in the area and laying the foundation for the ecological studies of benthic foraminifera in hypersaline environments in and outside the Gulf. Murray's six major publications revealed that the foraminiferal families Soritidae, Peneroplidae, and Nummulitidae were the main constituents of Larger Benthic Foraminifera (LBF) assemblage in the area, with the genus *Peneroplis* being the most prominent.

Since Murray's work, the Arabian Gulf has seen an increase in the discovery of new LBF families. Our study aims to update his findings by visiting several interrelated studies after Murray's studies and supported further by conducting field sampling in Saudi Arabia and Bahrain, with a focus on areas with different salinity levels. We also considered the abnormal morphologies frequently found in the Gulf. Our literature survey of 34 published and unpublished study about LBF (excluding Murray's papers) in the entire Arabian Gulf reveals several key findings. The first findings are two additional families, Alveolinidae and Amphisteginidae, bringing the total number of LBF families to five compared with earlier reports. Secondly, the Peneroplidae, particularly the species *P. pertusus* and *P. planatus*, was found to be the most prevalent and widespread in the Arabian Gulf, followed by one member of genus *Coscinospira* (*C. hemprichii)*. The third aspect of our reveals that only 7 out of 34 publication report deformities among LBF. In addition to fill the gap of some unexplored area, our field samples data of LBF from three localities (East Bahrain, Half Moon Bay, and Al-Uqayr) reveal that more than 40% of specimens are deformed, and moreover the proportion of deformities increases at higher salinity sites. In general, the adult or more developed younger stage displays more deformities than the juvenile or undeveloped later stage specimens (but these still exhibit deformities). We also discover that, according to the different salinity data, the number of genus *Peneroplis*

is larger at higher salinities (over 50 PSU) in a 5:1 ratio than the number of genus *Coscinospira*, while the ratio for salinities between 40 and 50 PSU is equal to or higher.

These findings and our new discoveries have raised intriguing questions for future studies in the Gulf: how diverse the LBF are; what is the cause of morphological deformities in a hypersaline environment; and the resilience of foraminifera within the system, despite its initial characterization as being less diverse.

Can benthic foraminiferal morphological deformities be considered lethal in a natural hypersaline environment? Case studies at several localities of the western Arabian Gulf

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The occurrence of morphological deformities in benthic foraminifera is a well-known phenomenon across the world. Deformities can be caused by anthropogenic factors (i.e., heavy metals and nutrients), natural ecological factors (such as salinity, pH, and oxygen levels), and mechanical factors. While in general, their deformities for some species are not linked to the actual death of the organism based on culture experiments and field findings; only deformities attributed to decreasing pH as well as salinity, and heavy metals pollution are considered as main culprit. Only a small number of studies outline the impact of a high salinity environment, especially in a natural hypersaline environment such as the Arabian Gulf.

To address that point, we conducted our morphological abnormalities in foraminifera study in the western side of the Arabian Gulf, consisting of six representative localities with varying salinity. A standard procedure was used to identify living and dead specimens, including Rose Bengal staining, unbiased splitting, and dry sampling with approximately 300 specimens. We used several techniques to confirm the physio-chemical proxies from sea water and bottom sediments, both in the field (on-site parameter measurements) and in the laboratory. Substrate (sediments) underwent geochemical analysis for identifying heavy metals and total organic carbon (TOC) constituents, along with field physio-chemical data acquisition for the water such as salinity, temperature, and pH of the water. Our physio-chemical data results show the abnormal constraints within our study area mostly concerned from the above normal sea water salinity (hypersaline/>40 PSU), while the other parameters such as heavy metals and TOC are below the hazardous limit or even below detection limit. Analysis of the foraminifera assemblages results reveal that larger benthic foraminifera (LBF) such as the genera *Peneroplis*, *Monalysidium* and *Coscinospira* have a very large proportion of morphological deformities (above 50% from the entire assemblages for each locality) and predominantly consist of dead specimens, while smaller benthic foraminifera (SBF) such as *Quinqueloculina*, *Elphidium* and *Ammonia* have fewer deformities, and some were pink-stained, and therefore alive at the time of collection.

Our initial findings suggest that foraminiferal assemblages that exhibit morphological deformities with different lethal effects are potentially triggered by elevated salinity. Our current conclusions can be employed as a future baseline for other localities that may be confronted by rising salinity in the future, even though more supportive investigations, such as culture-based experiments, are required to support the field observations.

Development of the Late Karpatian to Early Badenian benthic foraminifera assemblages in the Sava Sub-basin (Croatia), SW Central Paratethys

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The Miocene sediments of the North Croatian Basin belong to the south-western margin of the Central Paratethys. In this study, we described the benthic foraminiferal assemblages that inhabited the new marine environments in the Sava sub-basin during the Late Karpatian and Early Badenian in two localities: 1) Čučerje (Plaz) locality on the NW margin of the Sava sub-basin, and 125 km away 2) Tisovac locality, situated on the SE margin, respectively. The age of the marine sediments was determined according to the calcareous nannoplankton, which belongs to NN4 and NN5 Zones; i.e. regional MNN4c and MNN5a Zones.

During the Late Karpatian, in the Čučerje, marls were generally deposited on a mid-outer shelf, in a sedimentary basin that had a restricted connection with the Mediterranean during the Mi2 climatic event. The benthic foraminiferal assemblage is characterized by low biodiversity and the dominance of *Bulimina subulata* and *Cibicidoides pseudoungerianus*, while the species *Favulina hexagona*, *Pappina primiformis*, *Melonis pompilioides*, *Spiroloculona canaliculate* and *Bolivina hebes* are represented with a smaller number of specimens. The Early Badenian assemblage of moderate diversity is characterized by the first appearance of the warm-water taxa *Glabratella* sp. and *Pararotalia* sp., and higher percentage of planktonic foraminifera (up to 50%), indicating a warmer climate and open connection with the Mediterranean Sea. With the progress of transgression and the creation of the new environments, the community becomes richer both in the number of species and the number of individuals. Dominant species are *Uvigerina macrocarinata* and *Spirorutilus carinatus*, while *Schlumbergerina*, *Heterolepa, Cibicidoides,* and *Siphonina* occur frequently. The species such as *Lobatula lobatula*, *Quinqueloculina mammila*, *Elphidium rugosum*, and *Pararotalia aculeata* are present in smaller numbers. The upper part of the Lower Badenian, consisting of silty and sandy sediments, present a shallowing-upwards cycle. In these sediments, the predominantly infaunal benthic assemblage has been replaced by a shallow, warm-water community with *Elphidium* spp, *Ammonia viennensis*, *Porosononion granosum*, *Pararotalia aculeata,* and *Amphistegina mammila*.

In the southeastern part of the Sava sub-basin, in the Tisovac locality, the beginning of the marine transgression in the Late Karpatian is marked by a small and poor community with only a few specimens of *Bulimina subulata*, *Bolivina* sp., and *Nonion* sp. Already in the next sample, this community increases and is characterized by the dominance of the species *C. pseudoungerianus* and *Ammonia viennensis*, and by the presence of the genera: *Cibicidoides*, *Lenticulina*, *Heterolepa*, *Sigmoilinita*, *Valvulineria* and *Guttulina*. With the maximum marine transgression in the Lower Badenian, the community reaches an abundance of about 32 species. The most important genera are *Schlumbergerina*, *Lobatula*, *Cibicidoides*, *Elphidium*, *Neocorbina,* and *Heterolepa*. In the upper part of the Lower Badenian, *Schlumbergerina*, *Cibicidoides, Bulimina,* and *Sigmoilinita* are still frequent, but the share of agglutinated species such as *Haplophragmoides*, *Cyclammina* and *Textularia*, significantly increase, making up to 20% of the community.

During the Late Karpatian and Early Badenian infaunal benthic foraminifera, together with *Cibicidoides* spp. were pioneers in the settlement of the new marine environments on the southwestern margin of the Central Paratethys.

Using electron backscatter diffraction to investigate shell microstructure and preservation impacts on planktonic foraminiferal calcite

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A growing body of research is focussed on understanding the mechanistic processes of biomineralisation, and many of the processes involved in biomineralisation are currently poorly constrained. In this work we present novel data visualizing the internal microstructure and preservation quality of planktonic foraminiferal calcite, using electron backscatter diffraction analysis (EBSD). EBSD is an SEM-based microscopy technique that enables microstructural crystallographic characterization at high resolution, where intra-test crystal structure can be visualized and geometrically quantified. Here we present microstructural EBSD data, paired with chemical electron microprobe analysis (Mg/Ca) for both well preserved and diagenetically altered specimens of the Neogene species *Globigerinoides ruber* (cancellate wall texture) and the Paleogene species *Morozovella crater* (muricate wall texture). Well preserved specimens are assumed to be representative of the original calcite microstructure for each species and accordingly shed light on biomineralisation processes. EBSD crystal maps and associated pole plots show the shell is composed of mesocrystals (0.4 - 110 μm^2), and the preferred crystallographic orientation of calcite growth is shown to be perpendicular to the growth surface. By contrast specimens that have been diagenetically altered have strikingly different EBSD maps and whilst preferred crystal orientation is preserved, much of the original biogenic calcite structure is lost via replacement with inorganic crystal precipitation. We link our EBSD observations to quantitative electron microprobe analysis Mg/Ca distribution datasets, and find that the Mg/Ca banding that is typical of primary biogenic calcite is intact in our well preserved specimens, but is largely absent in our poorly preserved specimens. Our results shed light on the biomineralisation processes of two species with distinct wall textures, but also highlight the extent to which microstructural reorganization due to diagenesis can impact geochemical signals.

Menthol-induced bleaching of *Amphistegina lobifera* and investigation on diatom photosymbiont flexibility

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Large benthic foraminifera (LBF) are unicellular eukaryotes that occur in oligotrophic (sub-)tropical shallow-water environments, such as coral reefs. Because LBF host endosymbiotic algae that are sensitive to temperature and other environmental changes, as corals, they are vulnerable to bleaching (loss of photosymbiotic algae and pigments associated). However, the uptake of new symbiont strains after bleaching events and the symbiont flexibility of LBF remains widely unresolved. To better understand bleaching and symbiont flexibility, the bleaching agent menthol combined with the photosynthetic inhibitor DCMU has been used on several coral reef organisms hosting dinoflagellates. More recently, menthol-induced bleaching has been tested for the first time on the diatom-bearing LBF *Amphistegina lobifera* and the dinoflagellate-bearing *Sorites orbiculus*. Bleaching was achieved in ~97% of organisms over a six-week experiment, which showed that menthol bleaching is an effective method to rear foraminifera aposymbiotic. However, re-inoculating new symbiont strains on LBF after menthol-bleaching treatment has not yet been tested.

This project, therefore, aims to investigate whether there is a significant difference in the rate and effectiveness of bleaching between two size classes *of A. lobifera* (0.5-1 mm and 1-2 mm) collected from the Red Sea, Israel, to assess if choosing smaller species for aposymbiosis investigations has an advantage on bleaching success and survivorship. Furthermore, the aim is to assess the capacity of aposymbiotic LBF to take up diatom strains and re-establish symbiosis. Bleaching and re-inoculation will be measured through the reduction of symbionts and uptake of new strains in menthol-bleached hosts using symbiont density analysis of images taken via confocal laser-scanning microscopy (CLSM) weekly. Furthermore, Pulse-Amplitude Modulated (PAM) fluorometry measurements will be used to assess photosynthetic efficiency during menthol-bleaching and after the uptake of newly re-inoculated symbiont strains to confirm the re-establishment of symbiosis.

The results showed a ~85-93% reduction of diatom density compared to initial levels in *A. lobifera* in the 1-2 mm size class and ~73-92% bleaching in the 0.5-1 mm size class. The results showed that bleaching is successful, with slightly higher success rates in the larger specimens, and that most likely a six-week phase would allow rearing the LBF fully aposymbiotic.

For the following re-inoculation experiment, the aposymbiotic foraminifera will be incubated with diatoms that have previously been found to be hosted in *A. lobifera* from the northern Red Sea, such as *Minutocellus* spp., *Nitzschia* spp., and *Fragilaria* spp. To our knowledge, this is the first study to experimentally determine symbiont flexibility in LBF using the menthol-beaching approach. The findings of our study will have implications for understanding the ecological role of thermally tolerant symbionts and their preferential incorporation in the host within coral reef ecosystems. Successful re-inoculation can provide a first understanding of symbiont flexibility as an adaptive trait of LBF.

Benthic Foraminifera of the Albian-Cenomanian (Cretaceous) Washita Group in North-Central Texas, USA

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The upper Albian-lower Cenomanian (mid-Cretaceous) Washita Group of North-Central Texas consists of nine formations (in ascending order): Kiamichi, Duck Creek, Fort Worth, Denton, Weno, Paw Paw, Main Street, Grayson, and Buda formations. Apart from the Kiamichi Formation, which is a shaley claystone, the Washita Group comprises alternating marl and limestone beds deposited in the shallow, epeiric seaway that flooded the region during the late Albian and early Cenomanian. The diverse and well-preserved benthic foraminiferal assemblages of the Washita Group of North-Central Texas were well documented throughout the early to mid-twentieth century by several foraminiferal workers, including H. Tappan, A. Loeblich, and F. Lozo, among others. Nearly two hundred species of mid-Cretaceous benthic foraminifers were identified from the area within two decades. However, few recent studies have sought to review these species since their initial descriptions for instances of synonymy or misidentification, or to investigate the full stratigraphic range of species beyond the formation from which they were initially described. The purpose of this study is to re-evaluate the taxonomy of the Washita Group foraminiferal assemblages and provide insight on the overall distribution of foraminiferal species.

One hundred and thirty-one samples from 21 localities of the Washita Group of North-Central Texas were included in this study. Materials from all formations of the Washita Group were studied, except for the Buda Formation that rarely outcrops in North-Central Texas. Samples include collections of the present authors for the purpose of this study, as well as samples collected by F. Lozo, A. Loeblich, and H. Tappan, which were loaned to the authors by the Department of Paleobiology at the Smithsonian National Museum of Natural History (NMNH). Type material of species originally described from North-Central Texas deposited in the NMNH Cushman Collection was used to aid in species determination.

From the studied material, 84 species of benthic foraminifers have been identified, 25 of which are agglutinated. Of the species identified, six are new and yet to be described. The species considered new by the authors were previously included

as paratype forms of other species or were misidentified in previous studies. The lowest unit of the Washita Group, the Kiamichi Formation, yields very few small benthic foraminifers, including the genera *Gavelinella*, *Laevidentalina*, *Lenticulina*, *Marginulina*, *Praeplanctonia*, and the agglutinated genera *Ammobaculites* and *Trochammina*. The genus *Praeplanctonia* was not observed outside of the Kiamichi Formation. In the overlying Duck Creek Formation, the assemblage rapidly diversifies with the appearance of the genera *Circinatiella*, *Citharina*, *Conorboides*, *Flabellinella*, *Globulina*, *Gubkinella*, *Gyroidinoides*, *Lingulogavelinella*, *Paleopolymorphina*, *Palmula*, *Pseudosaracenaria*, *Psilocitharella*, *Pyramidulina*, *Pyrulina*, *Spirillina*, and *Tristix*, and the agglutinated genera *Acruliammina*, *Cribratina*, *Gaudryina*, *Glomospirella*, *Haimasiella*, *Quasispiroplectammina*, *Reophax*, *Scherochorella*, *Simobaculites*, and *Textulariopsis*. Most species that first appear at this level continue through the Grayson Formation. Diversification of the benthic fauna continues in the Weno Formation, with the first appearances of the genera *Eouvigerina*, *Lagena*, *Pravoslavlevia*, *Pseudopolymorphina*, and *Ramulina*, and near the contact between the Main Street and Grayson formations, with the appearances of the genera *Lingulina*, *Massilina*, and *Praebulimina*.

Middle Pennsylvanian-Cisuralian (Early Permian) fusulinids from the Cache Creek Complex near Meadow Lake, southern British Columbia, Canada: An exotic fauna with Paleo-Tethyan affinities

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Upper Moscovian (Middle Pennsylvanian) to Artinskian (mid-Cisuralian) isolated limestone exposures of the Cache Creek Complex northwest of Meadow Lake, British Columbia, yield rich and diverse fusulinid assemblages with distinct paleobiogeographic affinities to Eurasian Paleo-Tethyan faunal realms. The Cache Creek Complex, or the Cache Creek terrane, comprises a narrow, elongate band of amalgamated tectonic blocks of considerable lithologic variability (e.g., limestone, chert, argillite, volcanic units, intrusive bodies, ultramafic units) extending from southern Yukon to southern British Columbia. Collectively, the Mississippian to Jurassic rock bodies of the Cache Creek Complex are interpreted to be the obducted remains of various bathymetric high features that developed in the Panthalassic Ocean, with the upper Paleozoic units likely originating as oceanic plateaus or seamounts in the far westernmost portion of Panthalassa, adjacent to the eastern Paleo-Tethys Ocean. The Cache Creek terrane was subsequently accreted during the Late Jurassic to the North American Plate as part of composite blocks associated with the surrounding Quesnel and Stikine terranes.

Although fusulinid taxa of known Paleo-Tethyan affinity have been recognized in the allochthonous, unstratified limestone bodies of the Cache Creek Complex since the late 1870s, only a few studies have been conducted on the Pennsylvanian and Cisuralian fusulinids of the accretionary complex. This paucity of research is a consequence of the rather limited areal extent, protracted temporal range, and lithologic heterogeneity of the Cache Creek Complex. The few other investigations of Pennsylvanian and Cisuralian fusulinid faunas of the Cache Creek Complex have been mostly concerned with sections of the so-called Pope succession near the town of Fort St. James, British Columbia, located approximately 380 kilometers to the north-northwest of Meadow Lake. To date, the Late Moscovian to Artinskian fusulinids of the Meadow Lake area have only received the preliminary treatment of a 1970 abstract by M.K. Nestell and the late W.R. Danner. The present study is a taxonomic re-evaluation and augmentation of the initial report by these authors.

In total, 21 fusulinid species of 17 genera have been identified from 12 sampling locations in the study area. Although the Meadow Lake exposures preserve a disordered and stratigraphically discontinuous record, the recovered fusulinid collections provide the following age constraints for the 12 sampling locations: upper Moscovian (one site), lower Kasimovian (one site), middle Kasimovian (one site), upper Kasimovian (one site), middle Gzhelian (two sites), lower Asselian (five sites), and Artinskian (one site). No Sakmarian fusulinids were collected from the study area. The assemblages include both taxa that were previously unreported from the Cache Creek Complex and forms already known to occur in the age-equivalent Pope succession. Fusulinid genera collected for the first time from the Cache Creek Complex include *Acervoschwagerina*, *Eoparafusulina*, *Pseudochusenella*, *Rauserites*, *Schellwienia*, and *Sphaeroschwagerina*. Previously reported genera included *Carbonoschwagerina*, *Cuniculinella* (reported as "*Chalaroschwagerina*"), *Fusulinella*, *Nankinella*, *Obsoletes* (reported as "*Protriticites*"), *Pseudoschwagerina*, *Quasifusulina*, *Quasifusulinoides* (reported as "*Quasifusulina*"), *Schubertella*, *Schwagerina*, and *Triticites.* Many of the fusulinid species found in the Cache Creek Complex are not known to occur elsewhere in North America, but the presence of critical Paleo-Tethyan marker taxa in the assemblages permits zonal correlations to be made with a number of thoroughly studied Eurasian localities, including (but not limited to) the Carnic Alps (Central Europe), the Donets Basin (eastern Ukraine), the Russian Platform, the Darvaz (Central Asia), western Guizhou (South China), and the Akiyoshi, Chichibu, and Mino terranes (southern Japan).

Evaluation of the effects and emerging perspectives of electric current stimulation on larger benthic foraminifera: a case study on the genus *Amphistegina*

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Many marine animals are electroreceptive species being capable of detecting natural electric fields in their environment and utilize them in important life processes such as movement, orientation, and foraging. However, our understanding of how animals, particularly benthic organisms, interact with anthropogenic sources of electric fields remains quite limited. Among benthic organisms, foraminifera are commonly used as bioindicators in marine environments, but studies on the effects induced by electrical stimulation are not documented. Here we provide an overview of the effects of different electrical stimulation on a larger benthic foraminiferal species. Specifically, we document the effects of short-term exposure (72 h) to different electric current densities on the viability of benthic foraminiferal species *Amphistegina lessonii* by checking the pseudopodial activity and defining the tolerance to different electrical densities (range 0.29 to 20 μA/cm^2). After 3 days of treatment, *A. lessonii* stimulated with constant direct current showed pseudopodial activity at lower electric current densities (0.29, 0.86 μA/cm^2) up to 24 h. With increasing stimulation time, the percentages of pseudopodial activity decreased and pseudopodial activity is basically absent at high current densities (5.71 and 8.57 μA/cm^2). The viability of *A. lessonii* exposed to pulsed direct current is higher at low and middle electric current densities (from 0.29 to 5.71 μA/cm^2) than at high electric current density (from 11.43 to 20 μA/cm^2). Based on these results, the selected benthic foraminiferal species seems to better stand pulsed direct currents than constant ones, which will also be used in subsequent experiments.

Furthermore, electrical stimulation could be responsible for oxidative stress as revealed by several biomarkers (i.e., proteins and enzymes). We also document the effect of different low pulsed direct electric current densities on the photosynthetic activity (Pulse Amplitude modulated Fluorometry, PAM) of *Amphistegina* diatom endosymbionts to determine their photosynthetic performance. Finally, we evaluate whether the electrochemical technique used in this study could promote the precipitation of dissolved ions in seawater and its consequent effect on the growth rate of *Amphistegina*. With this experimental work, we hope to increase the knowledge of electrostimulation on the important protist *Amphistegina* and evaluate at which current densities the stimulation can have a positive effect.

ExploRarE: Exploring the potential of REEs as productivity indicators in planktonic foraminifera along western Iberian Margin

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The carbon dioxide (CO_2) emitted to the atmosphere since the Industrial Revolution led to a global, unprecedented increase of its concentration from 280 ppm to over 400 ppm. The ocean has been absorbing around 30%, partly compensating the excess of atmospheric CO_2, with drastic impacts on the Marine environment, including changes in productivity. The Eastern Boundary Upwelling Systems (EBUS) are among the world's most productive ocean ecosystems, playing also an important role in the atmospheric CO_2 sequestration. Three out of the four global EBUS are already suffering the effects of climate changes with winds intensification whereas for the Canary/Iberian EBUS the impacts remain uncertain. The Iberian EBUS supports large communities that are socio-economically dependent on this system. Thus, it is critical to understand how it is responding to climate-driven changes and how it will evolve in the future. One way of addressing this question is by establishing the differences between anthropogenic and natural climate variability, by using productivity tracers. Though over the last 50 years, several methods have been applied to reconstruct productivity, each of them holds specific limitations. Hence, the search for more robust, high-fidelity productivity proxies is still necessary. For a long time, rare earth elements (REEs) were recognized as having potential to reconstruct past ocean conditions. Since then, several methodologies have been tested and applied, yet, there is no clear agreement on which cleaning methodology is more efficient to use for REEs measurements. To address this subject, one of the objectives of the ExploRarE project is to evaluate four cleaning procedures: 1) oxidation; 2) oxidation and reduction using hydrazine; 3) oxidation and reduction with sodium

acetate; 4) oxidation, reduction using hydrazine and alkaline chelation with DTPA. We used four planktonic foraminifera species commonly found along the western Iberian Margin, i.e., *Globigerina bulloides*, *Neogloboquadrina incompta*, *Globorotalia inflata,* and *Globigerinoides ruber*, picked from the fraction >250 µm of previously washed deep-sea sediment samples. Each planktonic foraminifera sample was gently crushed, divided into four aliquots and the aliquots cleaned following the different cleaning protocols, respectively. In each sample, the cleaning approach test was repeated three to five times. The cleaned subsample was then analyzed in the ICP-MS in the clean laboratory of IPMA. After choosing the more efficient cleaning procedure, we will apply it to both living and fossil planktonic foraminifera and compare the results with other established productivity proxies. Ultimately, this project will provide new insights on the paleoceanographic use of REEs and contribute for the development of a new productivity proxy, enabling better and more robust estimates for future climate-drive ocean conditions.

(Meta)Barcoding all forams - An invitation to contribute to the Foraminifera Reference Database *ForamBase*

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Consistent taxonomic assignments are essential for cross comparison of results between regions and studies. Reference databases are critical resources for molecular analysis and taxonomy, but only have value when entries are properly illustrated and placed in a solid taxonomical framework. Despite the high diversity and ecological importance of Foraminifera in many marine ecosystems, there is currently no integrative database containing nuclear and mitochondrial sequences, photos and metadata for Foraminifera. We propose to build such a centralised database for Foraminifera based on existing resources and available databases, providing an invaluable tool for understanding foram ecology, taxonomy, and global scale geographical and ecological patterns.

To achieve this, we invite you to share Foraminifera samples suitable for molecular work and collaborate across institutions to build this resource for the foram community. We are building a reference database containing at least nuclear (18S) and mitochondrial (COI) markers, which will be complemented with photos, CT-scans, and additional molecular sequences. Our ultimate goal is to publish a comprehensive foraminifera reference database with a group author. All contributors to the database will be acknowledged by co-authorships.

Participating in the effort to build the ForamBase will be straightforward - share your foram samples or sequences with us, and your name and affiliation will automatically be added to the group author ForamBase_Contributors of the database manuscript. We envision the ForamBase becoming the new baseline resource for molecular foram taxonomy, enhancing our understanding of foraminifera diversity, their ecological role and evolutionary significance.

Thank you for considering our invitation. We look forward to collaborating with you to enhance the scientific community's understanding of foraminifera.

Assessing seasonal, size, and depth-related influences on planktic foraminiferal Mg/Ca ratios in the eastern Mediterranean Sea through comparison of sediment trap and surface sediment samples

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Paleoceanographic studies often use the temperature dependence of the Mg/Ca ratio in foraminiferal calcite to reconstruct past climate. In addition to temperature, incorporation of magnesium into planktic foraminiferal tests is related to the magnesium concentration, salinity, and pH of the water in which the test grew, along with species-specific effects. In regions of high salinity, high-Mg overgrowths can impact foraminifera in the sediment, leading to anomalously high Mg/Ca in these parts of the ocean. Because of this, data from surface sediments in the eastern Mediterranean Sea and Red Sea have been removed from calibration sets even in the absence of such overgrowths, leading to greater uncertainty when applying the Mg/Ca proxy in these regions.

We assess samples from a sediment trap series in the oligotrophic Ionian Sea. The traps collected material at approximately 500 m water depth between 1999-2001, 2002-2003, 2004-2005, and 2008-2011. The >125 µm fraction was

assessed for species assemblage and the size of individuals. Specimens of *Globigerinoides ruber* (white) dominate the assemblage year-round, but the largest sizes and greatest numbers occur during late summer. However, specimens in the studied trap samples are thus far smaller than the size fraction typically targeted in sediments (>250 μm). Based on notes taken during sample retrieval and splitting, large planktic foraminifers were not captured in this sediment trap series, which was collecting over the course of 20 years (1991-1994, 1999-2006, 2008-2011), raising questions on the circumstances which would lead to the growth of larger *G. ruber* (white) in this region. Species and size assemblage will be determined in a nearby surface sediment sample for comparison.

Mg/Ca in *G. ruber* (white) specimens from six summer samples in 1999 and 2000 (32 specimens) and one winter sample in 2001 (7 specimens) were measured using LA-ICP-MS. Between one and five spots located on the final three chambers were measured on each specimen. Results from the two seasons are not statistically distinct. Final chamber Mg/Ca is somewhat higher on average in the winter sample (3.0 mmol/mol; stdev = 1.2; n = 15 shots) than in the summer samples (2.6 mmol/mol; stdev = 0.8; n = 58 shots). Similarly, Mg/Ca ratios in the previous two chambers are higher in the winter sample (4.4 mmol/mol; stdev = 1.1; n = 13 shots) than in the summer samples (3.9 mmol/mol; stdev = 0.8; n = 59 shots). Final chamber Mg/Ca values are lower than in previous chambers, consistent with previous literature. These results suggest that the foraminifera dwell below the surface mixed layer in summer, where water temperatures are similar to winter mixed layer temperatures.

These results confirm the summer seasonal bias of foraminifera-based proxies in this region, but pose questions to the origin of larger (>250 μm) specimens and the validity of using foraminifera growing at depth as an indicator of summer sea surface temperatures. Implications for proxy reconstructions and plans to expand the dataset will be discussed.

Assessing the use of carbon isotope between epifaunal and shallow infaunal as a proxy for paleo-productivity in the Southeast Pacific

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The difference in carbon isotope between epifaunal and shallow infaunal benthic foraminifera species ($\delta^{13}C_{epi\text{-}sii}$) seems to be proportional to the organic matter carbon flux to the seafloor. Therefore, it has been proposed that the carbon isotope difference between epifaunal and shallow infaunal benthic foraminifera could be used as a paleo-productivity proxy. The Southeast Pacific margin is an ideal natural laboratory to evaluate the potential of this proxy due to the contrasting gradients in productivity and organic matter type.

In this work, we test the applicability of the $\delta^{13}C_{epi\text{-}sii}$ to reconstruct paleo-productivity in this region based on surface sediment samples retrieved along the Peruvian and Chilean continental margins between 24 and 4,000 m water depth. We analysed stained and unstained specimens of the shallow infaunal genera *Uvigerina* (*U. peregrina, U. auberiana)*, *Bolivina* (*B. interjuncta, B. plicata, B. spissa*) and epifaunal genera *Cibicidoides (C. wuellerstorfi, C. mundulus, C. lobatulus),*

Cibicides (C. aknerianus) and *Planulina (P. limbata,* and *P. ariminensis)*. We compared our $\delta^{13}C_{epi\text{-}sii}$ with satellite surface chlorophyll and derived surface water primary productivity (seasonal, yearly, interannual and decadal), bottom water oxygen and nutrients concentrations; and bulk sediment productivity proxies and organic matter quality indicators as total organic carbon, total nitrogen, C:N ratio, biogenic opal, calcium carbonate, $\delta^{13}C_{org}$ and $\delta^{15}N_{org}$.

Preliminary results show that $\delta^{13}C_{epi\text{-}sii}$ computed between *Cibicidoides/Planulina* and *Uvigerina* species has a negative relationship with chlorophyll/primary productivity/TOC/C:N/$\delta^{15}N_{org}$ and a positive relationship with oxygen. An unclear relationship is reported of $\delta^{13}C_{epi\text{-}sii}$ for these pair's species with biogenic opal, calcium carbonate and $\delta^{13}C_{org}$. For the $\delta^{13}C_{epi\text{-}sii}$ calculated between *Cibicidoides/Planulina* and *Bolivina* species, an unclear relationship is observed with any of the environmental variables.

Stable isotopes of oxygen and carbon in benthic foraminifera: Proxy validation in the Southeast Pacific, an international collaborative endeavour

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The oxygen ($\delta^{18}O_{BF}$) and carbon ($\delta^{13}C_{BF}$) isotope signals of benthic foraminifera (BF) are widely used for reconstructing bottom water temperature, salinity, density, oxygen and nutrient content. However, the accuracy of these reconstruction can be biased by vital (kinetic and metabolic) and environmental effects (microhabitat, phytodetritus, carbonate ion saturation) as they influence $\delta^{18}O_{BF}$ and $\delta^{13}C_{BF}$, causing offsets or isotope disequilibria between the stable isotope signature of the BF and the ambient bottom water. The Southeast Pacific (SEP) is an important region due to its role in heat transfer, productivity, and carbon-oxygen-nutrient cycling. Over the past two decades, paleoreconstructions in this region have relied on $\delta^{18}O_{BF}$ and $\delta^{13}C_{BF}$ for understanding past environmental changes. Nevertheless, no proxy validation for stable isotopes in BF has ever been done. We conducted the first-ever assessment of the stable isotope disequilibria in common epifaunal and infaunal BF species in the SEP, and evaluated its implications for paleoceanography. We utilized a large sample set of modern and/or living (Rose Bengal-Stained) BF collected along the Peruvian and Chilean continental margins, alongside sedimentological

and geochemical (water and sediment) characteristics. Through this extensive dataset, we analyzed the effects of 1) organic matter respiration (i.e., Mackensen effect), 2) microhabitats, and, 3) carbonate chemistry on $\delta^{18}O_{BF}$ and $\delta^{13}C_{BF}$. Epifaunal BF $\delta^{18}O$ values reveal a 1:1 relationship with ambient bottom waters across the entire water column. Infaunal BF show positive offsets to the bottom waters. Epifaunal BF $\delta^{13}C$ generally follows a 1:1 relationship with bottom waters between 4000 and 800 m. While infaunal BF $\delta^{13}C$ data become progressively depleted compared with ambient bottom waters, with deeper infaunal habitats. However, above 800 m this relationship with the bottom waters breaks down, and epibenthic BF $\delta^{13}C$ values show a positive offset in the order of 0.7‰. A similar trend towards more positive values in the upper 800 m is also seen for the infaunal species. Regression analyses of the isotopic disequilibria with ambient bottom water data and bulk sediments characteristics suggest that the combination of low oxygen concentrations, poorly remineralized organic matter and low carbonate ion concentrations affect the $\delta^{13}C$ signatures of infaunal and epifaunal BF within the upper 800 meters in the SEP, where the epifaunal BF actually show a quite uncommon positive disequilibrium.

Spatio-temporal distribution patterns of benthic foraminifera in the northern Barents Sea

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The most pronounced declines in the extent and thickness of the Arctic sea-ice are occurring in the Barents Sea. In this region, the irregular topography and seasonal sea ice dynamics associated with the Atlantic Water inflow and mixing increase the spatial variability in biogeochemical processes. In this study, we aim to extend the knowledge of how distinct depositional environments associated with seasonal food availability and temperature conditions affect the Arctic benthic foraminiferal community structure. Living (rB stained) benthic foraminifera were collected from the Barents Sea shelf, slope and Arctic Basin. The community was analysed from surface sediment samples (0 - 1, 1 - 2 cm) collected at eight stations during August and December 2019, and March and May 2021. The size fractions 63, 125 and 500 µm were analysed separately. Foraminiferal diversity and faunal composition patterns were observed in association with sedimentary parameters, such as elemental carbon and nitrogen content, stable isotopic composition and grain size. We observed that agglutinated species were dominant (> 50 %), particularly at shallow, southern sites with high sand content. The agglutinated species, *Lagenammina difflugiformis* and *Adercotryma glomeratum,* are common throughout the study area. *Portatrochammina bipolaris* and *Textularia torquata* are abundant in shelf sites associated with Atlantic Water inflow. Their abundance is highest mainly during winter when the inflow is intensified. In the shelf sites, allogromiids were abundant, reaching > 40% of the assemblage. High percentages of calcareous species were observed at slope stations, where the presence of cold deep-water species such as *Melonis affinis* and *Pullenia bulloides* are characteristic. A substantial proportion of calcareous species were decalcified (> 25 %), mostly in southern shelf sites and subsurface samples. *Elphidium excavatum* var. *clavatum* and *Robertina* sp. show the most severe degree of dissolution, while *Melonis affinis* displays mild degrees of dissolution. Areas with frequent dissolved individuals had a low inorganic carbon content in the sediments, where the low calcite content does not reach a saturation state. The highly abundant calcareous species *Epistominella arctica* and *Stetsonia horvathi* were frequent found in slope and basin sites, associated with deep water depth and high clay content. These species showed peaks in abundance during winter and lowest values during summer. Overall, there was more spatial than temporal variability in abundance and faunal composition in the study area. Shallow bank areas had the lowest richness and abundance whereas deeper shelf, slope and basin areas had high numbers of taxa and abundance. Although there were no intra-annual differences in the analysed sedimentary parameters, the species composition observed showed an abundance increase during winter periods (December 2019, March 2021) particularly in the smallest size fraction (63-125 µm). The abundant small size individuals are possibly an effect of reproduction based on the previous year's productivity. This suggests that smaller individuals and species are responding to interannual productivity pulses associated with different sea ice cover and Atlantic Water inflow. Continued biodiversity assessments within the Barents Sea are necessary to improve our understanding of seasonality in the benthic realm providing insights into the past and future of the Arctic ecosystem functioning.

Vacuoles size and abundance in Foraminifera: new insight about their metabolic adaptation to low oxygen environments

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Several benthic foraminiferal species of the order Rotaliida were shown to be facultative anaerobes and able to perform denitrification, entering the very restricted group of eukaryotes exhibiting this metabolic pathway. In certain environments such as fjords or oxygen minimum zones, they might be responsible for up to 50-100% of the total benthic denitrification. These observations support that benthic foraminifers could play a key role, so far overlooked, in the nitrogen cycle. However, the exact way they are performing denitrification is still hypothetical. In species dwelling in deep sea sediments, the concurrent observation of (1) higher concentrations of nitrate in their cell relatively to the ambient sea water (>1000 times), (2) the presence of numerous and large vacuoles in their cytoplasm and (3) the preferential clustering of mitochondria around vacuoles, led to the idea that vacuoles could be the place for nitrate storage to sustain denitrification. While an extended surface of contact is necessary to optimise exchanges between vacuolic content and the cytosol to support metabolic activity, an efficient storage capacity requires high volume. Following this reasoning, and because volume increases quicker than surface (cubic vs. square, respectively), there should be a trade-off between storage volume and surface of exchange for different oxygen and nitrate concentrations in the foraminiferal environment.

Here, we present preliminary data for the species *Bolivina spissa* sampled at ~1400 m depth in the central part of the Sagami Bay (Japan). Specimens were collected from different sediment depth (every 1 cm down to 5 cm depth) to characterise their vacuole pattern regarding the oxygen (hypoxic or anoxic) and nitrate concentrations (40µM to absence) profiles in pore waters. Sediment samples where fixed with glutaraldehyde on board directly after sampling. Specimens were then isolated, decalcified, stained with osmium, embedded into resin and imaged using a micro-CT (Computed Tomography) scan. Volume, surface area, and position of vacuoles in the cell were determined using the software Amira and followed by 3D reconstruction of the whole individual associated with their vacuole pattern. Further TEM (Transmission Electron Microscopy) images on the same specimens will help us to establish other organelle distributions regarding the vacuoles considered such as mitochondria.

Our results did not show a clear and systematic difference in the vacuoles pattern of specimens sampled from different sediment depths (i.e. different oxygen and nitrate conditions). Conversely, the distribution of vacuoles was different regarding the chamber, showing an increase in number and a decrease in size from the older toward the youngest chambers. The differences observed regarding individual chamber might indicate that each chamber could perform different activities hence vacuoles in different chambers have different roles. We will further discuss the relationships between these patterns and their environment linked to their living depth in sediments, i.e. different oxygen and nitrate concentrations.

Correlative analyses of cellular structures and elemental distribution of soluble compounds: Cryo-SEM imaging coupled to EDS elemental mapping in the denitrifying species *Bolivina spissa*

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Benthic foraminifers perform a wide variety of metabolisms to cope with adverse conditions of their surrounding environment. Among these metabolic adaptations, numerous species were shown to be facultative (an-)aerobes able to perform denitrification. In some environments, they are responsible for 50-100% of the total benthic denitrification, making them major protagonists in this process and ultimately emphasising their potential key role in the nitrogen cycle. Concurrently, while they significantly contribute to nitrogen cycle, little is known about the mechanisms involved regarding this metabolical pathway. Several denitrifying species belonging to the rotaliids are known to store nitrate in their cell with concentrations >1000 times higher than in their surrounding environment. In some species, parallel observations of a remarkably developed vacuolic system surrounded by mitochondria clusters led to the hypothesis that vacuoles are likely to be the place where nitrate is stored in the cell. However, vacuole content is difficult to assess, mostly because ultrastructure observation generally requires cell fixation and subsequent preparations for sectioning that includes a dehydration step, causing the loss of dissolved elements such as nitrate. One way to preserve the liquid phase is the cryo-fixation of specimen prior observation, but this technique is challenging to implement.

Here, we present data about cellular structures using cryo-SEM (Scanning Electron Microscope) imaging combined with the distribution of elements using EDS (Energy Dispersive X-ray Spectroscopy) mapping on cryo-fixed specimens of the denitrifying species *Bolivina spissa*. Individuals were sampled in October 2022 at the central part of the Sagami Bay (Japan) at ~1400 m depth. Specimens from the topmost centimetre were isolated, directly embedded in a sucrose-based aqueous glue and cryofixed (liquid nitrogen-cooled isopentane) onboard while others were cryofixed only after exposition to different conditions of oxygen and nitrate concentration (presence/absence) for two days. After cryo-fixation, specimens were cracked open using a diamond knife aiming for a clean cut limiting topographic variations of the sample surface. After sublimation and chromium coating steps, the same sample regions were SEM imaged and elemental composition was mapped by EDS

analysis. After spectra treatment to deconvolve signal from noise, the superimposition of SEM images and EDS elemental maps allow to visualise the elemental distributions among cellular structures.

Our results show that nitrogen seems to be accumulated in vacuole-like structures within the cytoplasm, confirming the initial hypothesis that vacuoles are the place for nitrate storage in *B. spissa*. The fact that specimens from all experimental conditions were found to be accumulating nitrogen in vacuoles suggests that their storage capacity allows them to sustain their metabolic activity for more than two days. Additionally, some vacuoles appeared not enriched in nitrogen, indicating that vacuoles might be used for other purposes, or that their nitrate content was already consumed. Finally, phosphorus, another element recently suggested to play a role in energy metabolism, was observed accumulating in denser "grape" like structures.

Benthic foraminiferal assemblages of the Espirito Santo Continental Shelf, Southeastern Brazil (SW Atlantic)

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This work presents the preliminary results of a study that aims to integrate the recent benthic foraminifera assemblages (total fauna, > 63 μm) and sedimentological data along depth gradients in the Espirito Santo Continental Shelf (ESCS, southeastern Brazilian Continental Margin, 18° 20' and 21° 20' S). The ESCS varies in width and shelf-break depth, currently presenting a morphology that was shaped by several changes in relative sea level during the Quaternary. The ESCS sedimentation is essentially mixed (coeval carbonate/terrigenous deposition), with rhodolith beds on the entire outer shelf. The Doce River is the main source of terrigenous sediment to the shelf. Northward of the river, the South Abrolhos Shelf keeps the most important coral reef system of the South Atlantic. Surface sediment samples (0-2 cm) were collected in 2013 comprising six transects evenly distributed in the ESCS (B-F) and North Campos Basin (A) at depths of 25, 40, 50, and 150 m. Density, diversity, life strategy, test composition, and assemblage composition change with depth and according to the influence of the Doce River. The microfauna is dominated by hyaline taxa, mainly represented by species of the genus *Globocassidulina*. However, a high abundance of porcelaneous taxa (e.g., *Archaias angulatus*, *Articulina pacifica, Miliolinella subrotunda, Peneroplis planatus, Quinqueloculina* spp.), combined with sandy sediments and low organic matter content, was observed along the transect C and in the two transects located in the South Abrolhos shelf. To the north of the Doce River, the relative abundance of *Hanzawaia boueana* increased in the sandy carbonate-poor sediment. The low $CaCO_3$ content in this sector of the ESCS indicates a strong influence from the Doce River sediment plume. To the south of the Doce River, species from the genus *Cibicides* and *Cibicidoides* were more frequent and abundant, mostly along the transect of the North Campos Basin. The microfaunal and sedimentological data observed in the 150 m isobath indicate a clear beginning of the transition from the shelf to the slope, with an increase in the P/B ratio and higher hyaline abundances, when compared to shelf samples.

Inhabitation of bathyal hydrocarbon seeps by basal benthic foraminifera evidenced by ultrastructural observations

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While the cellular adaptations of calcareous foraminifera in certain extreme environments (e.g., anoxic, euxinic, methane-enriched sediments) include peroxisome proliferation, symbiosis, kleptoplasty, and mitochondria-test pore associations, there is still much to be learned about the mechanisms allowing thecate (i.e., organic-walled) and agglutinated monothalamid (single chambered) foraminifera to occupy these seemingly extreme environmental conditions. As monothalamid foraminifera are considered by most to be early-evolving forms, it is important to define their cytology. This is especially true for populations inhabiting environments representing habitats of the Proterozoic Oceans, where life may have first evolved.

A first step to establish how foraminifera can live in extreme environments is by analyzing their cellular ultrastructure via Transmission Electron Microscopy (TEM). Limited studies have been conducted on hydrocarbon-seep foraminiferal

ultrastructure, with none on thecate and agglutinated monothalamid forms, to our knowledge. Cytological observations of five thecate morphotypes and two sacamminid morphotypes are presented. Specimens were collected from *Thioploca* mats (colonial filamentous sulfur-oxidizing bacterium) in deep-water hydrocarbon seeps in the Gulf of Mexico (~700m and 2000m). TEM observations of seep microbial-mat associated allogromids reveal intact mitochondria (indicator of vitality), nuclei, Golgi, and peroxisome-endoplasmic reticulum (P-ER) complexes. Further, there is evidence of phagocytosis of varied bacteria. Observations of saccaminid foraminifers also reveal intact mitochondria and other organelles (e.g., mitochondria, Golgi, endoplasmic reticulum), as well as abundant phagocytosed bacteria, including possible methanotrophic bacteria and *Thioploca* in one specimen, adding to the evidence that this specimen was active in the seep-influenced habitat. The evolution and paleoecology of these single-chambered basal morphotypes remains poorly understood because of their sparse fossil record. Increasing our knowledge of the modern ecology and distribution of these taxa could help shed light on their evolutionary history, as early-evolving foraminifera may have been capable of inhabiting environments similar to those of early oceans, before oxygen was freely available. This contribution will greatly augment understanding of extremophile foraminifera, adding to the burgeoning understanding of microeukaryote and microfossil diversity, adaptations, and metabolic pathways. Partial support from Cushman Foundation of Foraminiferal Research, The Ocean Ventures Fund of WHOI, and the Investment in Science Program of WHOI.

Assessing biodiversity of benthic foraminifera in an anoxic-hypoxic karst subterranean estuary of the Yucatan Peninsula, Mexico

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Karst subterranean estuaries (KSEs) form in coastal carbonate aquifers where precipitation, saline groundwater, and oceanic water interact. These environments are biogeochemical hotspots that provide a unique opportunity to study the ecology and diversity of organisms inhabiting a range of physico-chemical gradients. To date, most studies of KSEs in the Yucatan Peninsula and Cozumel Island, Mexico have focused on the water-column community, composed primarily of endemic crustaceans. These organisms have drawn interest from many, but we are just beginning to describe the diversity and ecosystem functioning within these complex systems. Despite considerable efforts into describing ecosystem functioning within the KSE water column, very little is known about the role of the benthos. Better understanding of the diversity and community composition of benthic meiofauna (small eukaryotic organisms, including foraminifera) in these systems is a crucial first step toward understanding their role in KSEs. In particular, benthic foraminifera are well-known environmental indicators that can inhabit a range of extreme habitats, including anoxic and sulfidic conditions, yet little is known about their diversity in KSEs. Sediment samples collected from Cenote Crustacea, a hypoxic to anoxic coastal cave in the Yucatan Peninsula, were analyzed to establish a baseline for benthic foraminiferal diversity in this system. Persistent anoxic conditions were recorded for all but six days (two three-day rain events) of the five-month logging period in the marine layer of the cave, and severely hypoxic conditions were recorded for the entire logging period in the brackish layer with long-term loggers deployed in the cave. Living benthic foraminifera were distinguished with the fluorogenic probe CellHunt Orange and metabarcoding analyses. Cave sediment samples were collected along salinity and oxygen gradients, allowing for an evaluation of community-structure variation throughout the cave. Eukaryotic and prokaryotic metabarcoding of bulk sediments is in progress. This research will serve as the first assessment of living benthic foraminiferal diversity in Yucatan cave sediments, spanning a two-year time series. The data will provide the foundation for a study on a larger scale assessing the drivers of benthic (metazoan and meiofaunal) biodiversity and their role in ecosystem functioning in additional Mexican KSEs. Funded by NSF OCE 2136377 to JMB and NSF OCE 2136322 to EB.

Agglutinated foraminifera as early indicators of microplastic pollution in two Mediterranean marine caves

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Marine caves are considered extreme environments for aquatic life because, due to their enclosed setting, they are affected by extreme conditions for scarcity or absence of light, limited nutrient availability, the difficulty of larval dispersal, and possible hypoxic conditions. Moreover, caves connected with karst systems receive terrestrial contributions (water, sediments, and organic matter) that, interacting with the marine ones, determine wide spatial and temporal environmental variability. Combining all these variables determines a strong environmental gradient from the outer to the inner parts of caves that is reflected in the biota's zonation; despite these unfavorable conditions, marine caves are biodiversity reservoirs. However, they are extremely fragile environments because they are affected by natural environmental stress and potentially exposed to contamination from both the land and the sea; for this reason, they are included in the European Habitats Directive for protection and conservation. Recently, microplastic pollution was recorded for the first time in the water and sediments of a Mediterranean marine cave.

Benthic foraminifera were recognized as reliable environmental indicators in these environments, where they develop more and more different assemblages from those of the surrounding marine area with the increasing distance from the cave entrance. In particular, the agglutinated taxa, not abundant in the shallow water Mediterranean environment, are relatively numerous in cave assemblages.

This work considered two Italian marine caves with different characteristics: the huge Bue Marino cave (Sardinia), which receives terrestrial contributions through the vast karst system of the Gulf of Orosei during rainy periods, and the small Argentarola cave (Tuscany archipelago), which is permanently characterized by fully marine conditions. Sediment samples from the two caves were analyzed for grain size, organic carbon (C_{tot}), microplastic and benthic foraminifera. In the Bue Marino cave, sediment ranged from sandy silt to sand, it was rich in C_{tot} (up to 8.07%), and microplastics were 10-27 items kg^{-1}. The agglutinated, infaunal, and opportunist *Eggerelloides advena* was the dominant species, with *Ammonia tepida* and *Ammonia inflata*. In the Argentarola cave, sediment was silty clay or clayey silt, poor in C_{tot} (at most 0.13%), and microplastics were 70-300 items kg^{-1}. The most abundant foraminiferal taxa were the epifaunal calcareous *Spirillina vivipara* and *Patellina corrugata*, and the infaunal agglutinated *Lagenammina difflugiformis*, while *Glomospira charoides* was common.

Microplastics were searched in the tests of the three agglutinated species through Micro Fourier Infrared Spectroscopy (μFTIR) because it was supposed that these items could be incorporated by specimens collecting grains during the building of new chambers; moreover, it is easier to recognize the signal associated with the presence of MPs in the agglutinated than in the calcareous tests. FTIR spectra revealed the presence of plastic components in *E. advena* (Bue Marino) and *L. difflugiformis* but not in *G. charoides* (Argentarola). The different responses among species may be attributed to their different ability to select the grains from the sediment for building new chambers.

This result is particularly alarming from an environmental point of view because it testifies that microplastics enter a biological matrix, being included in the trophic chain, without the need to be ingested and metabolized. On the other hand, this study demonstrated that some species of agglutinated foraminifera are powerful proxies of microplastic pollution in sediments. Moreover, because the peculiar conditions of marine caves favor the presence of agglutinated species, agglutinated foraminifera may be successfully applied as early indicators of this pollution in these environments.

Benthic foraminifera as bioindicators of reef health in Jobos Bay, Puerto Rico

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Monitoring tools are needed to support effective management actions to protect the coral reefs in Jobos Bay National Estuaries Research Reserve (JBNERR) at Salinas, Puerto Rico. These reefs occur along a strong environmental gradient between an historically impacted terrestrial environment (i.e., by agriculture and waste disposal) with a currently increasing human population, and the clear, oligotrophic waters of the Caribbean just offshore. Here we show the feasibility of benthic-foraminiferal assemblages as bioindicators to understand the role of environmental parameters on these reefs. Water-quality, nutrients, sediment parameters, and foraminiferal assemblages were assessed in samples from the fore-reef and back-reef of Cayo Morillo, Cayo Pájaros, and Cayo Caribe. Temperature and salinity reflected seasonal variations; nitrates and ammonium concentrations indicated terrestrial runoff; and sediment parameters such as predominant grain-size and proportions of organic carbon and carbonate calcium indicated wave energy and wind influence. Foraminiferal assemblages

in the fore reef were dominated by *Amphistegina* (algal-symbiont-bearing) indicating suitable water-quality, while the back-reef stations were dominated by heterotrophic species such *Discorbis* and *Quinqueloculina,* reflecting their dominance in finer sediments with higher organic content. Low densities associated with water depth and wave energy limited further interpretation of foraminiferal assemblages. The dominance of symbiont-bearing taxa in fore-reef sites suggest suitable water quality for reef development. This pilot project provides the first description of foraminiferal assemblages in JBNERR reefs, providing baseline data on their ecological preferences.

A well oxygenated eastern tropical Pacific during the warm Miocene

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The oxygen content of the oceans is susceptible to abrupt climate change, and has declined in recent decades, with the largest effect in oxygen deficient zones--mid-depth regions with oxygen concentrations <5 μmol/kg. Here, we investigate changes in ocean oxygenation during the warmer-than-present Miocene Climatic Optimum (17.0–14.8 Ma), a possible analog for future climate. We use two foraminiferal proxies of ocean deoxygenation namely the iodine to calcium ratio and foraminiferal bound nitrogen isotopes. To that end we develop a new method that allows us to measure I/Ca and other elemental ratios in the same foraminifera sample solution. Planktic foraminifera I/Ca and $\delta^{15}N$ show that dissolved oxygen concentrations in the eastern tropical Pacific, home to the largest modern oxygen-deficient zone, exceeded 100 μmol/kg during the Miocene Climatic Optimum. Paired Mg/Ca-derived temperature data suggest that an oxygen-deficient zone developed in response to an increased west-to-east temperature gradient and shoaling of the eastern tropical Pacific thermocline. The new records align with model simulations that suggest weaker equatorial Pacific trade winds during warm periods may lead to decreased equatorial upwelling, causing equatorial productivity to be less concentrated in the east. These findings shed light on how warm climate states like during the Miocene Climate Optimum may affect ocean oxygenation, supporting models suggesting that the recent deoxygenation trend and expansion of the eastern tropical Pacific oxygen deficient zone may eventually reverse.

Species distribution and biostratigraphic evaluation of fossil foraminifera from Miocene to late Pleistocene sediments obtained from deep wells offshore Brunei Darussalam

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Fossil foraminifera are indicators of past environmental conditions and are also useful for marine biostratigraphy. In this study, the foraminiferal fauna from drill cuttings of two deep wells; Well A with 5 intervals (labelled C1, C2, C3, C4, C5) reaching to 2210 meters deep and Well B with 8 intervals (labelled D1, D2, D3, D4, D5, D6, D7, D8) extending to 3431 meters depth from offshore Brunei was investigated. The results are used to interpret the palaeoenvironment and to update the biostratigraphic record of the Miocene sediments in Brunei. The obtained samples were dried, weighed, and washed over three sieve sizes (250, 125 and 63 μm). All samples were standardized to 100 grams. The sieved fractions were examined through a stereomicroscope and documented through Scanning Electron Microscope (SEM).

A total of 247 species of foraminifera has been retrieved from both wells; Well A revealed 140 species comprising of 36 planktonic and 104 benthic foraminifera, while in Well B, 107 species of foraminifera consisting of 32 planktonic and 75 benthic foraminifera have been retrieved. Highest number of foraminifera species was seen in Well A, interval C2 (830 to

860 m deep), with 57 species of foraminifera including *Globigerinoides ruber* (~1065 number of specimens), *Lenticulina calcar* (954 number of specimens), *Bulimina aculeata, Bolivina robusta, Fijiella simplex*, *Uvigerina peregrina, Globorotalia crassaformis*, and *Trilobatus trilobus*. Well B shows lower species number with only 38 taxa retrieved from interval D2 (623 to 716 m deep) including highest to lower no. of specimens: *T. trilobus* with 259 number of specimens, *Globorotalia limbata* (135 number of specimens), *Uvigerina asperula* (123 number of specimens), *Cibicidoides kullenbergi,* and *T. quadrilobatus.* Overall specimens display great to moderately good preservation state. Retrieved foraminifera assemblages indicate past environment as distal marine from inner neritic to outer neritic, partly upper bathyal of tropical to subtropical water settings. Rare littoral environment occasionally occurred especially in palaeonvironment of Well A due to presence of *A. beccarii.*

The age of the sediments is from middle Miocene to late Pleistocene (~15.1 to 0.208 Ma) due to marker taxa *Orbulina suturalis* (M6), *Neogloboquadrina acostaensis* (M13a) and last occurrence of *Globorotalia menardii, Globorotalia ungulate, Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata (PT1b)*.

This study will provide more information on the past marine-coastal environment occurred in the Miocene. Moreover, data will be used to contribute towards upgrading the biostratigraphic record of much older sediments which are rarely published in Brunei and its nearby region. At a later phase of the project, stable isotope analyses on the planktonic foraminifera *Orbulina universa, Globigerinoides ruber, Pulleniatina obliquiculata, Globorotalia limbata, Trilobatus trilobus* and common occurring benthic foraminifera shells of *Cibicides kullenbergi, Lenticulina calcar, Pseudorotalia yabei* will be conducted to provide further palaeoclimatic information.

Paleoenvironmental evolution of Abrolhos Depression (Brazil - SW Atlantic) based on the distribution of benthic foraminiferal assemblages

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The post-last glacial maximum transgression was marked by secular climate fluctuation events that directly influenced paleoenvironmental evolution on global continental shelves. During the transgression, cooling events such as the Younger Dryas (YD) and rapid melting events such as the Meltwater Pulse (MWP), among others, played an important role in varying the rates of relative sea level rise, as well as in the formation of coastal environments. The focus of this study is the south shelf of Abrolhos, which is marked by a feature known as the Abrolhos Depression (AD), having previously been described as a paleolagoon. The objective of this study is to investigate the formation of this paleolagoon and the paleoenvironmental variations to which it was subjected during the marine transgression in the last 18 thousand years. The study was conducted using a core located in the center of the DA, collected at a depth of 63 m. The main focus of the paleoenvironmental analysis was the identification of benthic foraminifera and carbon 14 data, in addition to the use of previously available geochemical proxies. Throughout the core, there were 85 classified taxa, of which 69 were at the hierarchical level of species and 16 at the hierarchical level of genus. It was possible to divide the core into 4 Biofacies based on the assemblages of benthic foraminifera: the Biofacies CH gather samples from the base, 288 to 251cm, and the dominant species of this group were found to be *Cribroelphidium* sp. and *Hanzawaia boueana*. The Biofacies At brings together samples from 241 to 111cm, where the dominant species is *Ammonia tepida*. Another common species in this group is *Cribroelphidium excavatum*. The Biofacies AC gathers samples from 101 to 41cm, where the dominant species are *A. tepida* and *C. excavatum*. The Biofacies HQ brings together the top samples, 31 to 2 cm, where the dominant species are *H. boueana* and *Quinqueloculina lamarckiana*. From the analysis of foraminifera assemblages, the paleoenvironmental evolution of the AD can be reviewed to point to the following model: The base of the core indicates the presence of carbonate concretions that can compose a karstic ravine surface. The deposition of the Biofacies CH occurs on this surface and suggests marine influence and the beginning of the formation of the paleolagoon around 13,000 years BP. The formation of the DA occurs during the YD and it presents two distinct phases in terms of sedimentation and circulation in the lagoon environment. At first, between 12800 and 12500 cal years B.P., the lagoon is characteristically confined with less circulation, and from around 12,500 years onwards there is an increase in the lagoon circulation, marked by an increase in the density, richness, and diversity of benthic foraminifera. The end of the YD is marked by a significant change in the biofacies, where the organisms point to a shallow marine environment (Biofacies AC), which is corroborated by all sedimentological and geochemical proxies. This paleoenvironmental change is associated with MWP-1B. With the continuous rise in sea level, the environment becomes open marine, but there is still a change at around 8000 years B.P., which definitively marks the presence of organisms typical of the outer shelf, that is, from depths greater than 50 m.

Toxicological effects of CBs and nicotine as emerging pollutant for benthic foraminifera

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Marine debris is a global environmental issue. The chemistry of water and sediments, thus environmental quality and eventually the trophic chain, are affected by the dispersal of chemicals. Various studies have provided evidence that smoked cigarette butts (CBs) represent an important part of marine litter from the Mediterranean coasts to South America and Australia. CBs are the predominant human coastal litter item that can be bioaccumulated in marine organisms. CBs present a vector for transporting and introducing toxicants, including nicotine, harmful metals, total particulate matter and known carcinogens to aquatic habitats.

The health risks associated with smoking cigarettes have been addressed for decades while the fate of CBs after the disposal has only more recently received some attention. In particular, the European regulation classified CBs as hazardous waste for their acute toxicity (H6) mainly due to the nicotine content. It is a matter of fact that distribution and diffusion of CBs and their associated toxicants in the aquatic environment can be a threat to various prokaryotic and eukaryotic species inhabiting these aquatic habitats, including Foraminifera.

In this study, the viability and ultrastructural analysis involved three foraminiferal species from three different biomineralization pathways: the calcareous perforate *Rosalina globularis*, the calcareous imperforate *Quinqueloculina* spp. and the agglutinated *Textularia agglutinans*. The toxicological effects of CBs and synthetic nicotine were evaluated in terms of survival rate, cellular stress, and decalcification. FTIR (Fourier-transform infrared) spectroscopy analysis allowed us to investigate the response of key macromolecules and calcium carbonate to this pollutant. To further enrich our knowledge on bioavailability of nicotine in the medium culture, High Performance Liquid Chromatography analysis (HPLC) was carried out.

Different acute tests were conducted at different times; all confirmed that CBs and synthetic nicotine are acutely toxic at lethal and sublethal concentrations for all three cultured foraminiferal taxa. Each species showed a species-specific response related to the type of shell biomineralization. FTIR analyses showed that synthetic nicotine promotes shell decalcification and also alters the composition of cytoplasmic macromolecules, such as lipids and proteins. At lethal concentration the lipid content increased maybe due to vesicles formation. Proteins signal evidenced overall cellular dyshomeostasis associated to beta sheets and aggregate structures. Finally, the HPLC analyses confirmed that foraminifera can absorb until the 85% of the synthetic nicotine to which they have been exposed.

It is clear that CBs and nicotine contained in them affects the viability, the shell-building mechanism, and the macromolecular composition of the foraminifera themselves. The integration among acute toxicity assay, synchrotron and chemical HPLC analyses provided a valuable approach for the assessment of nicotine as biomarker of exposure to the toxicants associated with smoking and the impact of this emerging and hazardous material on calcifying marine species.

AI for unknown marine Foraminifera

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Life characterizes the Earth, and the most extraordinary feature of life is diversity. Despite 2 million species of identified eukaryotes, the most recent biodiversity estimates suggest that more than 80% of species remain unknown to science, among them foraminiferal Monothalamea. We want to focus on these tiny single-celled creatures forming an organic “soft” test, recently approached by taxonomic studies, counting relatively few known species vs a huge number of undescribed morphotypes spread across the marine realm. Few researchers deal with their taxonomy because of the difficulties in the morphological identification and their time-consuming task. In addition, due to the fact “soft” monothalamids are not fossilizing, they are generally overlooked by micropaleontologists. However, they are abundant and represent an important foraminiferal component living in the marine ecosystem whose further knowledge might fill some empty, but potentially important, knowledge areas to responsibly manage and conserve the planet’s resources. In fact, lack of biodiversity data

impairs our ability to deeply understand the issues affecting our oceans. The fact that "soft-shelled" monothalamous foraminifera often represent a largely undocumented component of foraminiferal diversity in coastal sediments makes them worthy of attention. Moreover, the missing taxonomic information on monothalamids, might be responsible for the biodiversity underestimate and compromise the biodiversity loss evaluation in case of environmental deteriorations.

In this view, the last decades, molecular systematics partially solved problems related to their taxonomic identification. However, sometimes molecular phylogeny identifies clades represented by undescribed or undetermined morphotypes from the morphological point of view. Based on this, we tried to develop an AI based approach to overcome the listed issues. Our AI approach concerns the use of machine learning techniques in order to support experts in the identification of 1) new morphologically-based species and 2) morphotypes in order to decrease their redundancy due to difficulties in classification. A total of 1000 images have been selected from scientific literatures and specific morphological targets have been chosen to capture taxonomic features of specimens per images (i.e., chamber shape, shell type and composition, type of aperture, type of cytoplasm, presence of stercomata or other inclusions). The dataset obtained from this step has been processed by clustering algorithms (i.e., K-Means and DBSCAN), resulting in different levels of clusters.

Preliminary results evidence that when the algorithm considers elements like basic chamber shape, the nature of shell and the shell type, all the morphotypes as well as the species of monothalamid group in 12 clusters where the chamber form is the major morphological element segregating each cluster. Moreover, in each cluster the taxonomic ranking of some monothalamous morphotypes (sp., family level) might be improved until generic level. Therefore, this complies the recent taxonomic revision present in WoRMS based on molecular SSU rDNA phylogeny completed with the description of major morphological trends in the evolution of this group. Authors conclude that basic chamber shape is one of the major taxonomic features separating orders or families among foraminifera as confirmed by the machine learning technique.

Our preliminary results therefore suggest that the taxonomic community might directly benefit from the AI system to fill the biodiversity gap on this key group at the base of the trophic chain among bacteria and pluricellular organisms.

Oceanographic condition on the southwestern Portuguese Margin during the Marine Isotope Stage 35: an atypical interglacial

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The Mid-Pleistocene Transition (MPT) was the most prominent global climate event of the Quaternary period. It was characterized by a global gradual cooling with an increase in ice sheet sizes and severity of glaciations, in parallel with the transition of 41 to 100 ky climatic cycles starting around 1250 ka, and the full establishment of maximum glaciations and 100 ky cycles around 700 ka. However, the exact timing and mechanisms behind this transition are still a matter of debate, with the number of high-resolution North Atlantic records that extend into the early Pleistocene, prior to the Mid-Pleistocene Transition, still being limited. Millennial-scale climatic variability is observed also in the early Pleistocene, including Marine Isotope Stage (MIS) 35, which, lasting from 1190 to 1148 ka, stands out as the longest interglacial period within the last 1.5 Ma.

To better understand this atypical interglacial, we produced high-resolution sea surface temperature (SST) and export productivity (Pexp) records determined from planktonic foraminifera assemblages, between MIS 36 and MIS 34 (1220–1140ka) in IODP Site U1385 located off the SW Portuguese margin. The Portuguese margin is considered a key paleoceanographic region since it records the climatic conditions at the high latitudes of both hemispheres (Greenland and Antarctica). For a broader perspective, these data are combined with benthic and planktonic foraminifera stable isotope records, XRF-derived element ratios, and total organic carbon data from this and nearby sites.

The results show relatively cold and productive conditions (11ºC and 82 $gC/m^2/y$) during the MIS 36/35 transition.

Temperature proxies during MIS 35 follow the insolation trend, with stable temperatures around 16ºC (4ºC colder than the present interglacial) between 1190 and 1162 ka, maxima of tropical-subtropical and transitional assemblages coincide with a maximum insolation period suggesting an intensification/ persistence of warm subtropical waters. The maximum in productivity (*Neogloboquadrina incompta*, Pexp) during MIS 35 is recorded at the beginning of the interglacial, followed by relatively high and stable (as well as warmer) conditions between 1190 and 1162 ka. However, low *Globigerina bulloides* but high *N. incompta* abundances suggest diminished coastal upwelling conditions but a stronger influence of a North Atlantic Drift branch (paleo-Portugal Current).

During the cold event that marks the inception of glacial MIS 34 (1152 ka) SST drops to 6ºC and Pexp to 63gC/m2/y, only to rise again to 22ºC SST and 50gC/m^2/y Pexp at 1147 ka, i.e., during the subsequent warmer period. These fluctuations in SST and Pexp likely reflect fluctuations of hydrographic front(s).

The ecology and evolution of the deep-sea foraminifer *Chilostomella ovoidea* and its enigmatic plastid

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Foraminifera represent some of the most abundant microeukaryotes in many marine benthic environments. Contributing to their ecological success is their ability to thrive even in the most challenging environments, such as the hypoxic sediments in the deep sea. To cope with such extreme conditions, different foraminiferal species have developed a variety of ecological strategies, such as nitrate respiration in the absence of oxygen or harboring diverse ecto- or endosymbionts. Yet, despite the potential ecological significance, the deep-sea foraminiferal symbioses remain poorly understood.

Chilostomella ovoidea is a common and abundant species in bathyal deep-sea sediments. Previous research has indicated that *C. ovoidea* has several unique traits that include, for example, abundant chitinous structures in its cytoplasm and a distinct low-diversity intracellular microbiome. Surprisingly, *C. ovoidea* also harbors an intracellular plastid, of which the closest known relative is the plastid of the xanthophycean alga *Vaucheria litorea*. Retaining chloroplasts is common for kleptoplastic foraminifera living in the photic zone, but the function and origin of intracellular plastids in dark habitats like the deep-sea sediment is yet to be resolved.

In this study, we collected living *C. ovoidea* specimens from Sagami Bay, Japan, and used single-cell genomics and transcriptomics to gain molecular insights into the ecology and evolution of *C. ovoidea* and its potential symbionts. Gene expression analyses were used to identify the metabolic capabilities of the *Chilostomella* host. The single-cell metagenome was utilized to analyze the identity and function of the intracellular plastid. Our preliminary results indicate that the plastid genome is highly reduced and lacks several key features, such as the ability to photosynthesize. These findings suggest a potentially unique evolution of *Chilostomella* in conjunction with the plastid, where kleptoplasty has likely developed into a more permanent endosymbiosis. Such unique symbiosis may contribute to *C. ovoidea*'s ability to thrive in hypoxic and anoxic environments.

Revitalizing historic and iconic Trinidad type sections through archival research within Hans G. Kugler´s Legacy in Basel, Switzerland

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Cenozoic planktonic foraminiferal biozonations originated largely in Trinidad, SE Caribbean. Renowned micropalaeontologists like A Senn, HH Renz, J Cushman, PW Jarvis, RM Stainforth, P Brönnimann, B Carr-Brown, HM Bolli, and JB Saunders erected historic type sections there. Their efforts were economically driven within companies like Trinidad Leaseholds Ltd. Less known to the micropalaeontological community was that these pioneering works were orchestrated by Chief Petroluem Geologist Dr. Hans G. Kugler (1893-1986). He prioritized the use of microfossils while drilling for oil in Venezuela and Trinidad. Kugler, Father of Trinidad Geology, built the foundation of Trinidad`s geology where microfossils played an essential role.

Kugler's Legacy is unique and highly treasured for Caribbean micropalaeontology. It is home to the world's largest Trinidad collection, stored at Natural History Museum Basel (NMB), Switzerland. The Legacy comprises an 85 box archive, field books, maps, photo collection, rock and microfossil collections, raw sediment samples, and a very special hand library. Kugler and collaborators, in the 1930s-1970s, established iconic type sections in Trinidad. From these type sections, replicate samples were distributed around the world (e.g. Natural History Museum London and The Smithsonian Institute, USA), though the majority is stored at the NMB. Among others, these Trinidad type sections became international standards for biostratigraphy.

For this project, all archival documents were read, contextualized, catalogued, and where possible, reconnected to original objects at the NMB. Very important documents were digitized. This project is the first deep investigation into Kugler`s archive. We found that Kugler meticulously preserved practically all relevant information, including that of his

collaborators. The Legacy was originally systematically built with numbered documents and books. However, order was lost when shipping the Legacy from Trinidad to Basel in batches and bits. Our current research has shown that the original numbering system is extremely useful in finding virtually any relevant information. Kugler´s archive also details advances in field mapping, aerial photography, oil well drilling, and electrical logging.

Unique to Basel, Kugler´s Legacy is the only means to restore scientific context (age, location, date, author, etc) to Trinidad type material stored at the NMB and around the world. From our research, original type samples can be restored to their original geographic position using literature, photos and maps within the archive. Interestingly, many Trinidad type samples are encrypted with a peculiar biostratigraphic code, rendering them unsuitable for new scientific investigations. We have, however, uncovered ciphers within the archive that decode the samples, something largely unknown for over 25 years.

Our new research will allow the construction of age-depth models and subsequently contribute to quantitative refinement and help decipher age information of historical reference samples around the world, that otherwise would be lost to science forever. Our effort may thus inspire similar studies on other Trinidad classical type localities using archival materials and collections held at other museums around the world. We also call to draw much more attention to linking micropaleontological archives with their collections – such as those maintained at NMB and others around the world – which reflect much of the historical rise of the petroleum industry, its influence on micropaleontology, climate research, and man's attempt to tackle current global climate deteriorations.

Biogeography of benthic foraminifera in contourite drift systems

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Contourite Depositional Systems (CDSs) are areas along continental margins where thick sedimentary deposits accumulate due to the persistent action of intensified bottom currents. The hydrodynamic conditions in CDSs pose unique challenges for the benthic meiofauna with respect to substrate (in)stability, winnowing and potential displacement. At the same time, CDSs provide ideal habitats for suspension feeders. Faunal studies on benthic foraminifera from the SW Iberian Margin have demonstrated that intensified bottom currents linked to Mediterranean Outflow Water (MOW) favour a distinct group of suspension-feeding foraminifera. Through occupation of elevated substrates these foraminifera optimize the acquisition of food particles carried by the bottom current, giving them a competitive advantage over other epibenthic organisms. Abundances of this elevated epifauna (EEF) follow gradients of bottom current velocity, making them a potentially powerful proxy of hydrodynamic properties of ocean currents in the past. However, quantitative information on the distribution of benthic foraminifera in CDSs beyond the Iberian Margin is sparse. This lack of biogeographic knowledge inhibits the development and application of assemblage-based proxy methods to successfully unlock paleoceanographic and paleoclimatic archives of CDSs linked to intermediate and deep waters of the thermohaline circulation in the Atlantic Ocean. Here we present new benthic foraminiferal data from surface samples in CDSs of the northern North Atlantic (Björn, Gardar and Eirik drifts, 55-62°N) and along the Brazilian Margin (11-22°S) and integrate them with available foraminiferal data sets from the Iberian Margin.

Multivariate statistical analyses reveal that the quantity and quality of organic matter flux, hydrodynamic conditions at the sediment-water interface and substrate properties act as major controls on foraminiferal distribution in and between CDSs. A distinct biogeographic divide can be recognized, reflected in the distribution of different types of suspension feeding foraminifera. High abundances of attached EEF species such as *Cibcides lobatulus*, *C. refulgens, C. pachyderma* or *Planulina ariminensis* are sustained at strongly increased current velocities > 20 cm/sec along the European, Greenland and Brazilian continental margins at intermediate water depths. Assemblages along the pathway of MOW show a particularly high diversity of EEF species, probably the result of the Mediterranean heritage of this fauna. In contrast, cold, deep and comparatively less saline water masses with lower bottom current velocity (< 15 cm/sec) linked to the Atlantic Meridional Overturning Circulation are dominated by more delicate agglutinated tubular suspension feeders such as *Saccorhiza ramosa*, *Rhizammina algaeformis* and *Rhabdammina abyssorum*. EEF taxa are comparably rare or even absent as their competitive advantage is reduced at low current speeds.

The integrated CDS data sets suggest that assemblage-based proxy methods for the assessment of hydrodynamic properties cannot be generalized. For successful development and application, the regional effects of hydrodynamic conditions and ecological heritage on the distribution of suspension feeding (morpho)types have to be considered for a given study area.

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Paleoclimate and paleoenvironment reconstructions from middle Eocene successions at Beni-Suef, Egypt: foraminiferal assemblages and geochemical approaches

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The studied outcrops in north Egypt were lithologically subdivided into two middle Eocene rock units, the Qarara Formation (Lutetian) at the base and the overlying El Fashn Formation (Bartonian). The investigation of forty-three rock samples yielded 160 species of benthic foraminifera and subspecies which belonging to 4 suborders, 19 superfamilies, 34 families and 59 genera. Four local benthic foraminiferal zones were identified and named as follow: (1) *Bolivina carinata* Lowest Occurrence Zone (Lutetian), (2) *Bulimina jacksonensis* Concurrent-Range Zone, (3) *Nonion scaphum* Lowest Occurrence Zone and (4) *Brizalina cooki / Nonionella insecta* Concurrent-Range Zone (Bartonian). The depositional environments and prevailing climatic conditions were estimated depending mainly on the geochemical results coupled with the statistical analysis of the benthic foraminiferal fauna and their bio-ecological preferences, the lithologic features and the associated macrofossils and large benthic foraminifera. The lower part of the Qarara Formation was deposited in middle to outer shelf settings with low to moderate oxygen levels, humid and wet climatic conditions. The upper part of the Qarara Formation and the exposed part of the El Fashn Formation at Gebel Qarara were accumulated in shallow water-depth, well oxygenated environments, hot and arid climatic conditions. El Fashn Formation at El Heiba area was deposited in deeper settings compared to the same rock unit at Gebel Qarara, this change in the depositional environments may be related to changes in the paleotopography of the depositional basin or could be attributed to local tectonics. The strong similarity of the identified foraminiferal assemblages with Libya (southern Tethys) indicates migration through the Trans-Sahara Seaway, while minor similarities with the northwestern Tethys province and the North Atlantic could be correlated to their benthic nature which limit their distribution distance the cooler climatic conditions further to the north.

Apparent Megadiversity of Tibetan Orbitolininae: Revision Overdue

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The published literature concerning Lower to mid-Cretaceous (late Barremian–Albian, ?early Cenomanian) Tibetan Orbitolinidae suggests a megadiversity with almost exclusive reference to taxa with a complex embryo (subfamily Orbitolininae). In fact, 40 new species of the Orbitolininae were described from Tibet, alongside several well-established species and their synonyms. A critical revision (excluding study of type-material) concludes that among these supposedly new species just three appear to represent valid taxa: *Palorbitolinoides hedini* Cherchi & Schroeder, *P. pileus* (Fossa-Mancini) comb. nov. (junior synonym *P. orbiculatus* Zhang), and *Mesorbitolina tibetica* (Zhang) comb. nov. The genera *Columnorbitolina* Zhang and *Tibetella* Zhang are herein considered as junior synonyms of *Mesorbitolina* Schroeder. As a consequence, the mid-Cretaceous Orbitolininae assemblage of Tibet appears to be not substantially more diversified than in other regions of central and western Neotethys.

In contrast to the Orbitolininae, Dictyoconinae are clearly underrepresented in the Tibetan region. The first record of *Palaeodictyoconus actinostoma* Arnaud-Vanneau & Schroeder, a species previously known from eastern Spain, southeastern France and Central Iran is worth mentioning. Many other dictyoconids known from the western and central parts of the Neotethys are seemingly absent.

The stratigraphic record of the Tibetan Orbitolinidae still needs further data as well as knowledge concerning the apparently poorly diversified associated assemblages of other benthic foraminifera and dasycladalean algae. Finally, controversial recently published data on the biostratigraphy of orbitolinids from Tibet, such as the occurrences of *Palorbitolina lenticularis* (Blumenbach) in the late Aptian, or *Praeorbitolina* cf. *wienandsi* in the late Albian need to be reconsidered as they contradict widely accepted range charts.

Local biodiversity of recent foraminifera in three coral reefs in the extremely warm Persian/Arabian Gulf

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Extremely warm seas are characterized by hostile conditions due to temperatures that threaten sensitive symbiotic relationships or require specific adaptation strategies within local organisms. These environments can help to shed light on conditions in other areas of the world where climate change is causing increasingly extreme temperatures. The Persian/Arabian Gulf (PAG) is such a sea, hosting coral reefs adapted to extremely warm temperatures (up to 36°C in the summer) which is exceeding the thermal maxima of nearly all tropical reef fauna by more than 2°C, as well as having extreme salinities (>42 ppm). Due to these extremes there is a limited coral biodiversity, whereas foraminiferan biodiversity is comparable to other water bodies in the world, with ~750 benthic foraminiferal species identified to date. Benthic foraminifera are excellent indicators of coral reef health and are often used in biomonitoring studies as pollution indicators. In order to improve foraminifera biodiversity assessment in the local scale, three reefs of the Southern Gulf, off the coast of Abu Dhabi, were screened for biodiversity with replicated sampling along several 10 m transects (Ras Ghanada, Saadiyat and Dhabiya, n=12). Sediment samples were stained immediately in rose bengal to distinguish live from dead foraminifera. Living foraminifera community was analysed using three biodiversity indices (Shannon diversity, Margalef's richness and Dominance) and pricinpal component analysis. It was shown that 33 species were present. *Tretomphalus* sp. being the most abundant, which is remarkable. The fauna of Ras Ghanada was strongly dominated by the species *Tretomphalus* sp. (59 to 88 %), which was also observed to a lesser extent in Saadiyat (maximum of 67%). This species had a patchy distribution, as it occurred as a colonizing form mainly attached on dead coral fragments but also lose. The second most abundant species was the symbiont-bearing species, *Peneroplis planatus,* hosting red algae symbionts. The biodiversity indices showed that the fauna of Ras Ghanada had lower diversity and higher dominance of individual species compared to Dhabiya and Saadiyat. There are also differences among replicates within the reefs, showing that the benthic foraminifera assemblage in this coral reef habitat can vary substantially on small scales, and confirming that replicated sampling is essential. Furthermore, the reefs therefore differ in the proportion of test wall material. Within the Dhabiya reef, the highest proportion of agglutinated and porcelaneous-agglutinated tests was found. Dhabiya and Saadiyat are characterized by a high proportion of porcelaneous tests, whereas Ras Ghanada is dominated by hyaline species. The results of this project contribute to biodiversity assessments of extreme habitats, and can help to interpolate how this population is different from other locations. The PAG is an important study region for understanding local adaptations of species to extreme warm and saline conditions.

Menthol-induced bleaching as an effective method to rear foraminifera aposymbiotic

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Symbiotic relationships with microalgae and thermal adaptations of host and symbiont are shaping the stress tolerance of LBF (larger benthic foraminifera) to climate change. The aim to better understand bleaching has led to search for novel ways to gain aposymbiotic hosts. Menthol-bleaching is an innovative methodological approach which has been recently applied in *Aiptasia pallida*, a sea anemone, to rear aposymbiotic individuals for symbiosis investigations. Repeated menthol applications cause a cold-sensation in the host organism, which subsequently expels its microalgal symbionts. To test if this method can be used to rear LBF apo-symbiotic was tested in a bleaching experiment for 6 weeks. We applied the treatment to the diatom containing *Amphistegina lobifera* and dinoflagellate containing *Sorites orbiculus*.

In order to induce bleaching, the foraminifera were exposed to repeated seawater changes containing menthol at non-lethal concentrations in the presence of the photosynthetic inhibitor DCMU (3-(3,4-dichlorophenyl)-1,1-dimethylurea) diluted in seawater for a 6-week bleaching experiment. Survival rate of foraminifera was high, as pseudopodial movement was visible under the inverse microscope. The foraminifera in this bleached state were able to move and extend their pseudopodial network for feeding and locomotion. After the 6 weeks experiment, foraminifera were >95% symbiont-free, visible through images in the inverted epifluorescence microscope and chlα measurements. This method is hence effective and will serve in subsequent experiments to test symbiont-uptake post-bleaching, for which selected diatom species will be re-inoculated in the aposymbiotic hosts. With this approach we hope to shed light on symbiont flexibility in LBF and to test the capacity to elevate their thermal tolerance by selecting thermally tolerant symbiont strains before re-inoculation.

Life in a dark environment –physiological response of benthic foraminifera to the environmental changes of the Paleogene

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The Paleogene is a dynamic interval of Earth's climatic history, beginning with the trauma of the K/Pg, followed by a series of hyperthermal events, including the PETM and ETM2. These events represent severe disturbances/perturbations of global carbon cycling and the wider Earth system. Extinctions, migrations and evolutionary turnover are associated with all events, and their patterns give insight into physiological stress affecting marine biota.

We investigate morphological response (surface area, test volume, calcite volume, chamber number) in benthic foraminiferal species *(Nuttallides truempyi*, epifaunal; *Oridorsalis umbonatus*, shallow infaunal) at central Pacific Site 1210 (Paleo Depth 2100 m), Southern Ocean Maud Rise Site 690 (PD 1900 m), Walvis Ridge Site 1262/1263 (PD = 3500/1500 m), and Kerguelen Plateau Site 1135 (PD ~800 m) using computed tomography (CT).

Despite the lack of extinction of benthic foraminifers during the environmental crisis at the K/Pg boundary, taxa from the Southern Ocean display shifts in species abundance, richness, size, growth rate, and surface area:volume in the aftermath of the Chicxulub impact event, revealing the potential role of morphological plasticity for promoting resilience and survival in benthic calcifiers. In contrast, data from the central Pacific reveal very few changes, also suggesting that trait changes across the K/Pg occurred at different times in different environmental settings and groups, supporting the hypothesis that environmental heterogeneity is important in modulating resilience.

During the PETM and ETM2, the relative warming was similar at all study sites, thus differences in biotic effects between locations are probably not related to differential warming. During the PETM, environmental changes led to reduction of test volume of both species, negatively impacting their potential ability to generate gametes. Similar reductions are found for *N. truempyi* during the ETM2 except for the deepest site in the Atlantic. During the PETM, *N. truempyi* increased its surface area relative to volume in the Southern Ocean, potentially increasing its ability to forage and take up oxygen. In contrast, there is no clear pattern of change in shallow infaunal *O. umbonatus* which, given sufficient food, can thrive at lower oxygen conditions. Calcite volume/test volume decreased in both species during the PETM in the Southern Ocean during the PETM; the lack of response in the Pacific was possibly driven by persistent severe oligotrophy. For the ETM, no change in calcification was detected. Food availability at the Southern Ocean sites may have supported growth (indicated by test volumes), but did not supply enough energy for calcification to mitigate against acidification during peak PETM conditions.

Faunal composition and isotopic fingerprinting of benthic foraminifera to distinguish contourites from turbidites

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Benthic foraminifera in Contourite Depositional Systems (CDSs) potentially provide key information for the reconstruction of oceanic bottom currents. In the CDS of the SW Iberian Margin, abundances of a distinct group of benthic foraminifera are controlled by the velocity and nutrient load of bottom currents. This so-called "elevated epifauna" (EEF) comprises highly specialized suspension feeding benthic foraminifera attached to elevated substrates as an adaptation to strong bottom currents. A direct relation between EEF abundances and Mediterranean Outflow Water (MOW) velocity has been demonstrated in modern surface samples, highlighting their potential as a bottom current proxy. In the sedimentary record, however, contourite deposits are often intercalated with gravitational deposits that may compromise paleoceanographic interpretations. The reliable distinction of the contourites, turbidites and turbidites reworked by bottom currents and their respective content of foraminiferal shells is thus essential to ensure the reliability of the EEF proxy method. Here we present a unique, highly resolved set of faunal and isotopic ($\delta^{18}O$, $\delta^{13}C$) data from benthic foraminiferal shells > 250 µm in Pleistocene contourite and turbidite sequences at IODP Site U1389 in the Gulf of Cadiz. The data allow us to characterize and compare assemblage composition, abundances of EEF species and provenance of shells of EEF taxa.

Multivariate statistical analyses reveal foraminiferal assemblages distinctive for contourites and turbidites, respectively. EEF data along the bi-gradational contourite sequence indicate that their abundances may serve as a reliable indicator of bottom current strength even at strongly increased bottom current velocity beyond the limits of some established sedimentological proxy methods. When combined, sedimentological and micropaleontological proxy data thus allow for a more complete and robust characterization of the processes underlying contourite deposition.

Non-reworked and reworked turbiditic deposits show significant amounts of taxa with a bathymetric distribution limited to the shelf as well as EEF taxa. In the non-reworked turbidite, their abundances decrease along the normally graded sequence. Isotopic data of several hundred EEF shells suggest that at least 50% of *C. lobatulus* were re-deposited from the shelf, while the vast majority of *C. pseudolobatulus*, *P. arminensis* and *Discanomalina* spp. originate from the continental slope. The combination of high abundances of *C. lobatulus* and shelf taxa may thus serve as a good indicator of bias by turbiditic transport, in particular when turbiditic deposits have been reworked by bottom currents and are barely distinguishable from contourites.

While used in the present study to characterize the differential origin of EEF shells within a turbidite, isotopic fingerprinting potentially allows the characterization of gravitational mass wasting events in general by pinpointing its origin and allowing for assumptions regarding its pathway and transport distance.

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Benthic foraminiferal record of deep-sea biodiversity changes during the late Quaternary

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The biodiversity of deep-sea ecosystems is closely linked to climate variability as documented by the diversity and species composition of benthic foraminifera in late Quaternary sediments. The benthic foraminiferal diversity changes are primarily controlled by variations in food fluxes and bottom-water oxygenation with distinct regional differences. The observed regional diversity patterns and temporal trends suggest that highly diverse deep-sea ecosystems are more resilient to drops in oxygen than low-diverse ecosystems, supporting the diversity-stability hypothesis. Seasonally enhanced food fluxes in oligotrophic and well-ventilated deep-sea ecosystems, such as the Nordic Seas, commonly lead to a dominance of opportunistic taxa and thus do not necessarily result in a diversity increase. Absolute diversity contrasts between glacial and subsequent interglacial periods increase with increasing water depth, with relatively lower glacial diversity in the deep parts of the open oceans (Nordic Seas, Atlantic Ocean, Southern Ocean, Indian Ocean) but higher glacial diversity in the marginal seas (Mediterranean Sea, Red Sea). This difference can be attributed to the different regional response of thermohaline processes to climate changes. Specifically, benthic ecosystems of deep open-ocean basins profit from enhanced ventilation during interglacial conditions, while in marginal basins of the Mediterranean and Red seas, warm and humid conditions during insolation maxima repeatedly result in a temporal shut-down of deep-water formation with transient collapses of deep-sea ecosystems.

Foraminifera and Other Organisms: Determination of Interactions and Ecology (project FOODIE) in two contrasting environments

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Foraminifera represent a critical part of the meiofauna and are present in all marine benthic environments from salt marshes to abyssal trenches, they have also colonised the planktonic realm. Denitrification and kleptoplasty demonstrate that foraminifera have diverse life strategies and are part of a complex association network that remains poorly defined. Their life strategies could be influenced by the geochemical conditions of the living environment (microhabitat). An adequate description of these conditions with high-spatial resolution measurements is thus essential.

Our study combines high-throughput sequencing of the microbiome (prokaryote and eukaryote) with morphological and TEM (transmission electron microscopy) analyses of foraminifera sampled at the same time in the same location. In parallel, geochemical data were collected to characterise the microhabitats from which these foraminifera originated. Additionally, sediment samples were sequenced for environmental DNA (eDNA) to compare the foraminiferal microbiome with in situ micro-organism communities. Two contrasting sites were chosen: Bourgneuf Bay, a mudflat located on the French Atlantic coast, and the Gullmar Fjord, located on the Swedish Skagerrak coast. At both sites the biodiversity are well known and at Bourgneuf Bay foraminiferal population dynamics combined to sediment geochemistry are well understood through a long term survey (Mudsurv). Therefore, these sites are ideal to study the interactions of foraminifera with other organisms.

The main objective of this study is to document the trophic strategies of foraminifera and their interactions with the ecosystem of the sites studied. For Bourgneuf Bay, foraminifera belonging to five taxa have been sequenced for their microbiome in three different sediment depths. The three taxa with a hyaline test have also been examinated with TEM. For the Gullmar Fjord, 29 species sampled in three different sites could be sequenced for their microbiome. Among these species, six hyaline ones were fixed for TEM analyses. The microbiome profiling shows that kleptoplastic species contain diatom sequences (16S and 18S rDNA) in higher abundances and more systematically than more omnivorous or less specialised species. The diversity of the internal microbiome of foraminifera, the similarity of the microbiome in the same species between different locations and the ecological interactions between foraminifera and their microbiome will also be discussed. With TEM, kleptoplastic species show well preserved chloroplasts in higher numbers than non-kleptoplastic species, whereas denitrifying species have higher numbers of large vacuoles. Combining the microbiome and TEM results with geochemical characterisation and live foraminiferal distribution in the sediment will also help answering how the foraminiferal microbiome compare to the microhabitat, how environmental differences influence foraminifera and other micro-organisms and what are the most influential associations in the habitats examined.

Harmful Algal Bloom (Red Tide) Monitoring Utilizing Benthic Foraminifera on the West Florida Shelf (USA)

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Karenia brevis is the primary species of dinoflagellate that causes "red tide" in Southwest Florida, a harmful algal bloom associated with brevetoxins. Blooms of *K. brevis* can result in reduced water quality including anoxia, fish and wildlife mortalities, and human health concerns on the West Florida Shelf. The majority of observations for *K. brevis* and related impacts are focused in the nearshore neritic zone, since blooms occur there throughout the water column. Far less sampling in the benthic zone has been conducted, thus whether there's a role of the benthos in bloom initiation and other key dynamics remains unknown. Recent evidence that similar species, including *Karenia mikimotoi*, produce resting stages has led to an increased interest in understanding the life cycle of *K. brevis* and thus the role that the benthic environment plays on

initiation and termination of bloom events. This collaborative effort involves working with the Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute's Harmful Algal Bloom (FWRI-HAB) group to investigate *K. brevis* benthic coupling with the goals of 1) providing environmental context of the benthos; 2) establishing baselines of *K. brevis* bloom impacts/conditions in benthic environments utilizing multiple benthic foraminifera metrics including density, diversity indices, and marine biotic indices coupled with, and calibrated to, *K. brevis* abundance and 3) evaluating the historical record of the magnitude and frequency of red tide blooms constrained by short-lived radioisotope dating, coupled with seafloor ecological quality status based on benthic foraminiferal biotic indices.

To address these goals, surface sediment samples have been collected on a monthly basis since January 2021 at five sites along a westerly transect (70 km offshore, 5-40 m water depth) from Tampa Bay, Florida. Multicores have been collected at sites specifically identified as depocenters to produce continuous historical records and avoid sediment reworking as much as possible. Both stained (rose Bengal, for monitoring purposes) and total (for historical purposes) benthic foraminifera assemblages have been characterized to produce density, diversity indices (e.g. Shannon, Fisher's Alpha, Evenness), and marine biotic indices (f-AMBI). These benthic foraminifera metrics have been paired with sedimentology (texture and composition) and short-lived radioisotope dating for historical record constraint. Future work will pair the benthic foraminifera records of seafloor health with and calibrate the f-AMBI to indicators for *K. brevis,* and complements ongoing work using neritic cell concentrations of this HAB.

This study will present more than two years of monitoring data along with historical (last 100 years) profiles, linking benthic foraminifera indicators of seafloor health with potential red tide indicators. Preliminary evidence suggests that the f-AMBI recorded a decrease in seafloor ecological quality status in response to high concentrations of *K. brevis* during a bloom in late 2021. Ongoing and future work will include refining historical records, developing new tools for historical red tide tracers, and refining the calibration of benthic foraminifera-based marine biotic indices to various red tide indicators. These collective goals are critical for laying the groundwork for a benthic monitoring program to aid in forecasting bloom dynamics (initiation and termination) as well as the seasonal and interannual effects of red tide on the seafloor.

Trace elements through life and time of planktic foraminifera

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Trace elements incorporated within a foraminifera test along with stable isotope ratios can reveal the chemical and environmental conditions at the time of their growth. We investigate how chamber specific trace element ratios correlate with individual-level stable isotope ratios and which parts of the life cycle imprint the largest geochemical signal for the whole individual. We ask if these correlations vary over geological time, by species or individual growth stage. As the sensitivity of geochemical analysis improves, it is now feasible to build sufficiently powerful datasets to investigate palaeoclimatic variation at the level of individual chambers within individual foraminifera, rather than averaging analyses that obscures systemic sources of variation.

We present the largest trace element, mass and stable isotope ratio data set of four Menardella from Plio-Pleistocene sediments at ODP Site 925 in the western equatorial Atlantic Ocean. We measured trace elements in six chambers within the final whorl, whole test mass and stable isotope ratios for ~2,000 individuals over the *Menardalla menardii*, *M. limbata*, *M. exilis* and *M. pertenuis* evolutionary lineage. Deploying improved protocols for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), we quantify the elemental composition of fossilised foraminifera tests while controlling for individual ID, age and species.

We show how Mg/Ca ratios change through ontogeny, suggesting a change in how organisms use their environment during life by inhabiting different water depths and if symbionts were hosted. The ancestral species demonstrate a marked increase in Mg/Ca ratios during life, whereas descendent species show no detectable changes, suggesting the ancestral species alter their depth habitats during life, unlike their descendent species.

In earlier chambers, where the calcite wall is thickest, Mg/Ca ratios are 3-4 times stronger in correlation to whole test $\delta^{18}O$ values than later chambers, implying that the environment that determines the individual level $\delta^{18}O$ value is that experienced earlier in life.

The correlations between chamber-specific trace element ratios and individual-level $\delta^{18}O$ values reinforces the repeatability of these high-resolution techniques and the capacity of planktonic foraminifera to record the chemical and environmental conditions at a fine, mid-life resolution.

Warm Water Incursions and Water Mass Changes on the Ross Sea Shelf (Antarctica) During the Plio-Pleistocene Based on Foraminifera from IODP Exp 374

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International Ocean Discovery Program (IODP) Expedition 374 sailed to the Ross Sea in 2018 to reconstruct paleoenvironments and assess model simulations that show warming waters in the Southern Ocean led to the loss of Antarctic ice in the past. Site U1523 (water depth 828 m) is located at the continental shelf break and is sensitive to both warm water incursions from the Ross Sea Gyre and modified Circumpolar Deep Water (mCDW) coming onto the Ross Sea shelf when the Antarctic Slope Current weakens with a warming climate. Shelf sites U1521 (562 m) and U1522 (558 m) provide data for the environment closer to the Ross Ice Shelf. Multiple incursions of subpolar or temperate planktic foraminifera taxa occurred prior to ~1.8 Ma and after 4 Ma. Based on an updated age model at Site U1523 (2022), these warm water taxa incursions could represent Gi3 or Gi5, G15 or G17, Marine Isotope Stage (MIS) 91 or 89, and MIS 73-67 indicating warmer than present conditions and less ice cover in the Ross Sea. High abundances of foraminifera in the mid-to-late Pleistocene associated with MIS 31-37 and MIS 5e might also indicate a reduced ice shelf and relatively warmer conditions. The interval of abundant foraminifera around MIS 31 suggests multiple warmer interglacials during the Mid-Pleistocene Transition (MPT; ~800 ka). A change in benthic foraminiferal assemblages and a large increase in foraminiferal fragments after the MPT indicate stronger currents at the seafloor, and perhaps corrosive waters, suggesting a major change in water masses entering (mCDW) and exiting (High Salinity Shelf Water; HSSW) the Ross Sea since the MPT.

Carboniferous-earliest Permian foraminifera radiation certificated by a high-resolution biodiversity analysis

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A general foraminiferal biodiversification trend from the Carboniferous to the Early Permian has long been recognized by many researchers because of the sudden increase in fossil records. Several integrated quantitative analyses have been confirmed this trend, but only with limited data. A high-resolution biodiversity analysis based on 551 geological sections distributed over all the major Chinese tectonic plates was performed using a parallel computing version of the algorithm called CONOP.SAGA and the Chinese supercomputer "Tianhe II". As a result, the temporal resolution reached 36 kyr and 21 kyr for the Carboniferous and Permian, respectively. The precise details of the biodiversification process were revealed, including the high-resolution changes in species and genus richness, and the rates of origination and extinction. The biodiversification lasted 41.2 Myr from the middle Visean of the Carboniferous to the late Asselian of the Permian. The oldest type of larger benthic foraminifera, fusulinids, underwent an adaptive radiation event during this process and made a dominant contribution to the diversification. Fusulinid species richness increased nearly 40-fold during the radiation and developed two pulses in the late Bashkirian-Moscovian (Carboniferous) and Gzhelian (Carboniferous)-Asselian respectively, with peaks at the late Moscovian and late Asselian. During the same period, a diversification trend was also observed in the benthic brachiopod fauna. With a 246% increase in the total number of marine species, this event was named as the Carboniferous-earliest Permian Biodiversification Event (CPBE) to indicate the flourishing of the marine fauna. With the help of the high-resolution biodiversity analysis, more patterns and details would be revealed in the evolution of foraminifera.

Analysis of planktonic foraminifera abundance in ceramic samples from Pian della Tirena (Calabria, southern Italy): Application of JMicroVision software

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In the geological sciences, as in other scientific disciplines, the use of image analysis is becoming increasingly important for the analysis of remote sensing data and images, seismic images, thematic maps, and maps, but also for the study of thin-section samples photographed with a microscope-mounted camera.

For this thesis, an innovative study was carried out with the image analysis software JMicroVision version 1.3.4 to assess the abundance of planktonic foraminifera in photos of thin sections of ceramic and clay samples taken from the area of the archaeological site of Pian della Tirena (Calabria, southern Italy). The results obtained were compared with those obtained by traditional abundance analysis. This work encompassed all the steps for a quantitative analysis of the material, from obtaining the photos to collecting and processing the data, having as its ultimate goal to verify whether the measurement of the surface area occupied by planktonic foraminifera, calculated by the software, can represent a suitable and faster method than the traditional counting for the evaluation of planktonic foraminifera abundance.

The results obtained from both analyses are not directly comparable, so they were compared after their transformation into dimensionless numbers. Comparison of the data obtained with JMicroVision version 1.3.4 with those from the abundance calculation shows differences that are probably due to the limited size of the survey field used (8.6 x 6.4 mm) and the number of points classified (300). Therefore, further study is needed to identify the minimum area of the survey field and the minimum number of points to be classified so that the variability in the size of planktonic foraminifera is not a limiting factor.

Mg/Ca surface-water paleotemperatures at the Early Eocene Climatic Optimum from the Pacific Ocean: repercussions on planktic foraminiferal assemblages

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The Early Eocene Climatic Optimum (EECO; ~53-49 Ma), that records the peak of Cenozoic warmth and CO_2, induced climatic and paleoceanographic changes that significantly affected planktic foraminiferal assemblages. The main change is the permanent marked decline in abundance and diversity of the mixed-layer symbiotic bearing genus *Morozovella,* coupled with the increase of *Acarinina* starting from the basal EECO at the tropical Pacific Ocean (sites 1209-1210), similarly to the previously documented record from the Atlantic Ocean. A second significant variations is the change in coiling direction of morozovellids that moved from dominantly dextral to sinistral close to the K/X event, which differs from *Acarinina* which does not display any preferential coiling direction throughout. Even though a link between the aforementioned modifications and the EECO perturbation appears evident, the driving causes of the recorded modifications are still unknown.

With the aim to evaluate whether potential temperature increase may have impacted the observed planktic foraminiferal changes, we performed Mg/Ca derived paleotemperatures from tropical Pacific sites 1209-1210 through Laser Ablation (LA)-ICP-MS. Our results on B/Ca and Sr/Ca content in all the examined species and the low planktic foraminiferal test-fragmentation allow us to exclude significant influence on derived temperatures of pH variations and contamination. Our results reveal major temperature increase at the EECO as recorded by all the *Morozovella* species, after their abundance reduction, with respect to *Acarinina*, with *M. formosa* and *M. crater* recording higher increase and *M. aequa* and *M. subbotinae* the lower increase.

We hypothesize that the rise in temperature recorded by morozovellids may have contributed to a reduction in their symbiotic relationship that, in turn, caused their decline in abundance, as symbiosis is known to advantage life in oligotrophic mixed-layer habitat and helping test-growth. This hypothesis is also supported by the lower $\delta^{13}C$ signatures of the survivor sinistral morozovellids with respect to dextral morphotypes, and suggests less dependence on their photosymbiotic partnerships. It is thus possible that this character may have enabled sinistral morozovellids to be resilient, though in low abundance, to the EECO perturbance with respect to dextral forms. Although the exact causes of photosymbiont bleaching can be manifold, increased temperature is considered a primary factor of bleaching in present tropical larger benthic foraminifera. Even though it cannot be demonstrated whether sinistral and dextral morphotypes were cryptic species, the differences in their stable-isotope derived paleobiology could encourage this hypothesis.

The minor temperature increase recorded by acarininids may have been not sufficient to generate crisis in their symbiosis relationship. The acarininids $\delta^{13}C$ signatures do not display appreciable variations before and within the EECO thus to supporting this hypothesis. In addition, we record a thermocline temperature increase up to ~2°C through the analysis on

subbotinid specimens that may justify their drop in abundance and the chiloguembelinids virtual disappearance as being cold-water indices.

Impact of the Middle Eocene Climatic Optimum (MECO) on Atlantic planktic foraminiferal assemblages

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The Middle Eocene Climatic Optimum (MECO), centered at ~40 Ma, is characterized by marine bulk and benthic carbonate $\delta^{18}O$ values steadily declining by roughly 1‰ in over ~400 kyr, usually interpreted as a 3–6 °C increase in global temperature followed by a rapid return to pre-event conditions. This event is increasingly attracting the scientific attention as it records temperatures and pCO_2 that Earth will reach whether anthropogenic emissions will not stop (RCP8.5). Despite that, the biotic impact of the MECO are still poorly constrained. With the aim to contributing in filling this gap, we focus on planktic foraminifera, which, being extremely sensitive to the physical and chemical state of the oceans, can offer valuable insights on the impact of this global warming event on marine ecosystems. In addition, the $\delta^{13}C$ signal across the MECO event such as the paleoceanographic repercussions show great geographic heterogeneity. These features and the absence of a clear triggering mechanism make the MECO one of the most enigmatic events in the Cenozoic also known as middle Eocene **"**carbon cycle conundrum". We selected the Ocean Drilling Program sites, 1051, 1263 and 702 that cover tropical northern to farther southern high-latitude settings and provide established stratigraphic and stable isotope constrains.

The most pronounced change in planktic foraminiferal assemblages is recorded at Site 1051 (Blake Nose) as the 'large acarininids' (>150 µm) markedly and permanently reduce their abundance at the MECO top, as also recorded from Tethyan successions. It is well known that photosymbiosis is functional for growth in oligotrophic habitats so the loss of symbiosis may have represented a possible cause to explain the observed abundance reduction.

In the post-MECO interval planktic foraminiferal assemblages at Site 1051 do not recover the pre-event genera abundances. The planktic foraminiferal community shifted to a new permanent and different state thus we deduce that this group was not resilient to the MECO perturbance at this site.

In addition, our data suggest a southern migration of 'large acarininids' as, at Site 1263 (Walvis Ridge), the abundance drop of this group is much less marked. The southern migration of the 'large acarininids' is much more evident at Site 702 (Islas Orcadas Rise) where 'large acarininids' markedly increase at the MECO interval favoured by the temperature increase. The post-MECO assemblages here show a recovery of the pre-event abundances, with the exception of the genus *Chiloguembelina*, which shows a striking increase in abundance thus suggesting an intensification of the Oxygen Deficient Zone.

The recorded changes further document the complexity and the geographic variability of the MECO repercussions on marine ecosystem.

A critical review of Larger Benthic Foraminifera of the Cenomanian; planispiral (or near-planispiral) forms

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A key task for biostratigraphers is provide a biozonal/bioevent framework for geological corelation. This can be challenging because of lack of agreement on stratigraphic ranges and calibration between fossil groups and to the standard geological timescale. Larger Benthic Foraminifera (LBF) are a case in point. LBF are important biostratigraphic markers in depositional environments where classical biostratigraphic fossils such as planktonic micro- and macrofossils are rare or absent – for example, in tropical-subtropical shallow water platform and ramp carbonates. However, a seeming lack of taxonomic rigour in identifying species, together with a general lack of good age-calibration of their occurrences, has given rise to artificially extended biostratigraphic and paleogeographic ranges for many taxa, thus diluting their usefulness. In this study the occurrences of Cenomanian LBF belonging to a morphological subgroup consisting of essentially planispiral coiled and uncoiled forms, both agglutinated and calcareous (the "planispiral morphogroup") have been critically evaluated to determine (i) identity; (ii) stratigraphic range; and (iii) palaeogeographic distribution.

The last major review of mid-Cretaceous LBF took place in 1985, and even then, did not include all the planispiral taxa known at that time. Since then, a voluminous literature has appeared reporting occurrences and adding new taxa. An extensive literature review of some 600-700 published items on Cenomanian "planispiral" LBF – mostly published after 1985 – and a critical review of the confidence in species identification and age-calibrations therein, has led us to identify 39 taxa (including three in "open" status) which appear to be separable. These taxa belong to the Lituolida, Loftusiida, Miliolida and Soritida. The vast majority of these records are from Neotethys although some also occur in (or are endemic to) the Caribbean/West Atlantic and the Eastern Pacific. Much of the quality of the published taxonomic data is variable and many published records can be discounted or termed "unconfirmed" as to correct identity. In parallel, many records (confirmed or otherwise) are poorly age-calibrated due to a lack of corroborating biostratigraphy or (e.g.) chemo-stratigraphy or by using circular reasoning.

Although not a monographic treatment, we summarise and illustrate the main defining characteristics of each taxon and their possible "confusion" species and include new taxa described since the mid-1980s. We publish new, more confident, age-ranges for these taxa – confirmed by identity and/or age-calibration – and identify where (published) range data may be less reliable or completely unreliable. Paleogeographic distribution maps for each taxon are also provided. Particular stratigraphic issues around the Cenomanian-Turonian boundary are observed due to the difficulty of identifying that boundary in the field, especially in the central - eastern Neotethys region.

Although most Cenomanian "planispiral" LBF are generally long-ranging, an increase in diversity throughout the middle and late Cenomanian has shown potential for biostratigraphic resolution to at least substage level with this group. It is hoped that similar future treatment afforded to other LBF morphogroups (integrated with the "planispirals") will yield even higher biostratigraphic resolution of Cenomanian LBF and provide a sound basis for biozonation (both local and global), correlation, and age calibration.

Geochemical and Mineralogical investigation of "foraminifera barren layer" in Maastrichtian carbonate ooze of Walvis ridge

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The paleoclimate reconstructions for Maastrichtian are extensively based on test carbonate $\delta^{18}O$ of foraminifera from DSDP Site 525A (South Atlantic, Walvis Ridge). However, the fidelity of such datasets is contingent upon the taphonomic state of individual tests as well as assemblages. Two conspicuous foraminifera-barren levels stand out at 511 mbsf in contrast to the generally planktic foraminifera rich oozes. The stratigraphically adjacent levels of these barren layers yield assemblages of comparable taphonomy and species composition, indicating an apparent continuum of paleoenvironmental conditions. This warrants an investigation of the foraminifera-barren layer to ascertain whether it is of palaeoenvironmental or epigenetic hydrothermal origin.

Results show that the planktic foraminifera assemblages in the immediately underlying and overlying stratigraphic levels of the barren layers are fragile and are dominated by robust globotruncanids (~50%), while the other groups such as rugoglobigerinids, heterohelicids and globotruncanellids are lower in abundance. The relative abundance of *Heterohelix rajagopalani,* a robust thick-walled deep-dwelling biserial, is also high. Other stratigraphic levels away from the barren layer record typical Maastrichtian assemblages with abundant rugoglobigerinids, heterohelicids and globotruncanellids, and a lower representation of globotruncanids. Together these indicate the possibility of taphonomic inflation of robust species in the levels adjacent to the barren layers. X-ray diffraction study of the barren layers reveals jarosite, orthoclase and gypsum. This mineral assemblage suggests an interaction of oxygenated fluid with the host carbonate ooze. Mass balance calculations suggest that the ooze is a potential source of calcium for the formation of gypsum. It may be speculated that the sulphur supply for jarosite, natrojarosite and gypsum could have come from hydrothermal vents related to Walvis ridge activity. It can be concluded that the barren layers are of an epigenetic (hydrothermal) rather than paleoenvironmental origin.

Migration of the Subtropical Front over the Indian Ocean and its Impact on the Agulhas Current during Quaternary: Planktonic Foraminiferal Evidences

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Agulhas Current (AC) is the largest western boundary current transporting ~70 Sv water. It feeds the returning arm of the Atlantic Meridional Overturning Circulation (AMOC). The Indo-Atlantic exchange of waters occurs through the Agulhas Leakage (AL) transports heat and salt to the Atlantic Ocean in form of rings and eddies. AL is regulated by the latitudinal position of the Sub-Tropical Convergence (STC), which has been defined as the boundary between warm saline subtropical surface waters and cooler fresher Subantarctic waters, with its normal latitudinal position at 40^0 S. The onset of glacial climates causes the northward shift of the STC, which in turn not only reduces the AC flow, but also the AL.

We analysed 136 samples from IODP Hole U-1474A for the planktonic foraminiferal census data and $\delta^{18}O$ of *Globigerinoides ruber* to study the variation of AC during the last ~1 million year. The age model was developed using the stable oxygen isotope data.

We selected the key planktonic foraminiferal species on the basis of the relative abundance and watermass preference. The key species considered for the study are *Globigerinoides ruber* (warm tropical to subtropical watermass), *Globorotalia inflata* and *Globorotalia truncatulinoides* (subtropical to transitional water mass), *Neogloboquadrina pachyderma* (subpolar watermass, indicative of cold polar water intrusion at the lower latitudes), *Globigerinita glutinata* and *Neogloboquadrina dutertrei* (productivity indicators at tropical to subtropical latitudes) and *Globigerina bulloides* (subpolar watermass, indicative of seasonally enhanced productivity at mid and high latitudes). The Sub-Tropical Convergence (STC) index was calculated as: [*Globorotalia truncatulinoides/(Globorotalia truncatulinoides* + *Neogloboquadrina pachyderma* + *Globorotalia inflata*)].

The comparison of relative abundances of these species with the $\delta^{18}O$ and the STC index for the last 1 My points out towards 7 events of northward migration of the STC encountered at 940-870 ky, 760-640 ky, 520-450 ky, 400-350 ky, 320-270 ky, 210-150 ky, and 80-30 ky. These events are marked by high relative abundance of *Globorotalia inflata,* low abundance of *Globigerinoides ruber,* rise in the abundance of *Globigerina bulloides* along with positive excursion of $\delta^{18}O_{Globigerinoides\ ruber}$ and lower values of STC index. The higher abundance of *Globorotalia inflata* indicates cooler conditions, which are well corroborated by the lower abundance of warm water species, *Globigerinoides ruber.* The higher abundance of *Globigerina bulloides* marks increased productivity during the cold conditions due to upwelling. The cold conditions are also by the positive excursion in $\delta^{18}O$ values during these intervals. The lower values of STC index indicate the northward position of STC. These evidences are considered to represent a reduced AC flow. The events at 520-450 ky and 400-350 ky show abrupt rise in the abundance of *Neogloboquadrina pachyderma,* which otherwise was quite low. These are indicative of an extremely reduced AC and almost complete cessation of AL.

The events are indicative of glacial climate, leading to the waxing of the Antarctic Ice Sheet, thereby pushing the STC northward. The glacial climate would have reduced the AC flow, while the northward shift of STC would have caused the cessation of AL.

Quaternary Episodes of Variation in the Western Pacific Warm Pool: Planktic foraminiferal evidences from the Sulu Sea (ODP Hole 769B)

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The Sulu Sea is an important pericratonic basin in the proximity of South China Sea and western Pacific Ocean. It is connected via several shallow straits, which act as conduits for interocean exchange. The Western Pacific Warm Pool (WPWP) exerts a major impact on the Sulu Sea waters, due to its direct connection. There have been several changes in the WPWP during the Quaternary Period (last 2.6 My) due to development of glacial conditions and El Niño. These variations are well preserved in the pelagic sediments from Sulu Sea.

The *Pulleniatina* Minimum Events (PMEs), defined as the abrupt decline in the abundance of *Pu. obliquiloculata* due to changing water conditions, reflect the reduction in the Western Pacific Warm Pool and strength of the Kuroshio Current. We analysed 400 samples from the ODP Hole 769B to study the census data and oxygen isotope records of planktic foraminifera.

We discovered seven PMEs during the Quaternary Period which are proxies for the reduction in the WPWP. The age of the events are: PME7 (0.04-0.02 Ma), PME6 (0.16-0.13 Ma), PME5 (0.48-0.44 Ma), PME4 (0.79-0.65 Ma), PME3 (0.90-0.87 Ma), PME2 (1.8-1.36 Ma) and PME1 (2.21-2.08 Ma). The PMEs are accompanied with high abundance of eutrophic species, associated with enhanced fertility related either to upwelling or nutrient entrainment in the Sulu Sea. We have also found the occurrence of temperate fauna during PME7, PME6, PME5 and PME4, which indicates the influx of cold temperate and subpolar water mass in the Sulu Sea. The most plausible mechanism for this event could be the southward enhancement of Oyashio Current. The cool nutrient rich waters of the Oyashio Current caused a decline in the SST of the Sulu Sea and increased the fertility.

The PME3, PME2 and PME1 do not show presence of temperate fauna. The very high relative abundance of *Neogloboquadrina dutertrei* indicates the influx of nutrient rich waters from the Western Pacific Ocean via Luzon strait. These events suggest the development of El Niño like conditions.

The WPWP has reduced seven times during the last 2.6 My, where the pre-Mid Brunhes Event (MBE) reduction was the result of dominant El Niño like conditions, while the post-MBE reduction events were the result of enhanced Oyashio Current, which led to development of glacial conditions.

Automated image/video classification and object detection of foraminifera

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The project "Transforming ocean surveying by the power of DL and statistical methods" investigates objects/structures at and in the seabed reaching from micro to macro scale by utilizing a range of data capture methods, including digital photo/video, acoustics and electromagnetics, for identification/classification. Achieved data are further supported by auxiliary data (Water salinity, temperature, depth, current strength, etc.).

Here we present the usage of YOLO (You Only Look Once) networks to automatically detect/classify foraminifera (and micro plastics) in digital images and video sequences captured though the microscope. Initial work has shown promise to classify overall groupings of foraminifera (planktic, calcareous benthic, agglutinated benthic) within the sediment matrix at the 100 µm - 1 mm fraction. Training is conducted on pre-identified mono specific samples of the above mentioned foraminiferal groupings as well as on a separate sediment grouping. Further work relates to detection/classification of specific species within the benthic foraminiferal groups, detection of live rose-bengal stained specimens in addition classification of micro plastic groupings (fragments, fibers, film and pellets) in sediment samples.

The project entails an international collaboration between private sector partners and universities. The overacting goal of the project is to utilize synergies of statistics and deep learning to improve several aspects of classification and pave the way for a) groundbreaking new DL-methodology and b) establishment of workflow procedures for use in object classification relating to application in ocean surveying and geoscience.

Geochemistry of *Textularia agglutinans*: environmental and paleoclimatic importance

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Calcite precipitating foraminifera are widely used as geochemical recorders of paleoceanographic and environmental research. These foraminifera mainly belong to calcareous orders Rotaliida and Miliolida. Agglutinated species are generally overlooked in geochemical studies because their shells are mostly composed of collected particles from the surrounding environment that are either glued by an organic matrix or cemented by calcitic micrite. The benthic agglutinated species *Textularia agglutinans* d'Orbigny is exceptional. Its test consists of a thick internal self-precipitated calcitic wall covered externally by agglutinated practices, cemented by micritic calcite. This species is known for its widespread distribution, making him one of the most cosmopolitan foraminifera. In many environments, it consists a large percentage of the benthic foraminiferal assemblages. The evolutionary record of this species is exceptionally long, possibly spanning back to the Late Cretaceous. These qualities make *T. agglutinans* potentially important for paleoenvironmental research. To date, most of the research on *T. agglutinans* was primarily ecological and molecular. The few geochemical studies that were done on this species focused on the mineralogical characterization of its agglutinated shell.

The present study aims to characterize the geochemical composition of the calcitic layer of *T. agglutinans* in order to establish its future use as an accessible tool for the environmental reconstruction of paleotemperatures and heavy metal concentrations. The study is based on specimens collected from Israel's Mediterranean coast, where this species has become extremely abundant over the past years.

The collected specimens are cultured in the laboratory under a range of temperatures (17°, 20°, 24°C) representing the regional and seasonal range of the coastal seawater. Single-chamber analyses of the newly grown chambers will be done by using LA-ICPMS on specimens collected from the field and cultured in the lab. The Mg/Ca records will be used to establish the temperature calibration of this species and compare it to established curves of rotallids and miliolid species. This study also aims to determine the heavy metals (HM) composition of *T. agglutinans* and to explore its ability to record anthropogenic enrichment in seawater, as shown by rotallids and miliolid species. This will be done by exposing specimens to different HMs in variable concentrations and exposure times. Then, it will be clear whether *T. agglutinans* can serve as a recorder for long-term and short-term pollution, making monitoring the conditions in its many habitats possible. This research will provide chemical and biological information about a widespread species and ultimately will reveal the geochemical relevancy of agglutinated species with internal calcitic shells and external matrix.

Environmental compartmentation of the Santos estuary complex (SW Atlantic, Brazil): Response of biotic indices and pollutants

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The Santos estuary complex (SEC), located on the Brazilian southern coast (23°51' S and 23°58 ' S; 46°08' W and 46°19' W), comprises the Santos, São Vicente and Bertioga estuaries. It is considered an important petrochemical complex and hosts the largest port in Latin America. The region was urbanized and industrialized from the 1950s onwards in an uncontrolled manner and the activity of the petrochemical and fertilizer industries, among others, with a high polluting potential, made the SEC a large receiver of toxic waste and contaminated liquid effluents.

The main objective of the work is to comprehend the environmental compartmentation of the SEC based on benthic foraminifera indices and organic pollutants. Twenty-one stations were sampled in triplicates, during the austral winter and spring of 2019, using a manual sampling core and a multiple corer for benthic foraminifera analysis and a stainless steel van Veen bottom grab for the organic compounds. Sediment samples were kept in a solution of ethanol buffered with rose Bengal stain (2 g of rose Bengal to 1000 ml of ethanol 90%) to identify living (stained) foraminifera at the time of sampling. The samples remained stored in a refrigerator for at least 14 days to assure a good staining of the cytoplasm of living organisms. The sediments for organic compounds analysis were kept frozen. A volume of 50 cm^3 of wet sediment per sample was washed in a 63 μm mesh sieve, and then oven dried at 40 °C for benthic foraminifera analysis. Analyzes were performed on the >63 μm fraction, and at least 100 foraminifera tests were screened per sample.

Density (FD, number of individuals/50 cm^3 of sediment), Richness (S, number of different species in the sample), Shannon-Wiener Diversity (H'), Ecological Quality Status (EcoQS), Foram Stress Index (FSI) and Tolerant Species Index (TSstd) were calculated. Total organic carbon (TOC), aliphatic hydrocarbons (AHs), linear alkylbenzenes (LABs) polycyclic aromatic hydrocarbons (PAHs), and fecal sterols (the last two being chemical indicators of contamination by domestic effluents) were measured.

The most abundant species (relative abundance >1%) were *Ammonia parkinsoniana*, *Ammonia tepida*, *Ammonia* spp., *Cribroelphidium excavatum*, *Cribroelphidium* spp., *Haplophragmoides* sp., *Paratrochammina* sp., *Pseudotriloculina* sp., *Quinqueloculina* spp. and *Trochammina* sp. Cluster analysis was applied on the mean relative abundance values of the representative species present in replicates with Bray Curtis similarity index greater than 0.7. This analysis allowed us to identify six environmental compartments in the SEC: Santos Bay, inner and outer Bertioga estuary, São Vicente estuary, inner and outer Santos estuary. A principal components analysis applied on organic pollutants dataset revealed a stress gradient along the SEC, showing that Santos Bay and the outer Santos estuary are the environments with the lowest anthropic impact. Most of the São Vicente estuary and towards the upper estuary of Santos are characterized by a moderate anthropic impact, and Bertioga and the upper Santos estuaries are the most polluted in the SEC. A discriminant analysis applied to evaluate the predictive capacity of the biotic indices in the recognition of three classes of environmental impact (low, moderate, high) correctly classified 76.2% of the sites. Estuarine hydrodynamics plays the main role in this compartmentation.

Reconstructing past changes in cloud cover from foraminifera population geochemistry – A testable hypothesis

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One of the most important paleoclimate model parameters remaining to be quantified by sedimentary proxies is cloud cover in Earth's past. Because elevated regional cloudiness decreases surface irradiance levels, geochemical proxies sensitive to water column light levels should be sensitive to cloud cover change. Laboratory experiments have demonstrated that the carbon isotope ($\delta^{13}C$) composition of the symbiont-bearing species, *Orbulina universa,* varies with irradiance such that ambient light levels above symbiont P_{max} yields shells that are considerably enriched in ^{13}C relative to individuals growing at reduced, sub P_{max} levels. In oligotrophic regions of the ocean, P_{max} light levels are found shallower then ~30 m. The *O. universa* $\delta^{13}C$ range observed in laboratory experiments, ~2-2.5‰, agrees well with the $\delta^{13}C$ range recorded among *O. universa* individuals in fossil populations. Because *O. universa* inhabits the full photic zone in the ocean, the distribution of $\delta^{13}C$ values among individuals should reflect the habitat depth distribution of the population. Furthermore, the % of individuals living at shallow depths with irradiance $>P_{max}$ levels will yield the highest grouping of $\delta^{13}C$ values. As cloudiness increases, the P_{max} irradiance depth will shoal such that fewer individuals will record high $\delta^{13}C$ values. This change in $\delta^{13}C$ distribution is quantifiable and can be modelled. I will discuss how to test this hypothesis and present population geochemical data from fossil assemblages that suggests glacial equatorial Indian Ocean cloud cover during MIS 6 was significantly higher than later interglacial and glacial periods.

Understanding coral thermal bleaching thresholds during past interglacial extremes: Insight into thermal stresses dynamics on tropical coral reef ecosystems (RESILIENCE)

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Tropical and subtropical coral reefs are biodiversity hotspots distributed around the world and are currently under unprecedented stress. One of the main visual signs of thermal stress is bleaching, a predominant stressor on reefs, and one of the main drivers of coral-bleaching is drastic temperature changes (thermal stress), which is associated with photo-inhibition. The best approach to gain insights to how global climate change will impact reef ecosystems is to learn from the past. However, in the fossil record, bleaching cannot be observed! The Earth's paleoclimatic record, found in deep sea sediments adjacent to coral reefs, can provide us with relevant information on multiple prospective analogues for modern times.

Traditionally, isotope curves are based on results from whole-shell analyses of planktonic or benthic foraminifera pooled specimens, where isotope values are averaged and give indications of mean hydrographic conditions. However, the only way to record temperature extremes is to use individual foraminiferal analyses from the same sample.

Here we show how the $\delta^{18}O$ of single specimens (Individual Foraminiferal Analyses – IFA) coupled with Mg/Ca of the planktonic foraminifer *Globigerinoides ruber* (white) can be used to extract the relative frequency and magnitude of temperature extreme events from past interglacials, which exceeded the modern-day coral bleaching thresholds, in order to better understand possible warmer-world scenarios. As an example, we propose the Maldivian archipelago where Expedition 359 drilled and cored extended sedimentary drift deposits in the Inner Sea.

A preliminary investigation on Marine Isotope Stage 11 (MIS11) revealed that this interglacial was 0.30-0.41°C warmer than modern time and that sea-surface temperatures exceeded the coral bleaching threshold during this time interval. Additional MIS are being investigated in the present research.

The modern habitat is used as a baseline for past assessment of potential modern stresses (temperature and nutrients) and for defining temperature thresholds for coral bleaching. Further research will focus on the Great Barrier Reef (ODP Leg 133) and its shallow water equivalent (e.g., the coral reefs in Lizard Island) and the Great Bahamas Bank (ODP Leg 166) and its equivalent in the Florida Keys.

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Palaeoceanographic Changes and Ecological Impacts on Foraminifera during Eocene-Oligocene Transition in the Gulf of Mexico

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Within the overall Cenozoic cooling trend, the Eocene-Oligocene Transition separates warmhouse and coolhouse climate regimes. This time period consists of a rapid drawdown in atmospheric carbon dioxide, the permanent glaciation of Antarctica, and a reorganization of deep-sea circulation. At the Eocene/Oligocene Boundary, both planktic and benthic foraminifera experienced extinctions as they adjusted to changing climate and ocean circulation. Benthic foraminifera diversity decreased in some ocean basins but not all, suggesting deep-sea circulation changes likely contributed to this decline. Research indicates that Northern Component Water formed and circulated through the Atlantic and into the Southern Ocean in the late Eocene and early Oligocene; however, there is no data on its circulation into nearby ocean basins, like the Gulf of Mexico. In particular, the impact this change in ocean circulation had on benthic foraminifera in the Gulf of Mexico remains understudied. Here we present benthic foraminiferal assemblage, stable isotope, X-ray fluorescence, grain size, and seismic data from the southern Gulf of Mexico Deep Sea Drilling Project Sites 95 and 540. Preliminary results indicate that local volcanic activity and diagenesis likely overprint any temperature changes driven by global climate and, despite global cooling, the southern Gulf of Mexico deep water records exhibit a negative carbon isotope excursion at the Eocene/Oligocene Boundary. Grain size analysis of sortable silt, combined with XRF proxies (e.g., Zr/Al) indicate an increase in bottom water current velocity in the early Oligocene, congruent with global trends. We explore how these local and global changes impacted benthic foraminiferal communities of the southeastern Gulf of Mexico.

Differential gene expression over the life cycle of *Allogromia laticollaris* CSH to understand complex nuclear dynamics

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We combine fluorescence microscopy and single cell transcriptomics to elucidate underlying genome mechanisms that drive the highly complex life cycle of *Allogromia laticollaris*. The life cycle of this species includes an alternation of generations, extreme ploidy fluctuations, and a process of nuclear cleansing called *Zerfall,* but the genomic mechanisms underlying these processes are unknown. The *Allogromia laticollaris* CSH cell line was isolated at Cold Spring Harbor (NY, USA) laboratories and studied by Arnold in 1955 and McEnery and Lee in 1976. We are using this species to explore differential gene expression in different life cycle stages. We are working to analyse 48 transcriptomes spanning the life cycle of this lineage, a subset of which have associated Hoechst-stained images taken prior to sequencing. For each cell, we will compare nuclear number and sizes with presence and absence of certain gene families using PhyloToL, our in-house phylogenomics pipeline. The search for candidate genes will enable us to assess differential mRNA patterns associated with varying genomic organisation processes, which will provide insights into the molecular basis of extreme changes in genome content in *A. laticollaris*. Despite recent advances in genomics, these techniques are rarely applied to diverse eukaryotic clades such as foraminifera. Instead, our understanding of genome evolution is largely limited to a small group of model systems, which excludes a large diversity of complex and dynamic genomes present among microeukaryotes. Through studying the genomic mechanisms of this species with two powerful tools –fluorescence microscopy and molecular biology –, we are working towards a stronger understanding of the 'rules of life' that govern the evolution of genomes.

Early Cretaceous marine incursions in the Proto-South Atlantic Ocean: foraminiferal record from Brazilian basins

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The timing of the first marine connections of the South Atlantic Ocean in the Brazilian interior and marginal basins, during the Early Cretaceous, has long been subject of debate. Those basins show stratigraphic sequences that often contains marine abundant fossils, which represents the initial incursions related to opening South Atlantic. For decades, biozonation schemes applied to these mostly non-marine intervals were restricted to ostracods and palynomorphs local biozones. The scarcity of age diagnostic marine microfossils in the Early Cretaceous stratigraphic sequences from Brazilian basins resulted in a series of tentative chronocorrelations (still under debate) of local biozonations with the standard international biostratigraphic schemes.

Even the occurrence of those early marine incursions, due to the poor and sparse paleontological evidence, is still object of debate. Many studies registered the occurrence of foraminifers in these Brazilian basins (Campos, Recôncavo, and Sergipe-Alagoas). Since 1990, occurrences of benthic foraminifera (Ammodiscidae, Lituolidae, *Glomospirella arctica*, and *Paratrochamminoides kaminskii*), as well as foraminiferal linings recovered in palynological studies, were registered for Recôncavo and Campos basins, related to late Barremian–early Aptian. For Sergipe-Alagoas Basin, Aptian foraminifera (*Globigerinelloides aptiensis, G. barri, G. blowi, G. ferreolensis, G. maridalensis, Hedbergella labocaensis, H. maslakovae, H. semielongata,* and *H. similis*) were found associated to coeval ammonites.

Foraminifers were also recovered in Brazilian interior basins, as Araripe and San Franciscana. For the Araripe Basin, foraminifers were registered in the Early Cretaceous sedimentary sequence, represented by Barbalha, Crato, Ipubi, and Romualdo formations. The Barbalha Formation is the basal unit and is considered mostly non-marine. However, we recovered foraminifers from two boreholes (1-PS-06-CE and 1-PS-10-CE). The lower part of Barbalha Formation (Batateiras Beds) displays abundant benthonic foraminifera (*Bathysiphon* sp.), and in the upper part of this unit, *Leupoldina* sp., *Globigerinelloides* cf. *barri*, and *Globigerinelloides* cf. *ferreolensis* were found, correlated to early/early late Aptian biozones *L. cabri/G. algerianus*. In addition, in these boreholes planktonic foraminifers (ticinellids and hedbergellids) were found in thin sections associated with abundant radiolarians in the Crato Formation strata.

For the upper units of Araripe Basin (Ipubi and Romualdo formations), several studies recovered foraminifers. In the Ipubi Formation *Hedbergella* sp., *Hedbegella* aff. *tatianae*, and *Hedbergella infracretacea* were described, and for Romualdo Formation sections recent studies (from 2020) reveal early/late Aptian planktonic (*Microhedbergella miniglobularis, Hedbergella praelippa, Hedbergella aptiana,* and *Hedbergella sigali*) and benthonic (*Rhizammina* sp*., Bathysiphon* sp*., Ammobaculites* sp*., Quinqueloculina* sp*., Sigmoilinita* sp*., Patellina* sp*., Spirillina* sp*., Pseudonodosaria* sp*.,* and *Astacolus* sp*.*) foraminifers.

At the Sanfranciscana Basin (interior Brazilian basin) reports of radiolarian and foraminifera found in chert beds has been subject of debate about their origin. Those strata apparently are in a continental sequence, contrasting thus with the micropaleontological evidence. After a refined sampling we identified *Leupoldina* sp., *Globigerinelloides* sp., and *Hedbergella* sp. that corresponds to the early Aptian, *L. cabri* biozone. The occurrence of *Leupoldina* genus in Araripe and Sanfranciscana basins here reported indicates possibly the older marine ingressions correlated in the Brazilian interior basins until this moment, even if any correlation between those basins and the possible seaways that led those marine associations into those basins is still under heavy debate.

Foraminifera of the remote Chagos Archipelago – Community responses to local and global drivers and their effects on coral reef sediment production

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The production of carbonate sediments by coral reef organisms is an essential driver of tropical beach and island formation. Especially low-lying islands rely heavily on biological sand supply, but the ongoing degradation of coral reef ecosystems may diminish this important geo-ecological function. Benthic foraminiferal tests are abundant components of many reef sediments and locally contribute significantly to carbonate sediment production. Alterations in foraminiferal assemblages serve as sensitive bioindicators that allow us to reconstruct past and recent environmental conditions, assess ecosystem 'health' status or recovery potential. This is especially useful in regions that are difficult to access and often lack continuous monitoring.

To assess climate impacts on foraminiferal assemblages, we analysed changes in community composition in the remote Chagos Archipelago over the last 40 years. This group of atolls in the central Indian Ocean is hardly affected by local anthropogenic impacts, but is nonetheless exposed to global ocean warming. Assemblages in recently collected surface sediment samples on seaward and lagoonal reefs in Peros Banhos atoll were compared to data derived in 1979, pre-dating the severe global coral bleaching events in 1997/98 and 2015/16. Recent foraminiferal communities showed spatial

differences in species dominance, with Soritidae appearing in great densities at some shallow lagoon sites, indicating nearby seagrass or macroalgal habitats. All sites showed temporal shifts from species common in coral-dominated habitats in 1979 (e.g., *Amphistegina* spp.) to those indicating more algae-dominated realms in 2021 (e.g., *Neorotalia* spp.). Therefore, an approximation of the lagoon and seaward assemblages was observed in recent samples, with an increase of *N. calcar*, especially at seaward sites, and a generally lower relative abundance of *A. lessonii*. These long-term community shifts likely reflect changes in benthic communities and habitat availability following two major coral bleaching events.

In addition to the temporal comparison, we aimed to characterise fine-scale spatial differences in foraminifera assemblage and contribution to sediment supply across atolls, reef zones and natural nutrient gradients. While some islands in the Chagos Archipelago are inhabited by high populations of seabirds, providing important nutrient subsidies to highly oligotrophic nearshore coral reefs, invasive rats have depleted seabird colonies on other islands, with critical impacts on local ecosystems. To test whether seabird-derived nutrient inputs alter benthic foraminifera communities and their contribution to carbonate sediment production, we examine spatial patterns of foraminiferal densities, size classes and assemblages across reef zones adjacent to seabird- vs. rat-dominated islands in three atolls. Initial results reveal large variability of foraminifera test contribution to carbonate sediments across reef zones and depths, but indicate locally elevated input to reef sediments in lagoon sites due to many large test fragments of Soritidae and Homotrematidae. The foraminiferal sediment contribution around islands with large seabird populations appears to be slightly higher compared to islands with invasive rats within the same atoll. This is possibly due to guano-derived nutrient runoff or linked to higher microhabitat and substrate availability within the local reefs (e.g., more calcareous algae). Ongoing research focuses on improving estimations of in-situ productivity by foraminifera and their contribution to overall sediment budgets.

While the FoRAM Index suggests favourable conditions for high post-disturbance reef recovery potential due to the absence of local pollution, further climate change-related reef degradation may progress shifts in foraminiferal assemblages and related changes in sediment production around coral reefs, with important implications for sand supply to connected ecosystems and the islands.

Decoupling of productivity and carbonate dissolution in the western South Atlantic during MIS 5-4

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With ongoing anthropogenic perturbations in the Earth's climate system, it is important to understand the role of feedback mechanisms in regulating climate, and their sensitivity to rapid change. In the past, mechanisms modulating greenhouse gases (e.g. the biological pump) have been invoked to trigger the changes in atmospheric CO_2 between glacial and interglacial states, amplifying the relatively subtle orbital forcing on global temperature. Recent studies from the western South Atlantic (southernmost Brazilian continental margin), have suggested that an enhanced glacial biological pump was the main driver of calcium carbonate dissolution above the lysocline: when organic matter (OM) is remineralised, it releases CO_2 and lowers the pH of the water. This impacts the $CaCO_3$ preservation and recycles previously removed (in)organic carbon back into the ocean, decreasing the effectiveness of CO_2 export via the biological pump. Nevertheless, this hypothesis has not been shown elsewhere, for example, where high productive periods occurred at different times. In this study, we compare proxies for sea surface productivity (relative abundances of planktonic foraminifera species *Globigerina bulloides*, *Globigerinoides ruber* and *Globigerinita glutinata*), organic matter flux (benthic foraminiferal accumulation rates) and carbonate dissolution (calcium carbonate content, benthic/planktic ratio and planktonic foraminifera fragmentation index) from two cores recovered from the western South Atlantic (SIS-249, Pelotas Basin, 2091 mbsl, and GL-852, Santos Basin, 1938 mbsl). The cores span the marine isotope stages (MIS) 5–4 and are bathed by the North Atlantic Deep Water in present times. Core SIS-249 shows an increase from low to high productivity and carbonate dissolution from MIS 5 to 4. Conversely, core GL-852 records a decoupling between sea surface and seafloor conditions during 4, going from high productivity and high calcium carbonate dissolution during MIS 5 to low productivity and high dissolution in MIS 4. Although the sea surface productivity pattern documented by is different between cores, both record a high carbonate

dissolution event during MIS 4. Although benthic $\delta^{13}C$ records from both cores suggest a larger influence of the more corrosive southern-component water (SCW) during MIS 4, the $\delta^{13}C$ solely is not sufficient to prove changes in the geometry of bottom water masses, since carbon stable isotopes can also be affected by the other biogeochemical processes invoked here. Nevertheless, we suggest that the reconfiguration of the water masses geometry also drives carbonate dissolution during MIS 4.

Exploring the link between Pore Morphology in Benthic Foraminifera (*Ammonia*) and Dissolved Oxygen: Insights from Chilika Lagoon (INDIA)

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The depletion of dissolved oxygen in marine ecosystems is a major concern, with substantial environmental and socio-economic implications. Here, we present a study of benthic foraminifera, the most reliable indicator used in paleoclimatic and paleoenvironmental studies. *Ammonia*, a dominant benthic foraminifera, is distributed throughout the shallow marine areas of the tropical and warm temperate zones. They are highly sensitive to changes in environmental conditions, which are recorded and preserved in their tests. Therefore, the characterization of pore morphology in foraminifera is useful for understanding changes in local oxygen levels. In this study, Atomic Force Microscopy (AFM) was used to observe the pore structure through three-dimensional mapping and quantification.

The use of AFM has enhanced the characterization potential of the surface morphology, thereby providing a much closer perspective on pore studies. The *Ammonia* specimens were analyzed from the core-top samples collected from the Chilika Lagoon. A standard measurement frame was considered for the analysis of the penultimate chamber (n-1) on the spiral side. Based on the three-dimensional analysis, topographical mapping, pore depth and surface roughness were measured along with two-dimensional features, porosity, pore density and diameter.

Morphometric analysis was conducted for two different species: *Ammonia* cf. *beccarii* and *Ammonia parkinsoniana*. The results showed distinct and characteristic pore properties. Topographical mapping revealed contrasting pore patterns between the two species. The pore density of *Ammonia* cf. *beccarii* ($0.155/\mu m^2$) was higher than that of *Ammonia parkinsoniana* ($0.035/\mu m^2$). Moreover, it was found that the value of the pore depth bears a specific value in each species. *Ammonia parkinsoniana* showed a pore depth value approximately two–three times higher than that of *Ammonia* cf. *beccarii*. However, we are yet to understand the relationship between pore properties and dissolved oxygen. At present, we are working on exploratory data analysis to establish a correlation between pore data and dissolved oxygen in the lagoon.

This research study will develop a comprehensive knowledge of the pore morphology in *Ammonia* and its use as a proxy for dissolved oxygen in the lagoon. Subsequently, it will be applied to the core samples to deduce oxygenation trends of the distant past.

Neritic Benthic Foraminifers as Indicators of Ocean Deoxygenation in the Salisbury Embayment (U.S. Atlantic Coastal Plain) during the Mid-Miocene Climatic Optimum

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The Middle Miocene Climatic Optimum (MCO, ca. 17-14.8 Ma) is typified by atmospheric paleo-pCO_2 levels (~500 ppm) comparable to those projected for the year 2050, global temperatures ~5ºC warmer than present (pre-industrial), and global mean sea level ~50 meters higher than today. Thus, the MCO represents an informative ancient analogue to anthropogenic climate change. Here we use complementary micropaleontological (neritic benthic foraminifer communities) and geochemical (benthic foraminifer $\delta^{13}C$, alkenone unsaturation index $U^{k'}_{37}$) records constructed for a sediment core drilled in the U.S. Atlantic Coastal Plain (Haynesville, Virginia) to assess the effects of ocean warming and fluctuating sea level on coastal ecosystems during the MCO. The paleogeographic setting places the Haynesville study site in inner to middle shelf waters within a broad, shallow embayment of the Atlantic Ocean along the eastern margin of the North America called the Salisbury Embayment. Alkenone thermometry ($U^{k'}_{37}$) is at its upper limit of temperature detection (28-29ºC) over much of the Haynesville MCO record, suggesting exceptionally warm sea-surface temperatures. A major compositional change among benthic foraminifer assemblages coincides with an episode of increased organic carbon burial signalled by a modest but sustained ~1‰ increase in foraminifer $\delta^{13}C$ values marking the onset of the Monterey Carbon Isotope Excursion (MCIE) and elevated primary productivity as inferred from increased alkenone abundances. On the basis of an "enhanced benthic foraminifer oxygen index", the faunal shift entailed a transient change from aerobic assemblages composed largely of genera

(*Valvulineria*, *Cibicides*) reflecting oxic (>3 ml/l O_2) bottom waters to assemblages dominated by buliminids and bolivinids indicating suboxic (0.3-1.5 ml/l O_2) bottom waters and increased primary productivity. Benthic foraminifer communities show a marked decrease in species richness, diversity, and evenness across the suboxic interval. Moreover, foraminifer abundances increase dramatically from background levels (~100 specimens per gram) to an overall high (~7,000 specimens per gram) directly below the stratigraphic level of the MCIE onset in the Haynesville MCO record. This brief peak in foraminifer abundances likely reflects a stratigraphic "condensation" horizon associated with a marine flooding surface that, in turn, is overlain by a highstand systems tract characterized by the dysaerobic (suboxic) faunas. We therefore attribute the change in local redox conditions to ocean deoxygenation stemming from some combination of temperature-gas solubility effects, increased levels of primary productivity and microbial respiration, and a rapid rise in sea level that caused an onshore shift of deeper waters with lower dissolved oxygen concentrations over our study site. Benthic foraminifer communities subsequently revert back to more aerobic faunas as their abundances decline (0-100 specimens per gram) over the remaining upper half of the study section, suggesting a shallowing upwards sequence. The collective evidence is consistent with the view that a sharp rise in sea level increased shelf accommodation space for carbon burial during the MCO, which helped curtail the overall increase in atmospheric CO_2 levels being fuelled by tectonic outgassing at that time.

Reconstruction of the Oligocene paleoenvironment in the Central Paratethys, North Hungarian Paleogene Basin

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The geological research of the North Hungarian Paleogene Basin (NHPB) dates back more than 150 years, just like the study of the petrological, sedimentological, and tectonic features as well as the fossil content of the Paleogene formations (Buda Marl and Kiscell Clay). However, the geological structure of the basin is still not completely clear in certain areas, such as in the studied Szentendre region, north of Budapest. The taxonomic and stratigraphic results of foraminifera in the Paleogene formations were first published by Miksa Hantken. Although there have been several studies on the investigation of the Oligocene Kiscell Clay since then, a detailed study containing quantitative data on foraminifera from the Szentendre area has not been conducted yet. Our study aimed to give a detailed taxonomic description and quantitative analysis of the foraminiferal fauna of the borehole Szentendre II., to interpret the biostratigraphic and palaeoecological conditions. The previous paleontological results of the examined borehole, based on molluscs, nannoplankton, palynomorphs, and ostracods, have also been reinterpreted.

The fully cored Oligocene succession of the borehole Szentendre II. represents a whole Oligocene series on the western margin of the NHPB. The core samples contained well-preserved foraminiferal assemblages comprising 112 taxa of 82 genera. Two new species of benthic foraminifera are named and described from the marl layers of the Kiscell Clay. Apart from the typical highly diverse "Kiscellian fauna" the same fauna appeared but with low diversity. Its agglutinated fauna is dominated by specimens of the order Lituolida and Textulariida. Porcelaneous forms are mostly represented by the genera *Quinqueloculina*. Most hyaline taxa belong to the suborder Lagenina and Rotaliina. In general, the taxa have long ranges, only the appearance of *Epistomaroides cryptomphalus* is limited to the Oligocene. Further subdivision of the section was possible by defining five foraminiferal horizons, which correlated well with previously determined zones around the Paleogene Basin. According to the foraminiferal fauna, the section of the borehole should be divided into the Rupelian and Chattian.

To decipher the paleoenvironmental changes, we used planktonic/benthic ratio, diversity indices, principal component analysis, detrended correspondence analysis, and BFOI. Altogether 7 agglutinated and 9 calcareous morphogroups were established. Based on their ratio and considering the estimated paleodepth, the calculated benthic foraminiferal oxygen index and the occurrence of other fossils 7 ecozones were defined. In the lower part of the Rupelian of the Szentendre II. borehole section fluctuating BFO indices present changes in bottom water oxygenation. Presumably, the sediments deposited in lower oxygen conditions represent the upper part of the NP23 Zone. Above located sand layers might have been redeposited from the material of the nearshore Hárshegy Sandstone based on their foraminifera fauna so these layers were interpreted as intercalated turbidite layers. The high diversity of foraminifera in the Kiscell Clay indicated that the sedimentation took place in bathyal depth and normal salinity seawater. The Chattian age of the uppermost layers cannot be confirmed. Considering its shallow-water fauna, which is very similar to the upper Oligocene fauna of other Paratethyan areas, it probably belongs to the Chattian Törökbálint Sandstone.

Based on our detailed biostratigraphical and palaeoecological evaluation, the paleoenvironmental changes of Paratethys throughout the Oligocene could be traced. Although neither the fauna nor the lithological appearance of the studied sequence exhibits typical, well-known features, our horizons are arranged in the same succession as in other areas of the HPB. Therefore, these changes are not only local but also regional. It seems that the entire HPB was uniformly affected by environmental changes.

Climate change induced decrease in foraminifera abundance in an Arctic fjord (Hornsund, Svalbard). Implications for carbon burial

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Atlantification and glacier retreat, two processes linked to the modern climate change, can negatively impact foraminiferal assemblages. Although the impact of modern climate change on foraminiferal assemblages is relatively known, the changes in foraminiferal carbon contribution to the sediments remains understudied. The effects of climate change are prevalent in high-latitude North Atlantic fjords, where foraminifera are an important part of the benthic community. We picked Hornsund fjord as a study site because its oceanographic conditions are highly affected by Atlantification and loss of glacier volume. In the last two decades, Hornsund waters became warmer and more saline. The calving speed and meltwater volume of local glaciers rapidly increased. This induced changes in oceanographic conditions of fjordic waters that affected local foraminifera assemblages. Our study aimed to quantify changes in foraminiferal carbon contribution to the sediments in an environment highly affected by the modern climate change. Foraminifera are potentially be the most important calcifiers in glaciomarine sediments of the Arctic, as they constitute up to ~40% of inorganic carbon in the sediments of Adventfjorden, and up to 68% in Norwegian fjords. Changes in abundance and species composition of foraminifera assemblages can provide strong feedback to the carbon cycle.

We examined two foraminifera datasets from the same site—one from 2002 and one from 2019—in comparative perspective to assess the changes that have occurred in oceanographic conditions in an Arctic fjord over the last two decades. Additionally, we calculated how these changes affected the amount of carbon supplied to the sediments in the form of foraminifera tests. Our study revealed that the Hornsund foraminifera assemblages underwent a set of changes indirectly influenced by global warming. The 2002 assemblage represented conditions where Arctic Waters dominated. The 2019 assemblage represented conditions of increased Atlantic Water presence and loss of glacier coverage in the fjord's catchment area.

A fourfold decline in the contribution of foraminiferal carbon to the 2019 sediments compared to those in 2002 was found. In 2002 the foraminiferal assemblage was characterized by high species diversity and low abundance of agglutinated species. One of the most abundant species was *Nonionellina labradorica*. A species characterized by large size and high carbon content per test. The 2019 assemblage was defined by low abundance of foraminifera, as well as higher amount of agglutinated and small, opportunistic species. The most abundant species were *Cassidulina renifrome* and *Elphidium clavatum*. Both were characterized by low carbon content in their tests. The results highlight the negative impact of modern climate change-driven changes on the assemblage and the subsequent decrease in inorganic carbon buried in the sediments. These data allow for a better interpretation of palaeoceanographic sedimentary records and future predictions regarding the inorganic carbon cycle.

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Photosymbiotic partnerships and evolution in planktonic foraminifera revealed by single-cell metabarcoding

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Photosymbiosis, a mode of endosymbiosis with phototrophic algae, is generally thought to be an innovative adaptation to oligotrophic oceans. Among modern planktonic foraminifera, photosymbiosis has been discovered in nearly half of the species, most of which are found in the oligotrophic regions. Thus, photosymbiosis should be a key factor in understanding their evolution, diversity, and ecological adaptation in warm pelagic surface waters. Recent studies have identified photosymbiosis in modern species by detecting the photosynthetic signal from planktonic foraminiferal individuals and obtaining evidence of living algae in the cell. It has successfully revealed the existence of previously unrecognized symbiosis in planktonic foraminifera. However, even though symbiosis is determined, the type of algae has yet to be investigated for many host species. To better understand the evolutionary role of photosymbiosis, investigating host-symbiont partnership, its specificity/flexibility, and the persistency through the host phylogeny are to be resolved.

In resolving host-symbiont partnership, 18S metabarcoding is a powerful tool to reveal intracellular eukaryotic components. Since foraminifera also incorporate prey, this analysis can detect food components as well. In this study, we focused on the photosynthetic taxa alone, i.e., the composition of algal species, and tried to differentiate algal symbiont and algal food by comparing the results of symbiotic (17 species) and non-symbiotic (2 species) foraminifera. The samples were collected from various oceanic regions, including Northwest Pacific (Hakuho-maru KH-16-7), subtropical Pacific (Hakuho-maru KH-17-4), subarctic Pacific (Oshoro-maru 243), and tropical Atlantic (Meteor M140). DNA was extracted from each individual, and the V9 region of the 18S ribosomal RNA gene was targeted and amplified using universal primers. The sequencing was performed using the Illumina Miseq platform. The obtained sequences were taxonomically assigned based on TARA ocean database, and the information of trophism (possession of plastids) was also annotated. Algal sequence reads were extracted, and their composition was analysed and compared within and among species. In addition, phylogenetic analysis was performed to map the identity of photosymbiosis on the phylogenetic tree and the timing of the emergence of symbiosis. The molecular phylogenetic analysis was performed using reference sequences obtained from PFR2 database. Molecular clock analysis was conducted using BEAST2 framework.

Metabarcoding analysis revealed that each species of photosymbiotic planktonic foraminifera has almost a single algal species. The partnerships are highly specific regardless of the region, season, or depth at which they were collected. In addition to the known symbionts in planktonic foraminifera (dinoflagellate *Pelagodinium béii*, haptophyte *Chrysochromulina andersonii*, and pelagophyte *Pelagomonas calceolata*), two different pelagophytes and two Chlorophyta species were newly identified as symbionts. In contrast to the high specificity of the algae in symbiotic species, algal components for the non-symbiotic species were diverse, and the composition varied within the same species, probably reflecting the variability of algae incorporated as food. Molecular phylogenetic analysis revealed that dinoflagellate symbiosis is monophyletic, encompassing a lineage within Globigerinidae, and the age of occurrence dates back to at least the Oligocene. On the other hand, pelagophyte symbiosis spans different host lineages, indicating that symbiosis with pelagophyte was repeatedly acquired in multiple foraminiferal lineages. In other words, from the symbiont side, host specificity is low. Furthermore, symbiosis with non-dinoflagellate algae occurred relatively recently. In summary, the highly specific and conserved symbiotic relationship has been established only with dinoflagellates, whereas the other symbiosis are relatively new, and the host specificity is relatively low. We believe that future phylogenetic analysis, including fossil species among the revealed symbiotic lineages, will provide a more detailed picture of the evolutionary history of photosymbiosis.

Responses to DCMU, high light, and high temperature in *Trilobatus sacculifer* photosymbiosis

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Trilobatus sacculifer, a photosymbiotic planktonic foraminifera living in warm surface waters, has dinoflagellate symbiont *Pelagodinium béii*. Their relationship is generally thought to be mutualistic, in which symbiont photosynthates are transferred to the host, and the symbionts utilize the host derived inorganic nutrients. Previous studies revealed that the symbionts can proliferate in the host; hence the number of symbionts increases through the host ontogeny until the time of the host's gametogenesis. As such, this symbiotic relationship is quite intimate and indispensable with each other. Recently, corrupts of photosymbiosis, or "bleaching", due to environmental stress (especially extreme heat) were often reported in corals. Whether this kind of symbiont loss (and/or pigment loss) can occur in planktonic foraminifera has not been experimentally examined so far, but needs to be tested to understand the biological responses of photosymbiosis to global warming and predict their fates. High temperature and high irradiance are the two main environmental stressors that can induce bleaching. Here, we conducted three series of culture experiments in each of which a single variable changed; (1) photoinhibition experiments, (2) light experiments, and (3) temperature experiments.

In this study, the series of culturing experiments were conducted for 7–10 days using *T. sacculifer* alone, except for the DCMU experiments using free-living *P. béii* culture as well. Foraminiferal samples were collected during subtropical Pacific cruises by Hakuho-maru KH-16-7 for the DCMU experiments, KH-17-4 and KH-19-6 for the light experiments, and at Sagami Bay for temperature experiments. *P. béii* culture was originally isolated from *T. sacculifer* and has been maintained at the lab. The photoinhibition experiments were conducted using seawater which DCMU concentration of 0 μmol L^{-1} (control group), 1 μmol L^{-1} (L-DCMU group), and 10 μmol L^{-1} (H-DCMU group). The light experiments were conducted under three irradiance levels; 10–20 μmol m^{-2} s^{-1} (LL group), 70–100 μmol m^{-2} s^{-1} (control group), and 200–250 μmol m^{-2} s^{-1} (HL group). Finally, the temperature experiments were conducted under three temperature levels; 19.5°C (LT group), 24.5°C (control group), and 32°C (HT group). The photosystem II (PSII) parameters representing the physiological state of photosynthesis (F_m, F_v/F_m, σ_{PSII}, τ_{QA}) were measured daily by fast repetition rate fluorometry for each individual.

Based on the results of DCMU experiments, we could obtain the response profiles when photosynthesis is inhibited. Surprisingly, even though the chlorophyll content of individual foraminifera (estimated from F_m value) became nearly zero

in H-DCMU group, i.e., the foraminifera was bleached, it could graze on prey (*Artemia* nauplii) and formed new chambers. In the light experiments, F_v/F_m (photosynthetic activity parameter) significantly decreased in group HL after 6 days of culturing. The profile was similar to the results of H-DCMU group, probably reflecting the high light induced photoinhibition. Since a previous study reported that *T. sacculifer* grew well under 400–500 μmol m^{-2} s^{-1}, caution should be paid that photoinhibition of symbionts does not necessarily affect the host growth. In the temperature experiments, we could not observe any statistical differences in photophysiological parameters among the groups. The temperature of 32°C in the HL group was quite high, and it is often the level of bleaching reported temperature for corals. Nevertheless, foraminifera looked healthy and could grow, and the chlorophyll content increased. It was reported that the growth of free-living *P. béii* stopped at 30°C. Although we should be careful about the genotype of *P. béii*, it can be hypothesized that *in hospite P. béii* is relatively more tolerant to environmental stress than free-living one. Further examinations are necessary to test the above hypothesis, and information on other symbiotic species is essential to get a generalized view of photosymbiosis in planktonic foraminifera.

Biotic response of deep-sea benthic foraminifera at ODP Site 744 (Kerguelen Plateau) in the Southern Ocean during the early Oligocene

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The early Oligocene is an epoch that the marked Antarctic glaciation happened, and the latitudinal gradient of surface oceanography such as episodic food supply became more significant between low- and high-latitude areas. Deep-sea benthic foraminifera responded to such oceanographic changes across the Eocene–Oligocene transition (EOT).

We investigated the Oligocene deep-sea benthic foraminiferal fauna at IODP Site U1334 (eastern Equatorial Pacific; EEP) and noted transiently common *Astrononion echolsi* (33.3–33.0 Ma and 32.9–32.8 Ma). Because this species seems to be related to the Southern Component Water (SCW), the possible influence of the SCW to the EEP was expected during the earliest Oligocene. Here we report the faunal transition of benthic foraminifera (>105 μm fraction) at ODP Site 744 (Kerguelen Plateau, 2307 m water depth; ~1800 m paleodepth) during 34.8–30.4 Ma, in order to reveal how benthic foraminifera responded to the paleoceanographic changes across the EOT in the Southern Ocean.

At ODP Site 744, *Nuttallides umbonifer*, *Oridorsalis umbonatus*, *Epistominella exigua*, and *A. echolsi* are common constituents during the late Eocene to early Oligocene. Across the EOT, *Turrillina brevispira* were temporally dominant with *E. exigua* at 33.5 Ma. Then, *A. echolsi* was common during the early Oligocene. The timings at the pulses of *A. echolsi* (33.8–33.0 Ma and 32.4–30.7 Ma) were generally similar to those of *Astrononion* spp. in the abyssal depths of the Atlantic Ocean. In contrast, the first common occurrence of *A. echolsi* at ODP Site 744 in 33.7–33.2 Ma may correlate to that of IODP Site U1334 just during ~33.3–33.0 Ma. Thus, the first common occurrence of this species was likely traced among the Southern Ocean, the Atlantic Ocean and EEP.

Additionally, this first common occurrence of *A. echolsi* at ODP Site 744 consists of the two small maxima at ~33.6 Ma and ~33.4 Ma that are similar to those of published benthic $\delta^{18}O$ and opal mass accumulation rate (MAR) at the same site, suggesting the close relation to the Antarctic Oi-1 glaciation. Especially, high opal MAR implies the rapid increase of siliceous plankton and the change in mode of food supply from the surface ocean to the seafloor, especially on ballasting effect of particulate organic matter. Benthic foraminiferal fauna likely responded to such surface oceanographic changes in Kerguelen Plateau (Indian Sector of the Southern Ocean).

Faunal transition of benthic foraminifera across the Eocene–Oligocene transition at ODP Site 744 (Kerguelen Plateau) in the Southern Ocean

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The Eocene-Oligocene transition (EOT) is known as the onset of icehouse world. A two-step transition is common in deep-sea records, such as more positive shifts of stable oxygen isotope data of benthic foraminifera. It is generally agreed that the first step of the $\delta^{18}O$ change of benthic foraminifera (EOT-1) primarily due to decreasing temperature, whereas the second step largely resulted from development of the Antarctic ice sheet (Oi-1).

Deep-sea benthic foraminifera responded to such oceanographic changes across the Eocene–Oligocene transition (EOT). Here we report the faunal transition of benthic foraminifera (>105 μm fraction) at ODP Site 744 (Kerguelen Plateau, 2307 m water depth) during 34.8–30.4 Ma and compare the faunal transitions of benthic foraminifera across the EOT between the Southern Ocean and the eastern Equatorial Pacific Ocean. Paleo-depth of ODP Site 744 was inferred as ~1800 m that seems to locate above the calcium carbonate compensation depth in general.

At ODP Site 744, *Nuttallides umbonifer*, *Oridorsalis umbonatus*, *Epistominella exigua*, and *Astrononion echolsi* are common constituents during the late Eocene to early Oligocene. Such faunal association is generally similar to that of ODP Site 689 (Maud Rise, Southern Ocean). *Turrillina brevispira* were temporally dominant (maximum ~54%) at 33.5 Ma with *E. exigua* (~19%). The timing seems to correspond to the EOT-1. Then, *A. echolsi* was generally common during the early Oligocene. This common occurrence is similar to those of benthic $\delta^{18}O$, suggesting the close relation to the Antarctic Oi-1 glaciation. Thus, the faunal transition of benthic foraminifera across the EOT consists of the two-step transition, like that of stable oxygen isotope record of benthic foraminifera. Finally, *N. umbonifer* was common during the early Oligocene, occasionally reaching ~60% at ~31.4 Ma.

The distribution of planktonic foraminifera from Central Locunia province, southern South China Sea

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A total of 45 core top samples (10 cm) from the Sarawak margin were used for foraminiferal analysis. The Sarawak deepwater area, also known as the Northwest Borneo margin, is considered part of the Sunda Shelf, with water depths ranging from 200 m to 2000 m. The study area belongs to the North Luconia province, bounded to the west by the Bunguran Trough, to the south by the Central Luconia province and to the northeast by the Dangerous Ground in the southern South China Sea (SCS). These samples were collected using piston cores at water depths ranging from 269 to 1,774 meters by Furgo for PETRONAS in 2019. Twenty species of planktonic foraminifera were identified. However, the most common species with an average relative abundance of >5% are *Globorotalia menardii*, *Globigerinoides trilobus*, *Neogloboquadrina dutertrei*, *Globigerinoides ruber*, *Orbulina universa* and *Pulleniatina obliquiloculata*. Among these species, *Globorotalia menardii*, has been identified as the most dominant species, with an average relative abundance of 52%. It occurred at all 45 stations, followed by *Globigerinoides trilobus* and *Neogloboquadrina dutertrei* comprised 9% and 7%, respectively. *Globigerinoides ruber* and *Orbulina universa* hold 6%, and *Pulleniatina obliquiloculata* is of 5% average relative abundance. We noticed some stations are barren or near-barren of foraminifera; this would have been related to the hydrothermal activities (a record of the average heat flow of 60 mW/m^2 at the North Luconia). In addition, the preliminary carbon-14 Accelerator Mass Spectrometry dates of foraminiferal *Globorotalia menardii* ranged from 510 – 690 ± 30 cal BP. Therefore, we assumed the foraminifer test preserved is equivalent to the modern living foraminifera.

The assemblage of planktonic foraminifera from the Sarawak margin (located at southern SCS) shared eight common species with the deepwater sediment trap records at the South East Asia Time-series Study (SEATS) site in the northern SCS. Among them, *Neogloboquadrina dutertrei*, *Pulleniatina obliquiloculata* and *Orbulina universa,* recorded a similar value of average relative abundance in both regions. On the contrary, the average relative abundance for *Globorotalia menardii, Globigerinoides ruber, Globigerinoides sacculifer, Globigerinoides trilobus* and *Globigerinoides siphonifera* in the two regions are having significant differences. For example, *Globorotalia menardii* recorded a 52% average relative abundance at the Sarawak margin but only recorded 1% at the SEATS site, and *Globigerinoides sacculifer* is the most abundant species (34% average relative abundance) at the northern SCS but having just <5% in the southern SCS. Noticeably, species with similar average relative abundance in the northern and southern SCS regions are mostly thermocline dwellers. However, the surface mixed layer dwellers are the foraminifer species with significant average relative abundance differences.

A mid-Holocene cold spell in the Nordic Seas and its links to a global cooling event

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Apart from long-term changes, the climate of the Earth has been punctuated by numerous short-lived events that had a tremendous influence on terrestrial and marine ecosystems. The present interglacial period is relatively warm and stable, especially compared to the preceding glacial time. However, several prominent cooling events have been identified within the Holocene, some of them of overregional importance. Based on previously published marine records from the Nordic Seas, we describe for the first time an event centred around 6.7 ka BP. Planktic foraminiferal records along the North Atlantic Drift reveal distinct subsurface water cooling. It was preceded by a stepwise increase in sea-ice cover in the eastern Fram Strait, as indicated by a biomarker record. The results suggest that the onset of deep convection in the Greenland Sea and the westward shift of the main flow of Atlantic Water allowed sea-ice advection from the Barents Sea into the Fram Strait. The increase in sea-ice cover weakened the advection of Atlantic Water advection. The perturbation of the overturning circulation in the eastern Nordic Seas had far-reaching consequences, including changes in deep-water circulation in the North Atlantic, cooling over vast areas of both hemispheres, and weakening of the East Asian monsoon. The described events show that during a relatively warm and stable interval, fairly local cooling can occur and the resulting sequence of environmental changes can spread globally. Understanding the mechanisms behind events that occur within generally stable intervals is invaluable for future climate predictions.

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The life cycle of *Allogromia laticollaris* has brief haploid and diploid phases followed by a 12,000 fold amplification of genome content and then *Zerfall*

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In contrast to the canonical view of genomes that fluctuate only between haploid-diploid cycles, many eukaryotes have dynamic genomes that change content throughout an individual's life cycle. However, our understanding of eukaryotic genome dynamics is incomplete, as most studies have focused on 'model' lineages of animals, plants, and fungi. Here, we expand knowledge on eukaryotic features through analyses of the foraminifera *Allogromia laticollaris* strain CSH. Foraminifera (Rhizaria) are an ancient and ecologically important clade with complex life cycles that include dramatic changes in ploidy. Here, we apply fluorescence microscopy and image analysis techniques to over 2,800 nuclei in 110 cells to characterize the life cycle of *A. laticollaris*. We show that haploidy and diploidy are relatively brief life stages, and that *A. laticollaris* nuclei experience substantial endoreplication to generate up to 12,000 times the haploid genome content in uninucleate adults. Further, we find that *A. laticollaris* reorganizes a highly endoreplicated nucleus into thousands of haploid genomes through a non-canonical mechanism called *Zerfall.* First, and perhaps best, described by Føyn in 1936, we demonstrate that the nuclear envelope breaks down during *Zerfall*, extruding chromatin into the cytoplasm; this chromatin is then is reorganized into thousands of haploid genome complements through an intermediate thread-like phase. Based on these findings plus preliminary staining of RNA expression and insights from the literature, we believe that *A. laticollaris* uses spatio-temporal mechanisms to delineate germline and somatic DNA within a single nucleus. These analyses expand on our understanding of germline/soma distinctions in eukaryotes, and extend our understanding of genome dynamics across the eukaryotic tree of life.

Objective identification of *Lepidocyclina* (Foraminifera) species from the Eocene of Cuba based on growth-invariant morphometric characters

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The Lepidocyclinidae are one group of Cenozoic three-layered larger foraminifer that came to dominate the Paleogene neritic biota around the American-Caribbean faunal province, optimally documenting the maturity and evolution of benthic communities. The high evolutionary rates exhibited by members of this family have been routinely used in biostratigraphy to improve the correlation of shallow water deposits across America. Their extreme morphologic complexity is represented by an initial embryonal part consisting of a deuteroconch and protoconch, followed by an equatorial layer of numerous, radially to concentrically arranged chamberlets and two variably developed layers of lateral chamberlets. Taxonomic classification was basically defined by the embryonic apparatus as the only reliable tool for species identification, however, further growth expressed by the sequence of equatorial or neanic chamberlets have received less taxonomic and morphometric attention. Megalospheric specimens of *Lepidocyclina* from seven localities in Western and Central Cuba were morphometrically investigated using 11 growth-independent characters for equatorial sections of nepionts and 19 growth–independent and –invariant characters describing equatorial sections of neanic chamberlets. This provides a complete geometric reconstruction of the equatorial morphology for lepidocyclinids. Specimens were objectively classified by clustering and ordination methods resulting in four morphologically homogenous groups. These unprejudiced groups are then subjectively identified as *Lepidocyclina macdonaldi*, *L. pustulosa*, *L. ariana* and *L. ocalana* following the taxonomic rules and checked for significant differences. The D/P(deuteroconch/protoconch)-ratio separates *L. ocalana* (D/P > 1) from *L. pustulosa* (D/P ≅ 1), *L. macdonaldi* and *L. ariana* (D/P < 1). The form of neanic chamberlets differentiates both *L. macdonaldi* and *L. pustulosa* possessing arcuate chamberlets from *L. ariana* and *L. ocalana* with spatulate chamberlets. The smaller size characters isolate *L. pustulosa* from the other species. *Lepidocyclina macdonaldi* has the longest stratigraphic range occurring from ABZ 9 to ABZ 16 (American Larger Benthic Foraminifera Zonation). *Lepidocyclina ariana* is restricted to ABZ 12, while *L. pustulosa* and *L. ocalana* range from ABZ 13 to ABZ 16 and ABZ 15 to ABZ 16, respectively. An evolutionary trend could be detected in nepionts of *L. macdonaldi* starting from slightly smaller nepionts at the first appearance to significantly larger nepionts at the end of the Priabonian. Additionally, the arcuate chamberlets arranged in rows transform from not-connected to connected. Differences within *L. ocalana* can be explained by environmental influences due to the paleo-geographical position of samples. Subgroups within *L. macdonaldi* on the one side and *L. ocalana* on the other describing nepiont and neanic chamberlets explain the influence of environmental factors, therefore reaffirming an ecological species concept.

Chamber of Secrets: Decoding the Formation Process of Foraminiferal tests

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Calcareous foraminifera are widely used as index fossils and environmental proxies in the fields of Earth science and environmental assessment. Over the past 30 years, they have evolved as geochemical proxies with a focus on shell chemistry, and more information about their morphogenesis has been accumulated. Foraminiferal morphology remains a fundamental element for species recognition, even in the era of genetic barcoding. Additionally, morphological changes reflecting environmental conditions are known, and discussions of evolutionary history through geological times often involve morphological variations. Various research approaches have contributed to the accumulation of information on shell and morphogenesis.

In this study, we reevaluate our observations from a morphogenesis perspective, confirm the current state of knowledge, and discuss the necessary future research approaches. We used living foraminifera collected from shallow waters around Japan, *Ammonia confertetista* and others. Methods included time-lapse observations using differential interference microscopy, visualization of pH and Ca using fluorescent reagents, and observations of individuals in shell formation stages using SEM, SEM-EDS, and FIB-SEM.

Results from differential interference microscopy showed that chamber formation involves the aggregation of cells at the site of the new chamber, which is then covered by a membrane formed by pseudopodia. Calcium carbonate deposition occurs following the membrane template, which, in biogenic carbonates, often contains polysaccharides and enzymes promoting calcium carbonate deposition. In foraminifera, this membrane has been called the Primary Organic Membrane or, more recently, the Primary Organic Sheet. Furthermore, the outer and inner membranes are spatially determined through pores, and shell thickness appears to be controlled throughout. The chamber's general shape follows the morphology of this membrane/sheet structure. Although it has been suggested that pseudopodia secrete the membrane, our observations show that they are woven into the membrane. Recent cultivation observations and time-series sample preparation during shell formation have shown that pseudopodia themselves may be woven to form the membrane/sheet. Focusing on calcium carbonate crystals, deposition begins sparsely on the template and gradually assumes a layered, wall-like morphology. At the same time, high pH levels are observed at the calcification sites, while lower pH is found externally. Cells actively transport

calcium ions, and it is clear that they obtain carbonate ions from calcium ions and CO2 or bicarbonate ions in seawater and produce calcium carbonate by reacting both in specific locations. The manipulation of such microenvironments had limitations when observed using glass electrodes in the past. The development of visualization techniques using microscopy has deepened our understanding by making environmental changes visible as images.

Future research could potentially elucidate the mechanisms governing overall shape and the locations of chamber additions. As massive sequencers are developed and applied to foraminiferal research, molecular biology approaches may provide clues to solving these cellular biological functions. To interpret this, we would like to estimate the biochemical reactions occurring by conducting live imaging of shell formation through time-lapse imaging, chemical environment imaging of calcium and pH, and imaging of intracellular organelles. Furthermore, by applying the results of RNA expression analysis, techniques such as FISH can be employed, potentially identifying specific gene expression sites in the future.

Paleoenvironmental changes during the late Paleogene – Early Neogene in the SW Caribbean Region (ANH-San Jacinto-1 well): inferences from benthic foraminifera.

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Changing tectonic dynamics from oblique to orthogonal subduction played an important role in developing marine environments controlling bathymetry, subsidence, and accommodation space in the southwestern Caribbean region during the Late Cenozoic. Foraminifera and palynology have been used in the region to understand the temporal context and the most general elements of geological evolution. However, detailed micropaleontological studies are becoming relevant recently to understanding the magnitude of the regional signal in the Caribbean and the influence of the global climate on sedimentary systems.

The onshore ANH-San Jacinto-1 well in the central Sinu-San Jacinto Basin (NW South America) records a complete marine sequence from the late Paleogene to the Early Neogene marine deposits. Here we present the micropaleontology (planktonic foraminifera and calcareous nanofossils) age model and paleoenvironmental reconstruction based on the benthic foraminifera record along the core.

Our results show an age model from the late Eocene (Priabonian) to the Early Miocene (Burdigalian) between the planktonic foraminifera biozones E15-E16 to M2 and calcareous nannoplankton biozones NP19-20 to NN2. In addition, we identified 140 genera and 288 species of benthic foraminifera. Seven main assemblages are distributed stratigraphically along the core, showing variations in wall type, biodiversity, and microhabitats.

The late Eocene assemblages indicate shifts from shallow marine turbiditic environments, in the continental shelf (neritic zone), to deeper conditions in the slope (upper to middle bathyal zone). The transition between the Eocene and Oligocene shows low diversities, epifaunal and agglutinated benthic foraminifera dominance, and neritic depths, suggesting the influence of the global climatic transition due to the onset of the icehouse stage. With a rhythmic trend, the early Oligocene to the Early Miocene assemblages comprises infaunal and calcareous-walled foraminifera, higher diversities, and environments between the outer shelf and the upper slope. During this time, the basin behaved almost stable due to the significant influence on the environments caused by orthogonal subduction as the gradual increase of subsidence. The rhythmicity shown by the benthic foraminifera seems to respond to the global climatic trend during the Oligocene.

Our results show that although the solid regional signal plays an essential role in the behavior of micropaleontological communities, the global climatic signal exerts a strong control at low latitudes.

Early evolution of trochamminoids (trochospiral organic-cemented agglutinated foraminifera)

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Trochamminids are the oldest known trochospiral group of foraminifera. Exceptionally well-preserved tests of four species of trochamminids and one that seems closely related and of trochamminoid affinity have been found in the Lower Permian (upper Sakmarian, 290–293Ma) Holmwood Shale in the Irwin Basin of Western Australia. These represent the oldest known well-preserved representatives of the superfamily. Previously known Carboniferous trochamminids are very poorly preserved and diagnostic characters such as apertural position and three-dimensional chamber shape are obscured.

The studied assemblage consists of four trochamminid species *Trochammina geoffplayfordi*, *Trochammina gloveri, Trochamminopsis teicherti*, and *Tritaxis crespinae*. *Verispira holmesi* has an *Ataxophragmium*-like coiling but seems related to the broader Trochamminoidea. All the species have agglutinated angular, sometimes rounded, quartz grains set in a finer quartz matrix. An inner organic lining is present in the inner whorls of all species. The apertural position is characteristic for each genus, and all have a distinct lip developed on the upper margin of the aperture.

This study shows that by 290–293 Ma species of *Trochammina*, *Trochamminopsis* and *Tritaxis*, remarkably like modern species, had developed in a shallow-water interior sea with muddy substrate. Species of *Trochammina* and *Trochamminopsis* may have lived in the flocculent surface layer of the mud as do some modern analogues. Species of *Tritaxis* and *Verispira* may have lived as epiphytes on the monostromatic alga *Litostroma* or as epibionts on skeletal debris present on the seafloor. A broad stratigraphic review for possible ancestors and later evolutionary diversification shows that (1) no potential trochospiral ancestor is known among the Late Paleozoic calcareous Tetrataxoidea and broader Endothyrida; (2) Triassic *Duostomina* seems to be the oldest calcareous taxa with simple trochospiral coiling (also having an inner organic lining); (3) following the Late Paleozoic diversification of trochamminoids (evidenced among the studied material) major diversifications took place during the Late Jurassic–Early Cretaceous involving different chamber shapes and during the Cenozoic involving apertural modifications. Molecular analyses of few modern species suggest that the morphological group like modern *Trochammina hadai* (including Permian *T. geoffplayfordi*) lies at some genetic distance from *Trochammina inflata* (type species of the genus).

Invasive *Trochammina* in a south-west Australian estuary

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An invasive foraminiferan has been recorded for the first time in an Australian estuary. *Trochammina hadai*, originally described as endemic from Japan and subsequently found to be alien in coastal waters of California and Brazil, has been identified in estuarine sediment in the vicinity of Bunbury Port in Western Australia. Species determination is based on morphological, molecular and ecological similarities to the Japanese type. The species has not been recorded in other estuaries in Australia. The very close molecular similarity to living specimens from Japan and North America indicates rapid invasive dispersal of *T. hadai*, rather than slower natural dispersion with greater genetic drift.

Bunbury Port, in south-west Australia, is a major exporter of woodchip to Japan and the introduction of *T. hadai* may have come from ballast water out of shallow-draught woodchip vessels. Small sediment samples of estuarine mud obtained at water depths of <5 m contain abundant *T. hadai* (on average 0.4 mm in adult diameter) that are easily recognised in microscopic view of the sediment surface by their bright reddish-brown colour. The species lives in the top 1 cm layer of flocculent mud on the estuarine floor. This study demonstrates that foraminiferal species can be included among the invasive marine taxa in Australian estuaries. *Trochammina hadai* may also provide an indicator, identified by simple microscopic examination, for the detection of other more elusive exotic species, particularly from the vicinity of ports elsewhere.

Benthic foraminifera from shallow-water of Line Islands

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The Line Islands rank among the most isolated in the tropical Pacific Ocean, form a chain of 11 atolls, and hold a biogeographic key position for the translocation of taxa across the Pacific. Because of their isolated location, the islands constitute the ultimate steppingstone for the dispersal of species from east to west and vice versa. Since benthic foraminifera

are provided with only limited dispersal capabilities, these isolated stepping stones are critical for the biogeographic distribution across the tropical Pacific. These low-lying islands are also subject to global threats, including rapidly rising sea-levels, increases in water temperature and influences from anthropogenic sources.

We have conducted a comprehensive survey on modern benthic foraminifera from three island atolls: Kingman, Palmyra, and Kiritimati. The Kingman and Palmyra islands are the northernmost atolls of Line Islands and are uninhabited USA protectorates that are managed by the U.S. Fish and Wildlife Service as part of the Pacific Remote Islands Marine National Monument. Kiritimati Island belongs to the Republic of Kiribati with a population of about 10,000 people. Palmyra atoll, in turn, has no permanent residents and but its lagoon and surrounding reefs have suffered from extensive dredging, filling, and causeway constructions.

To date, the only publication on foraminifera from the Line Island region has reported merely 25 species of foraminifera, a number that sharply contrasts with the species richness of more than 200 taxa from other tropical islands. Here we present the first results of a comprehensive survey of modern benthic foraminiferal assemblages from the Line Islands and compare the foraminiferal assemblages and species richness patterns from inhabited and uninhabited islands from different depth and habitats. By placing our species richness results into context with numerous other tropical Pacific Islands surveys, we also assess the role of the Line Islands as a stepping stone for the translocation of species across the Pacific. Our study provides novel insight into underlying mechanisms that promote species richness patterns in different shallow-water habitats.

The Foraminifera of the Western Siberian Seas – with what sorts of treasures they filled their homes after life?

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Western Siberia is widely covered by marine sedimentary deposits comprising clastic Middle Triassic through Middle Paleogene rock units. To shed new light on depositional and post-depositional processes, we have conducted a comprehensive analysis on Late Mesozoic-Early Cenozoic materials from the West Siberian epicontinental basin. The foraminiferal tests, that are widely distributed in the Western Siberian basin, contain various authigenic mineral associations. These provide additional information about the post-depositional processes of the sedimentary units. The authigenic mineral infills recovered from the foraminiferal tests comprise calcite cement, glauconite, baryte, wurtzite, pyrite, and marcasite. Here we have studied authigenic mineral associations within foraminiferal chambers to provide a better understanding of the diagenetic history of the marine sediments of the West Siberian.

The material includes a total of 82 sedimentary rock samples of which 5 samples are from the Sokolovskii section in the southernmost part of Western Siberia, 65 core drilling samples from the Kyshtyrla Quarry located in the south western corner of Western Siberia, and 12 core drilling samples are from Kharasavey oil and gas field on the Yamal Penisula. The samples analysed were taken from three prominent formations: Tibeisale (Lower Paleocene), Sokolovsk (Upper Paleocene) and Tavda Formation (Upper Eocene). All samples were sieved over 63-µm mesh sieves and inspected for foraminifera by using a stereomicroscope. A total of 3570 foraminifera were recovered from all samples and 48 tests were dissected and polished to analyse the inner structure and chamber infillings of authigenic mineral associations. Chamber infillings were then examined by SEM and EDS-SEM.

The foraminiferal chambers examined were found to act as storage devices for iron sulfides such as pyrite, authigenic calcite, and gypsum. The pyrite mineral deposits are mainly small framboids (5–10 µm) and fine-grained globular and octahedral forms of pyrite (30–40 µm). Pyrite mineral infillings were predominantly associated with Upper Eocene deposits and rarely occurred in Paleocene sediments. The authigenic calcite often covered the internal surfaces of the foraminiferal tests and comprises mainly microsparite (<1 µm) and occasionally sparite (~10–20 µm). The external test layer was frequently coated by a thin layer of microsparite. Authigenic calcite was found to occur within tests from all formations. Gypsum infillings typically occurred as elongated crystals (up to 80–100 µm), partially filled the chambers and often surrounded the small pyrite framboids or other non-authigenic particles in chambers. Gypsum infillings were recorded only in the Upper Eocene units.

The formation of mineral infillings appears to follow a chronology of phases that can be inferred from crystal form and crystal boundaries, and the transitions between them. The first phase commonly includes the formation of pyrite framboids, that are later surrounded by calcite and gypsum (second phase). The formation of pyrite framboids is generally related to the

degradation of organic matter within the test chambers, the removal of dissolved oxygen by aerobic bacteria and the reduction of sulphate to hydrogen sulphide, and iron ion reactions. The second mineral phase includes the formation of authigenic calcite filling the chamber interior and covering of external surfaces. The formation of authigenic calcite is considered to be the result of redissolution and recrystallization of the primary total carbonate present in the sediment and in biogenic materials. The appearance of gypsum crystals appears to be linked to the pyrite aggregates is probably related to the oxidation of the sulfidic sediments.

Planktonic foraminiferal quantitative record of the Burdigalian to Langhian interval at Site 1264 (Walvis Ridge, south-eastern Atlantic Ocean)

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During the late Burdigalian to Langhian interval (Early to Middle Miocene) the Earth's climate was characterized by a global warming period (Miocene Climatic Optimum) from 17 to 14.7 Ma, which was followed by a gradual decline in temperature (Middle Miocene Climate Transition) culminating in the marked Mi3b cooling event at about 13.8 Ma. This evolution of the ocean-climate system favoured the development of marked meridional and vertical thermal gradients, the increase of zonality and the contraction of tropical and subtropical bioprovinces to lower latitudes. Planktonic foraminiferal assemblages were also affected by these climatic changes and their differentiation between low- and mid-latitude regions increased leading to the erection of different biozonal schemes.

High-resolution quantitative studies of planktonic foraminiferal assemblages and a good age control (e.g., by the integration with magnetostratigraphy and/or cyclostratigraphy) are fundamental to improve the understanding of spatial and temporal distribution of planktonic foraminiferal species. Moreover, this integrated approach enhances biostratigraphic resolution, the accuracy of age calibration of bioevents and the evaluation of their synchronism at a global scale.

Here, we present the results of high-resolution quantitative analysis of the planktonic foraminiferal assemblages, focussing on biostratigraphic markers, from the astronomically tuned Site 1264 (ODP Leg 208), located in the south-eastern Atlantic Ocean at a latitude of ~28°S. The investigated stratigraphic interval, spanning from ~17.5 to ~13.5 Ma, consists of foraminifer-bearing nannofossil oozes containing well preserved planktonic foraminiferal assemblages. The quantitative biostratigraphic analysis, performed with a time resolution of ~20 kyr, allowed us to obtain detailed distribution patterns of the marker species and to refine the stratigraphic position and the age calibration of the bioevents. The presence of taxa used as zonal markers in the (sub)tropical standard zonation (e.g., *Catapsydrax dissimilis*, the evolutionary stages of *Trilobatus*-*Praeorbulina*-*Orbulina* lineage) and taxa typical of temperate assemblages (e.g., *Globorotalia miozea* and *Globorotalia zealandica*) and the absence of *Globigerinatella insueta* s.s., typical of the tropical assemblages, indicate that planktonic foraminiferal assemblages at Site 1264 differ from those of the low-latitude regions since the late Burdigalian. Moreover, a comparison of the biostratigraphic record of Site 1264 with low-latitude distribution range of marker species and biochronology (literature data) highlighted diachronism of some main events, such as the first occurrences of *Praeorbulina* and *Orbulina* species, and differences in the distribution patterns of marker species (e.g., *Paragloborotalia siakensis*).

Phylogenetic patterns of Foraminiferal Organic Linings

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Foraminifera leave three types fossil records that include: composite mineral-organic tests (shells); foraminiferal organic linings (FOLs); and ancient foraminiferal DNA. All these record types differ in sample preparation techniques and methods of taxonomic identification. While our knowledge of the mineral record is impressive, our understanding of organic remains is still highly limited. In particular, the fossil archive of acid resistant linings is highly fragmentary, and in consequence, the overall foraminiferal record is strongly biased towards mineral tests. Despite these limitations, we explore the potential of the FOLs record for understanding the evolution of Foraminifera. We are especially interested in learning evolutionary trends of morphogenetic and biomineralisation principles emerged from the record of extremely diverse foraminiferal tests. Therefore, we have analysed the overall published Phanerozoic record of FOLs that integrates over 600 images (see *ForamL*, doi: 10.17632/xw7w5ns649.2). Exploration of the phylogenetic trends within the dataset is the first goals of our project. This was a non-trivial task, as most of the FOLs in the database have never been taxonomically identified. Despite

this limitation our meta-analysis demonstrates that nearly all foraminiferal organic linings show globular chambers with minimized distances between successive foramina. It means that multilocular foraminifera with tubular chambers are almost missing from the record. If we separate unilocular linings of monothalamean foraminifera from the dataset, it appears that most of the multilocular organic linings should be classified to the class Globothalamea. We hardly recognize linings attributed the class Tubothalamea. The Devonian *Tolypammina tantula* Bell assigned to Ammodiscina is nearly the only exception identified so far within Tubothalamea. However, its long uncoiled tubular test may suggest association with monothalamean astrorhizids, therefore, its tubothalamean assignment is still very uncertain. Our analysis does not allow identification of orders that represent globothalamean agglutinated and calcareous tests. We can just assume that some of multilocular linings with globular chambers could be classified to the order Textulariida. Foraminifera from this group tend to preserve linings that are similar to the linings of calcareous tests. Another intriguing observation is that planktic foraminifera belonging to the class Globothalamea do not preserve organic linings in the fossil record. Earlier dissolution experiments proved the lack of acid resistant organic linings after dissolution of planktic foraminiferal tests. We observe a limited number of lagenid linings, however, they are relatively rare, even in the Jurassic records where Lagenida dominate within mid to shallow marine sediments. All these phylogenetic patterns of irregular appearance of linings provoke main research questions. Why there is nearly no record of fossil linings that belong to Tubothalamea. Do all foraminifera truly produce fossilizable organic linings? Are these linings compositionally and structurally similar? What is their taphonomic potential? Foraminiferal organic linings as "residual organic remnants of foraminifera left after chemical dissolution of their mineral tests" represent residues of extracellular organic matrix incorporated and/or coating foraminiferal tests. The most prominent is the inner organic lining that seems to be directly associated with biomineralization, protection, physiology, combined functions in Foraminifera. These functions might follow phylogenetic trends and different evolutionary adaptations. All these problems encourage our interdisciplinary investigations.

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Foraminiferal succession across the Permian–Triassic boundary in Northern Thailand

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In Southeast Asia, Late Permian and Early Triassic foraminifers are rarely known so far, and therefore the foraminiferal faunal succession across the Permian–Triassic boundary has not yet been documented in detail. We investigated latest Permian to Middle Triassic strata distributed in the Lampang area of Northern Thailand to understand foraminiferal faunal features and transition across this systemic boundary. The Late Permian in this area is attributed to the Huai Thak Formation in the Ngao Group and previously, the Changhsingian *Palaeofusulina-Gallowayinella-Colaniella* foraminiferal fauna was described from it. The Triassic is called the Lampang Group and consists of the Phra That, Pha Kan, Hong Hoi, Doi Long, and Pha Daeng formations in ascending order. Of these, the Phra That Formation in the lowest is conventionally assigned to the Early Triassic, and is overlain conformably by the carbonate Pha Kan Formation of early Middle Triassic (Anisian) age. Although the Phra That Formation in its type area has been described as consisting mostly of siliciclastics, we newly found an entirely carbonate succession that is equivalent chronologically to the Phra That Formation, in other area of Lampang. Consequently, almost continuous carbonate stratigraphy ranging from the latest Permian to the early Middle Triassic can be established in the investigated section.

The studied carbonate strata are about 1300 m thick, with several unexposed intervals. The basal part, corresponding to the uppermost part of the Huai Thak Formation, consists of bioclastic limestone (wackestone/packstone) and contains variable foraminifers, such as *Palaeofusulina sinensis*, *Reichelina changhsingensis*, *Colaniella cylindrica*, *Rectostipulina quadrata*, *Dagmarita*, *Paraglovivalvulina*, and *Retroseptellina*. This foraminiferal fauna indicates a late Changhsingian age. Then, this latest Permian interval is succeeded continuously by approximately 800 m-thick dolomite and dolomitic limestone. Its lower portion is characterized by dolomite and laminated lime-/dolo-mudstone with diagnostic laminated microbialites in some levels, and contains *Postcladella kalhori* sporadically. The middle–upper portion is dominated by cross-laminated oolitic and pisolitic dolomitic limestone and dolomite, and rarely yielded a monotonous and restricted foraminiferal assemblage composed of *Postcladella*? or primitive *Arenovidalina*? and "*Glomospirella discoidalis*". These foraminifers suggest that the dolomite and dolomitic limestone succession is correlated broadly to the Lower Triassic. This further implies that the present dolomitic interval represents a contemporaneous heterotopic facies of the clastic-dominant Phra That Formation. The overlying, approximately 500 m-thick part consists mainly of dark-colored micritic limestone. Based on the lithological features, this part is considered as the Pha Kan Formation, which is known to be characterized by the Anisian *Citaella dinarica* foraminiferal fauna.

In view of foraminiferal succession and lithological features, the Permian–Triassic boundary is placed in the very base of the section, at the base of the dolomite-dominant interval, which directly overlies bioclastic limestone containing the late

Changhsingian *Palaeofusulina sinensis-Reichelina changhsingensis* fauna. The overlying, approximately 800 m-thick, dolomite-dominant succession is considered to be Early Triassic and is characterized by unusual foraminiferal features and carbonate lithology, such as restricted faunal diversity, laminated microbialites, and pisoid-rich dolomitic limestone. This is the first documentation of Early Triassic carbonates and foraminifers in Southeast Asia. The present Early Triassic section would have good potential for elucidating paleoenvironments of the eastern Paleotethys during the relevant time interval.

Transcriptome analyses unveil the molecular flamework of calcification in Rotaliida, benthic and planktic foraminifers: What are the differences among species?

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Rotaliida foraminifers have contributed to more than 20% of calcium carbonate ($CaCO_3$) production over the world ocean, owing to their abundance in both seafloor and pelagic oceans. Their $CaCO_3$ tests have been widely used in geochemical analyses to reconstruct paleoenvironments because their chemical and isotopic composition are interacted with physicochemical conditions of ambient seawater. Despite of such utilities, we need to examine the non-equilibrium state of chemical compounds between foraminiferal tests and the external environment. One of the biggest problems is how foraminifers biologically control the uptake of Ca^{2+} and inorganic carbon in biomineralization. Although the molecular mechanism of foraminiferal calcification had been completely masked, our recent study successfully estimated the metabolic pathway driving calcification in a benthic foraminifer based on comparative transcriptomic analyses. Foraminifers actively take up Ca^{2+} to boost mitochondrial ATP synthesis during calcification but pump excess intracellular Ca^{2+} to the calcification site to avoid cell death. The enzyme α-carbonic anhydrase (CA) induces the generation of HCO_3^- and H^+ from multiple CO_2 sources. The evolution of Ca^{2+}-related and CA genes is likely a key for calcification in Rotaliida. However, calcification mechanisms have been also thought to show species specificity among diversity in Rotaliida. In particular, the presence of microalgal symbionts may be involved in planktic foraminiferal calcification. Here, we conducted the transcriptome analyses of two planktic foraminifera species and examined the common and different points for calcification among benthic and planktic species.

In the present study, we cultured *Trilobatus sacculifer* (with microalgal symbionts) and *Globorotalia inflata* at three different temperatures to observe their chamber formation processes. These two species formed a new chamber via the arrangement of reticulopodia as same as the process of a benthic foraminifer *Ammonia beccarii*. Based on these observations, we extracted mRNA from single cells during calcification and non-calcification stages and conducted single-cell RNAseq analysis. Using comparative transcriptomics, we predicted the candidate genes, which were highly or only expressed during calcification in each species. Most genes, in particular Ca^{2+}-related and CA genes, were commonly used among three species. Interestingly, qPCR analysis showed expression levels of the Ca^{2+}-related gene are different among species and temperatures. These differences could be reflected in chemical composition of the foraminiferal tests.

Biological adaptation of Foraminifera to low oxygen conditions

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Marine low-oxygen areas have been increasing since the 1960s due to ongoing climate change and eutrophication, and has led to dramatic ecological and economic consequences that will most likely be amplified in the near future. Deoxygenation will affect the stability of marine ecosystems, of which unicellular protists called Foraminifera are a major

component. This key group of ecological indicators contributes significantly to both the nitrogen and carbon cycling in benthic ecosystems, but are also sensitive to changes in the environmental parameters like temperature, salinity and oxygen. Many foraminifera make a calcite test riddled with pores, which are hypothesised to be used for gas exchanges. The characteristics of these pores are observed to change according to oxygenation conditions and/or nitrate concentrations. However, so far, this have not been tested nor calibrated in controlled laboratory conditions. This study aims to better understand the adaptation capability of foraminifera to predicted hypoxic and anoxic conditions, in order to determine their fate in future oceans and evaluate their potential as proxy.

We investigated the response of two different species of foraminifera to different oxygen concentrations, the symbiont-barren species *Ammonia tepida* T6 and the tropical symbiont-bearing species *Amphistegina* sp. We analysed shell porosity as well as a range of different biological parameters, i.e. survival and shell growth rate. For both species, the number of newly formed chambers decreased with decreasing oxygen concentration, while survival rates were not affected. These results suggest that foraminifera can survive short periods of lower oxygen conditions, but will perform less well (create less new chambers). In both species, porosity increased with decreasing oxygen content. However, for *Ammonia tepida* T6, the porosity gradually increased with decreasing oxygen concentration, while for symbiont-bearing *Amphistegina* sp., shell porosity only increased at the lowermost oxygen conditions tested, suggesting symbionts might support the foraminifer until a certain hypoxia threshold. The results might indicate that species of foraminifera with symbionts might be more resilient to low oxygen conditions, but also that the shell porosity of symbiont-barren species could be used as a proxy for past oxygen conditions.

Cogwheel structures in foraminiferal shells

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Most studies designed to better understand biomineralization by foraminifera focus mainly on their shell chemistry in order to retrace processes responsible for element uptake and shell formation. Shell formation is a combination of not only chemical and biological processes but also structural limitations. Since the processes involved in the formation of the foraminiferal shell remains elusive, new focus has been put on potential structural constraints during shell formation. Revealing structural details of shells of foraminifera might increase our mechanistic understanding of foraminiferal calcification, and even explain species-specific differences in element incorporation.

Recently, shell structures have been studied in increasingly higher resolution and detail. This project aims to provide new insights on the structural features on foraminiferal shells, so-called cogwheels, which can be observed in the shell wall and at its surface after mild etching. Electron Backscatter Diffraction (EBSD) analysis of embedded foraminifera shows that individual cogwheels have their own crystallographic orientation perpendicular to the primary organic sheet, which suggests that these microunits are independent and likely separately formed during the calcification process. Finally, we present a novel method to image and quantify these cogwheel structures based on the freeware ImageJ, using field specimens from different environments and ecological groups, including benthic and planktonic species. Application of this method allows for comparing shell structures at specimen and species level, to unravel potential drivers of shell formation.

Response of benthic foraminifera biomass on the slope and plateau of Santos Basin (South Atlantic, Brazil) to different carbon flux models

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The biomass of benthic meiofauna is very representative in the oceans, with benthic foraminifera representing 50% or more of the eukaryotic biomass in deep-sea environments. The ecological indices of benthic foraminifera are influenced by different factors, and biomass is related mainly to the quality and quantity of organic matter (OM), which is a limiting factor

in these environments. A way of providing OM to the ocean floor organisms is the vertical carbon flux, which will indicate the export of OM from the euphotic layer to deep regions of the ocean through the water column. However, there is no consensus between the decantation velocity and model of carbon flux that can be applied in the understanding of benthic organisms distribution in deep-sea, which makes it difficult to compare the response of benthic foraminifera biomass to OM input to the bottom sediment. This study aims to understand the influence of carbon flux on the biomass in foraminifera in Santos Basin (South Atlantic, Brazil) and propose a model that is most suitable for deep-sea oligotrophic regions. Sediment samples (0-2 cm) were collected from 29 stations in 5 transects along the slope and plateau of Santos Basin, between depths of 400 m and 2400 m, during the winter of 2019 within the Santos Project –The Santos Basin Regional Environmental Characterization (PCR-BS) – coordinated by energy company PETROBRAS. The sediment was stored in a solution of Rose Bengal (2g/L) and 10% formalin buffer with borax, and the living benthic foraminifera were picked out, identified, and photographed for biomass. The biomass was calculated by biovolume methodology, comparing the individuals to geometric figures, and considered the cytoplasmic occupation of 35% of the test. Five models of flux carbon were compared with estimate of benthic foraminifera with different export efficiency equations (e-ratio) considering two decantation velocities (100 and 200 $m.day^{-1}$). The models of carbon flux data were based on remote sensing MODIS aqua and processed by SeaDAS 7.5.3 (average between 21 and 35 days before the benthic sampling). The Eppley-VGPM model, which considers the temperature effect over physiology/photoacclimation, was used to estimate the primary productivity and the hydrodynamic 3-D modelling was realized with HYCOM to estimate the origin of the photosynthesized particle. Five hundred and seventeen living species of benthic foraminifera were identified, and the biomass values demonstrated a latitudinal gradient, occurring with the lowest values in the south and the highest values in the north of the basin. The biomass values also evidenced a bathymetric gradient, occurring with the lowest values in the station at 2400 m water depth (plateau). The carbon flux values were higher considering the decantation velocity of 200 $m.day^{-1}$. The three carbon flux models that considered temperature and primary production (D05a, L113 and CF165) in the e-ratio equation demonstrated higher values compared to the others. The Kruskal-Wallis test demonstrated a significant difference both between the methods and between the decantation speeds. In addition, all methodologies indicated gradient of latitude and depth, such as the estimate of biomass of benthic foraminifera. Spearman's correlation analysis did not indicate significant correlations between total estimate of biomass and carbon flux results, but part of the species demonstrated significant weak to strong correlation coefficients. The highest number of significant correlations was found between the decantation speed of 200 $m.day^{-1}$ and two carbon flux models (D05a and L113). Thus, the biomass of benthic foraminifera demonstrated satisfactory responses to the carbon flux models analysed, mainly considering the decantation velocity of 200 $m.day^{-1}$ and the flux models, occurring the highest correlation values between the species and the models D05a and L113, demonstrating that these models can be used for oligotrophic deep-sea regions.

Benthic foraminifera biomass on the continental slope and São Paulo plateau of Santos basin (South Atlantic, Brazil): Comparison between different cytoplasmic occupation in the test

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The biomass of benthic foraminifera (BF) is important as it constitutes 50% or more compared to the biomass of others eukaryotic organisms in depth-sea environments and contributes significantly to the energy flux of meiofauna. This has been demonstrated in the literature, where the biomass presented a positive correlation to sedimentary organic matter (OM) contents and particulate OM flux. Different methodologies have been developed over the years for the measurement of the biomass, such as dry and wet weight, Adenosine Triphosphate (ATP), and nano-spectrometry, but these methodologies are very imprecise or/and expensive or/and destructive or/and not applicable for analyses of abundant communities. The biovolume methodology has some advantages, such as being a non-destructive and less expensive, although it is not an accurate method. For more accurate values of biomass calculated by biovolume, it should consider the measurement of the cytoplasmic occupation, as the area occupied in the test can vary according to the environmental conditions, and thus can be calculated by different methods (e.g., direct visualization of cytoplasm occupation (DV), wet combustion technique). Despite diverse percentages of test occupation being observed in previous studies, there are not studies comparing the results from different percentages in the same sample. Therefore, this study aims to compare three different estimates of biomass by biovolume based on different percentages of the cytoplasmic occupation of the test (DV, 32% and 35%, the last two proposed in the literature) of living BF in the slope and São Paulo plateau (SPp) of the Santos Basin (SB) (South Atlantic, Brazil) and in addition, to evaluate these values with sedimentary geochemical parameters, to understand the environmental conditions in the study area. Sediment samples (0-2 cm) from 29 stations in five transects along the continental slope and SPp of the SB, between depths of 400m and 2400m, were collected during the winter of 2019 within the Santos Project – The Santos Basin Regional Environmental Characterization (PCR-BS) – coordinated by energy company PETROBRAS. The sediment was stored in a solution of Rose Bengal (RB) and 10% formalin buffer with borax, and BF was picked out,

identified, and photographed for biomass. The biomass was calculated by biovolume methodology and evaluated according to different percentages of the cytoplasmic occupation in the test: DV (percentage of cytoplasm in the test stained with RB), 32% and 35%. The geochemical data demonstrated low OM input, but labile and good quality - high carbohydrate (CHO) (highest value 2.80 mg/g), phaeopigments (highest value 6.62 μg/g) and protein/CHO ratio (>1)-, mainly in the central and northern of SB due to the flux of particulate OM probably from the vortices present in these regions. The occurrence of 517 living species identified and the biomass estimate demonstrated a latitudinal gradient (values decrease towards the south) and bathymetric gradient, where the station at 2400m (SPp) presented lower biomass than the other stations. The distribution of biomass estimate in SB was influenced by the availability and lability of OM, demonstrated by the lower biomass in the south of the basin, where there is also lower quality and availability of food, in contrast to the values observed in the northern region of the SB. Although the biomass calculated by the DV did not show significant differences in comparison to the others (32% and 35%), the percentage of test occupancy observed (average cytoplasmic occupancy of 37.5%, varying between 17.6% and 68.8%) was different in relation to the percentages proposed in the literature. Therefore, even without a significant difference between the percentages of test occupation, the biovolume methodology by the DV proved to be more efficient, increasing the accuracy of the estimate of benthic foraminifera biomass in the oligotrophic oceanic regions.

Assessing the environmental drivers of seasonal-to-decadal shifts in planktonic foraminiferal assemblages in the Gulf of Mexico

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Marine ecosystems experience fluctuations in environmental conditions (e.g., temperature, salinity, nutrients, light availability, stratification, etc.) on daily up to millennial timescales and beyond, with magnitudes often exceeding those caused by anthropogenic forcing. There are few ecological datasets temporally resolved enough to disentangle the effects of natural environmental variability from those due to modern anthropogenic change. Here we use an exceptionally long running and resolved USGS sediment trap from the Gulf of Mexico (GoM; 27.5ºN, 90.3 ºW) to investigate whether there are emergent signals of anthropogenic change in the assemblage composition of planktic foraminifera from January 2008–January 2020. This study focuses on the GoM, a semi enclosed basin in the northwest subtropical Atlantic Ocean affected by a variety of factors including loop current dynamics, Mississippi River discharge, and the frequency and intensity of storms and tropical cyclones. The Gulf's relatively large seasonal temperature range (~10 ºC) and dynamic setting on a continental margin makes it an ideal location to explore the interacting effects of multiple environmental factors on the planktonic foraminiferal community.

We use Bray-Curtis dissimilarity to quantify differences in community composition from month to month and explore the dominant modes of variability using a principal component analysis. Temporal trends in β diversity (as compared to the initial month in the time series) and the principal component analysis show a strong two-phase (winter/summer) variability in community composition, unlike the seasonal patterns of winter/spring/summer/fall in the northern GoM. The first two principal components account for nearly 60% of the variance, with a secular trend in PC1 and β diversity from 2008 to 2020 towards more dissimilar populations, even in the same months and in the winter/summer population framework. We explore the environmental and anthropogenic drivers of these trends using regression and factor analysis against a suite of environmental parameters from in situ, remote sensing, and gridded data.

Nature of cooling events on the southern Iberian margin point to extreme contraction of the North Atlantic's subtropical gyre during the early Pleistocene

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The Gulf of Cadiz on the western side of the Strait of Gibraltar marks the transitional zone between the North Atlantic and the Mediterranean Sea and is nowadays influenced by North Atlantic subtropical gyre waters. Studies on deep-sea cores from that region have shown that during the Heinrich events of the last glacial cycle colder surface waters penetrated into

those southern mid-latitudes, but with reduced intensity. Making use of the centennial-scale paleoclimate records from IODP Site U1387 (36°48´N 7°43´W; 559 m water depth), which cover the early to middle Pleistocene interval of Marine Isotope Stage (MIS) 16 to MIS 52 (0.65 – 1.51 Ma), we are exploring the nature of cooling events during the Early to Middle Pleistocene transition (EMPT) and the early Pleistocene using the planktonic foraminifera fauna and transfer function and alkenone derived sea-surface temperature reconstructions.

Terminal stadial events during abrupt glacial/interglacial transitions, for example MIS 20/19, MIS 22/21, MIS 26/25, MIS 48/47 and MIS 50/49, recorded periods of extreme surface water cooling with annual sea-surface temperatures dropping below 15°C and planktonic foraminifera faunal based reconstructions for winter below 10°C. The abundance of polar planktonic foraminifera species *Neogloboquadrina pachyderma* exceeded 40% during those events, indicating the influx of subpolar surface waters into the southern mid-latitudes of the Northeast Atlantic. The terminal stadial events are related to disintegration of circum-North Atlantic continental ice sheets and their impact on the Atlantic Meridional Overturning Circulation (AMOC), similar to the late Pleistocene Heinrich events.

Additional stadial events with comparable characteristics are observed during early MIS 22, MIS 32 and MIS 38. The cooling on the Algarve margin during all those early Pleistocene events was more intense than during Heinrich events 1 to 6 pointing to an extreme contraction of the North Atlantic's subtropical gyre, at least along the eastern margin. Duration of the cooling events varied between 1000 and 3000 years with a cumulation within MIS 22 with its two extended phases of extreme cooling. Prevalence of subtropical surface waters after the cooling event occurred generally within 1500 years, independent of the duration of the preceding cooling event, pointing to common processes leading to reestablishment of a strong AMOC. The IODP Site U1387 data reveals cooling events were a regular feature, but were, unexpectedly, more intense during the early than the late Pleistocene.

Biostratigraphic and marine palaeoenvironmental change associated with the Plio-Pleistocene transition along the western continental shelf of southern Africa

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The oceanography and sedimentation of the western margin of southern Africa (Orange Shelf) have been influenced by the highly productive Benguela Upwelling System (BUS) since the late Miocene (> 5.3 million years ago) which later intensified in the Pleistocene. The Plio-Pleistocene environmental transition on the western margin of southern Africa has largely been understudied in a foraminiferal context. Previous work from the Namibian margin indicates a drastic change in palaeoenvironments during the Pliocene, notably a period of cooling and CO_2 levels that are similar to today. In an attempt to further refine the Neogene to Quaternary stratigraphy along the South African margin, and to determine how past environments changed during the Plio-Pleistocene, three vibracores from offshore western South Africa (260 – 403 mbsl) were analysed using a combination of faunal analyses, foraminiferal biostratigraphy, and strontium isotope stratigraphy. Collectively 600 benthic and planktonic foraminifera specimens from each sample were counted where 27 benthic species were identified from 36 genera and all 14 species were identified from the 14 planktic genera. Biostratigraphy showed evidence of the Plio-Pleistocene transition by the appearance of *Globorotalia truncatulinoides,* marking the start of the Pleistocene and the synchronous proliferation of *Globoconella inflata* abundances, while the rapidly diminishing *Siphonodosaria lepidula* abundances marked the end of the Pliocene. Cores from the outer shelf indicate a lapse in abundance for the region's primary productivity indicator, *Globigerina bulloides,* during the Plio-Pleistocene transition. *G. bulloides* saw resurgence following a strengthening of the Benguela Upwelling System with the development of Southern Hemisphere glaciation in the Pleistocene. Occasional samples showed periods of low abundance for *G. bulloides* and may be indicative of a shift in the frontal zone along the shelf generally associated with the large amplitude glacial-interglacial cycles for this time. The ongoing Sr radiometric age analysis on these samples will confirm whether such relationship exists. In the Pliocene samples, *Orbulina universa* remained dominant and was indicative of warmer waters in comparison to the colder Pleistocene. Occasional warmer periods were observed in the Pleistocene through *O. universa,* suggesting either a lapse of glaciation or an external influence such as warm water leakage from the Agulhas Current. For the benthic environments, *Uvigerina* spp. saw high and stable abundances across the Plio-Pleistocene and were consistent indicators of eutrophic environments under high organic carbon fluxes, contrasting the benthic conditions in the Miocene but still typical of strong upwelling regions such as the BUS. This remained true for the Pleistocene, where an intensification of upwelling supported and sustained infaunal taxa such as *Uvigerina* spp. in the benthic sediment. This study aims to further its palaeoenvironmental assessment by utilising a comparative core on the inner shelf of western southern Africa, which will aid in the development of a shelf profile in relation to palaeoceanographic change. The results from this study contributed to a better understanding of the stratigraphy of the region and the development of the Benguela Upwelling System in a foraminiferal context.

Historic sediment samples as early-Lessepsian baselines for the biogeography and diversity of benthic foraminifera in the Mediterranean Sea

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One of the most important effects of ongoing climate change on benthic foraminifera are changes in their distribution ranges. This has been shown especially for the Mediterranean Sea, where warm-adapted species are expanding their distribution ranges mostly from the eastern to the western basin. This is further facilitated by the Lessepsian migration from the Red Sea into the Mediterranean since the opening of the Suez Canal in 1869. Among the foraminiferal "invaders" are the symbiont-bearing *Amphistegina lobifera* and other tropical taxa, which are not only continuing their expansion towards the west but also appear to have lasting effects on local communities and diversity structures. Over the last years, it was possible to monitor the expansion of *A. lobifera* and other species by tracking new occurrence records and applying habitat models to predict their future distribution ranges in the Mediterranean.

However, in order to evaluate the degree and implications of shifting species' distribution ranges, it is also important to know about the situation in the past, *e.g.* before the onset of the Lessepsian migration. While we can monitor recent distribution changes over the last several decades and with the help of future studies, it is much harder to evaluate the biogeographic situation of the 19th century – especially in the early days of the industrialization and the Suez Canal. While older foraminiferal assemblages can be studied from sediment cores, there always remains an uncertainty concerning exact dating of the studied sediment layers and possible mixing with younger faunal elements even before the coring process.

Here, historic sediment samples can be a valuable asset to get a glimpse into the actual species distribution and assemblage composition at a specific time in the past. The Department of Geology and Paleontology at the Natural History Museum in Vienna houses a collection of sediment samples that have been donated by various internal and external scientists and/or collectors during the 19th century and have never been studied until now. The collection includes recent sediment samples from near-shore locations in Malta and Sicily – two islands that are the focus of several recent biogeographic studies on benthic foraminifera in the central Mediterranean. One set of samples from Sicily and Malta was collected between 1871 and 1874 by Theodor Fuchs (1842–1925), assistant at the then k.k. Hofmineraliencabinet. Another set from Sicily was donated to the Museum in 1889 by Tommaso di Maria Allery Marchese di Monterosato (1841–1927), a Sicilian malacologist. While the latter samples are not dated, his biography suggests that they were collected during the 1870s or early 1880s. As such, the samples provide a unique window into the times of early industrialization and shortly after the opening of the Suez Canal. The samples cover different locations and depth ranges and their preservation status is very good. Foraminifera were picked from a total of 30 samples.

The present study aims at providing a comprehensive inventory and catalogue of the benthic foraminiferal assemblages from central Mediterranean locations in the 1870s. This will be coupled with an up-to-date revision of existing reference literature and catalogues. These will provide an important baseline in terms of industrialization effects – especially climate change and pollution – and Lessepsian migration. The study will be further expanded by including evaluations of biodiversity and environmental indices. A comparison with modern material is also envisioned.

Tracking community turnover through time: A combined approach of propagule culture experiments and eDNA metabarcoding

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Shallow-water environments harbour diverse and variable communities of benthic foraminifera. Such environments are characterised by annual, seasonal, and diurnal changes in ecological variables such as temperature, salinity, and nutrient

supply. Benthic foraminiferal assemblages are known to respond quickly to such changes, leading to continuous faunal turnovers and highly dynamic community structures.

For several years now, culture experiments with foraminiferal propagules (juveniles <63 µm) have been established as a useful tool to analyse and evaluate assemblage reactions to changing variables (*e.g.*, temperature, salinity, pH, and others). The propagules are separated from the coarser fraction (>63 µm) and cultivated under different conditions, before analysing the grown experimental assemblages. The resulting differences show that assemblages can respond in the course of few weeks, supporting the assumption of the highly dynamic structures. However, such experiments were mostly single-time events and continuous faunal turnovers have not been analysed in detail before. Furthermore, there has never been quantitative information about the fine fraction itself.

In the present study, we combined for the first time the propagule cultivations and their subsequent census counts with simultaneous environmental(e)DNA metabarcoding. With this combined approach we aim to 1) assess the community turnover through time by sub-sampling the material in defined time intervals, 2) evaluate if the observed dynamics apply for the coarse, as well as the fine fraction and 3) support the recognition that morphological and molecular approaches complement each other profitably in environmental monitoring.

Sediment samples were collected in May and October 2019 from a shallow lagoon on Corfu Island (Greece) and sieved over 63 µm to separate the propagules from the coarser fraction. The in-situ material of the sampling site was taken as baseline for the following experiments (T0). The finer fraction (<63 µm) was set up in 2 replicate tanks for 15 weeks under stable conditions (22°C, 38 psu, constant aeration). The cultures were repeatedly harvested for grown foraminifera (>63 µm) after 5, 10, and 15 weeks (T1, T2, T3). At the same intervals, additional samples were taken and re-sieved for eDNA metabarcoding of both size fractions (<63 µm and >63 µm).

In our morphological dataset, we retained 117 species. Among those species, some were present in all samples and others were exclusive to the experimental assemblages (T1–T3). Certain species were also exclusive to samples originally collected in May and October, respectively, suggesting a seasonal effect, which continues within the experiments. These observations were mirrored by the OTUs retained from the metabarcoding dataset.

Our two resulting datasets both showed an assemblage turnover through time with regard to alpha and beta diversity. The most significant difference was between T0 (in-situ) and the experiments (T1–T3), but also all harvesting intervals showed significant changes in composition. The morphological count data also revealed strong variations in foraminiferal density as well as shell accumulation over time (especially between T2 and T3), which suggests one or more reproduction cycles during the experiment. The metabarcoding data revealed that both the coarser and the finer fraction experienced assemblage turnover through time.

The outcomes of our study are useful to better understand and quantify the mechanisms behind quick assemblage responses and community dynamics. They can also serve as a model study for combining morphological and molecular approaches in environmental monitoring to get deeper insights into the complex assemblage structures in shallow-water environments.

Upper Oligocene to Holocene planktonic foraminifera from DSDP Site 407, Reykjanes Ridge: towards a revised taxonomy of Neogene high-latitudes species

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Deep Sea Drilling Program (DSDP) Site 407, on the Reykjanes Ridge (Irminger Sea, Southwest Iceland), is one of the few sites from the high latitude North Atlantic with a record of Neogene planktonic foraminifera evolution. An early study of Site 407 shows good planktonic foraminifera preservation and progressive diversity loss over the past 23 myrs as climate cooled. However, the species names and higher taxonomy used in the early study (1979) are difficult to align with modern taxonomic concepts. This study reports a taxonomic and biostratigraphic reanalysis of the upper Oligocene to Holocene from Site 407. A key aim is to integrate recent understanding of *Neogloboquadrina* morphology and systematics, including the genetically-defined, dominantly sinistral-coiling concept of *N. pachyderma,* the dominantly dextral coiling concept of *N. incompta,* as well as the '5-sub-morphotypes' concept of *N. pachyderma* (defined in the Central Arctic Ocean).

Test fragmentation has concentrated dissolution resistant species to some extent. Nevertheless, the Site 407 record provides important information on northern high latitude assemblages. A hiatus spanning Zones M6-M12 (at least 5 myrs) occurs between 158.56 –160.06 mbsf based on (i) the sudden appearance of *N. atlantica*, *N. incompta* and *N. pachyderma* (all have their lowest occurrences [LOs] within Zone M13 Site 407 at 158.56 mbsf) and (ii) the presence of *Paragloborotalia acrostoma, Globorotalia archeomenardii, G. praemenardii, G. praescitula* and *G. zealandica* (Zone M5) at 160.06 mbsf. Diversity decreased from 28 species in the upper Oligocene to 10 species in the upper Quaternary. Upper Oligocene species include *Catapsydrax* spp., *Globoturborotalita ouachitaensis*, *Globorotaloides suteri*, *G. stainforthi*,

Globigerinella obesa, *P. opima*, *P. kugleri* and *Dentoglobigerina venezuelana. Paragloborotalia* diversifies in the Miocene with *P. acrostoma, P. birnageae*, *P. continuosa, P. mayeri* and *P. pseudokugleri.* An acme of '*Globigerina*' *pseudociperoensis* (upper Miocene), still of uncertain generic affiliation, may have biostratigraphic use. The *Fohsella* lineages are absent at Site 407, limiting application of several standard biozones. From the upper Miocene (above the hiatus), *N. praeatlantica, N. atlantica*, *N. incompta* and *N. pachyderm*a, become increasingly common. The LO of *N. pachyderma* is missing in the hiatus. The Miocene/Pliocene boundary, approximated by the LO of *Globorotalia tumida* at low latitudes, cannot be identified due to the absence of this species at Site 407. This boundary is instead approximated by the appearance of ice-rafted debris and presence of *N. atlantica* at 152.03 mbsf. The Pliocene is dominated by *N. atlantica*, which shows great morphological plasticity, and *Globigerina bulloides,* together with common very familiar looking *N. pachyderma* and *N. incompta* morphologies. Modern-type, high latitude assemblages dominated by *N. pachyderma*, including the 5 morphotypes, become a consistent feature in the lower Pleistocene (46.06 mbsf). Distinctive low latitude taxa such as *Globorotalia menardii* and *G. truncatulinoides* are missing. *N. dutertrei, Globigerinoides, Trilobatus,* and other low-mid latitude taxa occur sporadically. Well-preserved *Turborotalita quinqueloba* are relatively common in both the 63-125 and >125 μm fractions through the whole section, with moderate abundance variability between samples. In Oligocene and Miocene material, *T. quinqueloba* is accompanied by *Tenuitella* spp., which dominate the smaller size fraction. Above the late Miocene hiatus, there appears to be a continuous record of diverse neogloboquadrinids through the early Pliocene to Quaternary. This will be useful for better integrating *N. praeatlantica*, *N. atlantica* and *N. incompta,* into a stratophenetic model of *Neogloboquadrina* phylogeny. These results will eventually contribute to the 'Neogene and Quaternary Atlas' and possibly improve the use of *N. pachyderma* as a paleoceanographic proxy.

South Georgia palaeo-productivity and glacial evolution over the past 15 ka

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The island of South Georgia is a biodiversity hotspot, and is particularly sensitive to climate change due to its position close to the Polar Front in the Southern Ocean. However, due to a low number of well-dated subantarctic palaeoclimate archives, there is still uncertainty about how the climate of South Georgia changed in the recent geological past. Here, we reconstruct primary productivity changes and infer Holocene glacial evolution by analysing two marine gravity cores (GC666: 15.1 to 0.3 cal. kyr BP; GC673: 9.3 to 0.3 cal. kyr BP) on the inner South Georgia shelf. The study cores come from the northern ends of cross-shelf troughs that propagate from Royal Bay (GC666) and Cumberland Bay (GC673), on the northern part of the South Georgia Shelf. GC666 is more distal being ca. 21 km from the modern shore and GC673 is in the mouth of Cumberland Bay. We analysed benthic foraminiferal assemblages, stable isotopes, sedimentary total organic carbon and biogenic silica to reconstruct primary productivity changes and infer Holocene glacial evolution in both cores. Using Detrended Correspondence Analysis, we identified three different assemblages of benthic foraminifera: *Miliammina earlandi*, *Fursenkoina fusiformis*, and *Cassidulinoides parkerianus*. The assemblage of particular interest in reconstructing glacial changes is the *F. fusiformis* assemblage, which represents high productivity in both cores and may be associated with glacial runoff. Our multiproxy analysis from both cores provides evidence that the latest Pleistocene (15.1 to 12.3 cal. kyr BP) and early Holocene (12.3 to 7.5 cal. kyr BP) were periods of high productivity associated with increased glacial meltwater discharge. The middle Holocene (7.5 to 2.9 cal. kyr BP) is associated with a fall in sedimentation rates and lower productivity associated with a reduction in the size of South Georgia's glaciers, but with several short-lived episodes of glacial advance. The late Holocene (2.9 to 0.3 cal. kyr BP) saw an increase in productivity and glacial advancement associated with cooling temperatures (based on ice core data from James Ross Island) and increased precipitation. We propose that shifts in the South Westerly Winds drive the glacier dynamics reconstructed from cores GC666 and GC673. The relative abundance of *F. fusiformis*, interpreted here as a proxy for increased terrestrial runoff associated with the spring-summer melting of glaciers, is closely aligned with glacial trends previously constrained with plant macrofossil and pollen evidence from peat bogs and dating of glacial moraines. Thus, we conclude that palaeo-productivity can be used as an indirect proxy for glacier readvancements on the South Georgia shelf.

Research Avenue South, Edinburgh, EH14 4APPlanktic foraminifera iodine/calcium ratios and relationship to seawater oxygen content

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Iodine to calcium ratios in foraminifera calcite have emerged as an exciting proxy method to assess oxygen concentrations in past seawater. Planktic foraminifera I/Ca have been proposed as a proxy to assess changes in subsurface water oxygen concentrations, whereas benthic foraminifera I/Ca have been proposed as a proxy to reconstruct bottom water oxygen concentrations. In this study we focus on planktic foraminifera I/Ca. Recent core top studies show that in locations that are characterized by oxygen depletion in the subsurface waters, planktic foraminifera I/Ca values are relatively low compared with locations lacking oxygen depletion in their subsurface waters. Here we expand on this calibration using sample material from the Lamont Doherty core repository and IODP. We also compare the complete core-top calibration set with results obtained from planktic foraminifera captured by plankton-tows.

We use radiocarbon dating and benthic foraminifera stable isotope stratigraphy to ensure our core samples are Holocene/interglacial in age. I/Ca ratios were measured for a total of ~22 locations from the Indian and Pacific Ocean using twelve different planktic foraminifera species. Sample are from water depths between 200 and 4000 meters, and from poorly oxygenated (<10 µmol/kg) to well oxygenated (> 180 µmol/kg) settings. Our new core top I/Ca ratios show similar trends as previous studies, with generally lower values when 'minimum' oxygen concentrations are below 80 µmol/kg.

Compared to results recently obtained from plankton tows these values are an order of magnitude higher in well oxygenated areas. We will discuss situations under which planktic foraminifera I/Ca from sediment cores may gain additional iodine.

Integrated biostratigraphy of the Albian of the Southern High Latitudes

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We present an integrated micro- and nannofossil biostratigraphic evaluation of Albian strata documented at the Mentelle Basin (eastern flank of the Naturaliste Plateau, Indian Ocean, SW Australia) during Integrated Ocean Discovery Program (IODP) Expedition 369 (Sites U1513 and U1516, paleolatitude of between 57°S to 62°S during the mid-Cretaceous).

Characterized by deep-water benthic taxa, the Albian benthic foraminiferal record is dominated by cosmopolitan opportunist taxa, i.e., *Gyroidinoides, Saracenaria/Lenticulina*, *Pleurostomella, Dentalina* and agglutinated, monothalam forms like *Glomospira* and *Ammodiscus*. Besides opportunist taxa, the benthic foraminiferal assemblages documented at the Mentelle basin yield the contemporaneously globally documented *Gavelinella intermedia*, *G. utaturensis, G. schloenbachi,* as well as markers for the southern high latitudes documented in the Albian of South America, South Africa, and the Great Australian Basin, e.g., *Lingulogavelinella albiana, Scutuloris* sp. The potential for possible correlations of the benthic foraminiferal assemblages to other Lower- to mid-Cretaceous established calcareous markers can be considered.

Upper Albian microfossil assemblages demonstrate the decreasing abundance of benthic foraminifera and the decline of calcareous-, and an increase in the relative abundance of agglutinated taxa illustrated particularly in the extraordinary increment in the percentage of *Ammodiscus cretaceous*, *A. peruvianus*, *Glomospira charoides* and *Glomospira* sp.

The planktonic foraminiferal assemblage is dominated by the small-sized *Microhedbergella praeplanispira*, followed by common biserial and planispiral taxa. The large-sized fractions contain *Muricohedbergella simplex*, *Ticinella primula* and *Laeviella bentonensis* allowing identification of the upper Albian, although no marker taxa have been observed hampering the application of the tropical-subtropical biozonation.

Calcareous nannofossils of the Naturaliste Plateau/Mentelle basin are characterized by relatively diverse but distinctly high-latitude assemblages providing biostratigraphic control for the non-barren intervals of the Albian record. Sequential first occurrences of *Eiffellithus monechiae* and *Eiffellithus turriseiffelii* indicate Upper Albian subzones CC8d and CC9a-b, respectively.

With the exception of shifts in the abundance of respective microfossil groups, preliminary abundance data, particularly of benthic foraminiferal assemblages, suggest, despite documenting a distinctly depauperate record in the upper Albian of

the Austral Realm, considerable environmental stability. In bottom waters, no major benthic foraminiferal bioevents be identified.

The influence of post-mortem alterations in calcareous microfossils on their proxy values - exemplified by *Neogloboquadrina pachyderma* in sediment cores of the Arctic Ocean

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It has been accepted for a long time, that ordinary inspection of microfossil shells under the stereomicroscope allows to identify diagenetic overprint and moreover, that minor overprint may not impact isotope-, trace metal-Ca ratios or radiocarbon ages. This talk reports the impact of diagenetic alterations on calcareous foraminifera and shell-derived paleo-proxies. It summarizes results of many years work including thousands of comparative stereomicroscope- and scanning electron microscope pictures, EDS (Energy-dispersive X-ray spectroscopy), stable carbon and oxygen isotope, and radiocarbon measurements. Partial dissolution mainly impacts the shell by exposing an increased microfossil-surface to the surrounding pore-/bottom water with which it reacts. However, even more dramatic impacts on proxy records are observed when authigenic calcite is deposited on foraminiferal shells. Exemplified by *Neogloboquadrina pachyderma* shells from Arctic Ocean sediments, we show that a large proportion of modern to Holocene, and the majority of last glacial shells are altered by authigenic calcite overgrowth. We show that this diagenetic alteration has the potential to affect all shell-based proxies, first of all the radiocarbon age. Our investigations show that due to massive diagenetic overprinting of pre-Holocene foraminifera, ^{14}C ages increase rapidly downcore, and diminishing MIS2 sediments are inferred. As significantly less than 1% of preserved shells show no to little overgrowth, several tens of thousands to several hundreds of thousands of shells must be screened to pick 20-60 specimens that can be regarded suitable for radiocarbon measurements. The ^{14}C age-offset between pristine, translucent -white, overgrowth free shells compared to altered translucent-white shells with overgrowth in the same sediment horizon can be up to 20 ka in older sediments. As the majority of age-models for the last 45 ka rely on radiocarbon measurements of biogenic calcite, the reliability of published arctic paleoceanographic events assigned to late MIS3-2 age, is at stake!

Late Cenozoic cooling restructured global marine planktonic foraminiferal communities

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The geographic ranges of marine organisms, including planktonic foraminifera, diatoms, dinoflagellates, copepods and fish, are shifting polewards owing to anthropogenic climate change. However, the extent to which species will move and whether these poleward range shifts represent precursor signals that lead to extinction is unclear.

Understanding the development of marine biodiversity patterns over geological time and the factors that influence them are key to contextualizing these current trends. The fossil record of the macroperforate planktonic foraminifera provides a rich and phylogenetically resolved dataset that provides unique opportunities for understanding marine biogeography dynamics and how species distributions have responded to ancient climate changes.

Here we apply a bipartite network approach to quantify group diversity, latitudinal specialization and latitudinal equitability for planktonic foraminifera over the past eight million years using Triton, a recently developed high-resolution global dataset of planktonic foraminiferal occurrences. The results depict a global, clade-wide shift towards the Equator in

ecological and morphological community equitability over the past eight million years in response to temperature changes during the late Cenozoic bipolar ice sheet formation.

Collectively, the Triton data indicate the presence of a latitudinal equitability gradient among planktonic foraminiferal functional groups which is coupled to the latitudinal biodiversity gradient only through the geologically recent past (the past two million years). Before this time, latitudinal equitability gradients indicate that higher latitudes promoted community equitability across ecological and morphological groups. Observed range shifts among marine planktonic microorganisms in the recent and geological past suggest substantial poleward expansion of marine communities even under the most conservative future global warming scenarios.

Multi-million-year lags between planktonic foraminiferal functional richness and community responses to Cenozoic climate perturbations

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The origin and maintenance of the latitudinal biodiversity gradient (LBG), a key feature of global biodiversity, remains relatively obscure, especially with respect to past and future climates. LBG studies typically adopt a species-based-perspective, rather than a functional or trait-based one, especially in paleontological studies. Unlike species, which are evolutionarily ephemeral, functional groups can be consistent across an entire clade's history, providing broader perspectives.

Using Triton, a global dataset of Cenozoic macroperforate planktonic foraminiferal occurrences and network analyses, we contextualize changes in functional diversity, palaeolatitudinal specialization, and community equitability across the Cenozoic, identifying: 1. specialized morphological communities in the aftermath of the Cretaceous-Paleogene extinction, 2. ecological specialization of communities during the Early Eocene Climatic Optimum globally, except in southern mid-high latitudes, 3. an increase in specialized morphological communities in response to Antarctic glaciation preceding the loss of morphological diversity by millions of years, 4. a synchronous change in morphological specialization and richness ~19 Ma, coeval with pelagic shark extinctions, and 5. a significant delay between niche exploitation and diversification as bipolar ice sheet expansion triggered global paleoceanographic change, providing key context for late Cenozoic marine biodiversity patterns.

We find that functional responses of communities to large-scale Cenozoic climate events are separated from richness and reveal novel structural changes necessary for understanding how marine ecosystems respond to global change.

A review and new observations on *Tholosina vesicularis* Brady (1879), an extraordinary monothalamous foraminifera

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Tholosina vesicularis is a large, monothalamous, agglutinated foraminifer that can be found in a wide range of habitats, from temperate to polar regions, with an epilithic, epiphytic or epizoic lifestyle. Despite its global distribution and locally very high abundances, little is known about its ecological significance or nutrient demand. As it usually colonizes rocks and gravel, the species is often overlooked in ecological studies, confined to the < 2 mm size fraction.

The current study was conducted on a push-core (10 cm diameter) sample from the Swedish Gullmar Fjord taken at 7 m depth at the fjord mouth. The first five centimetres of the coarse sediment were cut in layers (0-1 cm, 1-2 cm, 2-3 cm, 3-5

cm) and stained with Rose Bengal. Subsequently, the samples were sieved to obtain the > 1 mm and 125-1000 µm fractions to determine the most abundant species of both fractions. The cell volume of the two most abundant species (*T. vesicularis* and *Ammonia* sp.) was compared to estimate their ecological impact due to their space occupation within the microhabitat. Qualitative stereo and scanning electron microscopy (SEM) were carried out to investigate the morphology and the protoplasmic content of *T. vesicularis* specimens in the < 1 mm fraction. Quantitative stereo microscopy was applied to map the distribution of the epilithic *T. vesicularis* populations.

The top layer contained a brick fragment (~17 cm² surface area) that was densely populated by *T. vesicularis* individuals (13 ind. cm^{-2}). Another rather large stone fragment (Quartzite, ~21 cm² surface area) in the same layer was also populated by *T. vesicularis*, however in a lower abundances (3 ind. cm²). The brick seemed to be a more attractive habitat for this species rather than the Quartzite, possibly due to its more heterogeneous surface presenting several gaps and slots. These might provide shelter to *T. vesicularis* from currents or potential predators. Furthermore, the diatom biofilm on the brick was more pronounced than on the Quartzite, potentially providing food for the foraminifer.

The spatial distribution of the *T. vesicularis* population inhabiting the brick fragment showed a clumped distribution pattern (Clark Evans distribution; R = 0.30, z = -11.78). This is the most frequent distribution pattern found for heterotrophs in nature, mostly due to a patchy distribution of resources in their habitat.

Tholosina vesicularis (median test diameter 450 µm, n = 74) was the most abundant species in the >1 mm fraction (87%, 199 ind. 10 cm^{-3}) of the topmost layer. *Ammonia* sp. (median test diameter 221 µm, n = 110) was the most abundant species in the 125-1000 µm fraction (67%, 337 ind. 10 cm^{-3}) in the topmost layer. Total cell volumes of the two species showed a far higher space occupation of *T. vesicularis* (median 50 mm^3 10 cm^{-3}) than *Ammonia* sp. (median 10 mm^3 10 cm^{-3}). There was a drastic decrease of *T. vesicularis* abundances down core (e.g. 4 ind. 10 cm^3 within the 3-5 cm layer), whereas *Ammonia* sp. was still highly abundant (e.g. 148 ind. 10 cm^3 within the 3-5 cm layer). Stereo microscopy and SEM of *T. vesicularis* individuals revealed that the foraminifer ingests copious amounts of diatoms. Thus, we stipulate that this species depends on freshly accumulated diatom-phytodetritus that diminishes downcore.

In conclusion, this study sheds light on *T. vesicularis* ecological significance such as its high space occupation and its dependence on freshly accumulated diatom-phytodetritus. The clumped population distribution pattern observed in this study may reflect the patchy distribution of resources in the foraminifer's habitat, indicating its adaptation to local conditions. Additionally, this study emphasizes the importance of considering larger size fractions in ecological studies to fully understand the distribution and ecological impact of epilithic species like *T. vesicularis*.

Adaptive thermal niche of planktic foraminifera and the emergence of mechanistic model

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Global oceans are warming at unprecedented rate and imposing selective pressure to marine plankton. However, we lack the quantification of the adaptive capacity of marine plankton to the ongoing warming environment. While some groups are well studied, information on planktic foraminifers is missing. Furthermore, the stability of foraminifera niche determines the precision of many paleoceanography proxies constraining past events of environmental change. Existing studies propose a static thermal niche based on the measurement of niche overlap at in different time intervals in earth history. This approach might overlook though a shift of their optimal temperature versus the theoretical niche. Here we reconstruct the foraminifera thermal fitness curve of 12 species using abundance and sea surface temperature (SST) data from the Last Glacial Maximum (LGM) and late Holocene from the literature. We find that the selected species have a significantly increased thermal maximum, minimum and optimum by on average 3.1, 2.9, and 3.7°C. Our finding suggests adaptation during the last deglacial warming and contradict niche conservation assumed in paleoceanography proxies like abundance-based transfer function. Niche-based models do not represent such adaptive response resulting in uncertainty and making a mechanistic foraminifera model necessary.

Therefore, we introduce our trait-based solution (ForamEcoGENIE) simulating foraminifera diversity and biogeography based on dynamic physiological processes such as predation and mortality rather than the empirically determined niche. ForamEcoGENIE is based on the intermediate-complexity Earth system model cGENIE and is well suited to palaeoceanographic study as it is based on functional trait (calcification, symbiosis, spines) instead of individual species. Focusing on four main functional groups instead of taxa allows to overcome the taxonomy differences throughout the geological record. The model is calibrated with core-top foraminiferal abundance data. Estimates of biomass and carbon export agree with literature data and under the glacial boundary condition the model agrees with data in biogeographical and niche shifts.

Using ForamEcoGENIE to project future foraminiferal growth, niche distribution, and biogeography in 2100 under emission pathways causing +1 to +4 °C warming relative to pre-industrial, we find a biomass loss of 5-17.5% which is mainly caused by a reduction of primary productivity. The North Atlantic is projected to have the highest biomass loss and

compositional shift, followed by the Southern Ocean. Thereby we conclude that the loss of high food availability will further impact the adaptive thermal niche. This trait-based mechanistic model ForamEcoGENIE is a unique tool to explore the biogeography and niche variability across different geological times.

Integrated stratigraphy of the last glacial-interglacial transition in the Sergipe-Alagoas basin, South Atlantic Ocean

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The last glacial-interglacial transition is characterized by major climate changes that affected the geographic distribution of planktonic foraminiferal species and changed sedimentary dynamics in shelf and slope settings. We present an integrated stratigraphic approach (chemo- and biostratigraphy) to characterize the last glacial-interglacial transition in the Sergipe-Alagoas Basin, in the western South Atlantic Ocean. We performed faunal and stable isotopic analyses of planktonic foraminifera, as well as major and minor elemental ratios of bulk sediment from two sediment cores collected from the Brazilian continental slope (Core SEAL-20230001, 2650 m water depth, and Core SEAL-20230070, 1300 m water depth). We identified planktonic foraminiferal biozones Y2 to Z at both cores, and the ages of the biozone boundaries were determined with planktonic foraminifera accelerator mass spectrometry radiocarbon ages and benthic foraminifera stable oxygen isotope stratigraphy. We identified 30 planktonic foraminiferal species at core SEAL-20230070 and 27 at core SEAL-20230001. At both cores, *Globorotalia truncatulinoides* and *Globoconella inflata* present highest abundances within the Last Glacial Maximum (LGM) and are practically absent during Heinrich Stadial 1 (HS1) and the Younger Dryas (YD). In core SEAL-20230070, the tropical Menardiiform complex is absent in the LGM and HS1, but is abundant in the YD. These observations suggest that marked environmental changes occurred in the pelagic ecosystem during HS1 and the YD in the western South Atlantic Ocean. These events were also characterized by increased continental runoff, as suggested by sedimentary elemental ratios, which may have affected nutrients supply and/or water column stratification in the region.

The evolution of the barrier layer in the centre of the western Pacific warm pool during the last deglacial based on planktonic foraminifera surface species

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The role of the tropical Pacific El Niño-Southern Oscillation (ENSO) in modulating global climatic changes is critical, particularly the role of the barrier layer (BL, a salinity stratification above the thermocline) in forming it, which could reduce subsurface entrainment cooling into the mixed layer and impede the energy transmission downward. Yet, prior BL changes are weakly restricted by marine archives. We analyzed the Ontong-Java Plateau sediment core KX97322-4 (00º01.73'S, 159º14.66'E, water depth 2362 m) to reconstruct previous changes in the BL. Based on the minor difference in calcification depth between two surface species of planktonic foraminifera (*Globigerinoides ruber* and *Trilobatus sacculifer*), we used stable isotopes of oxygen and Mg/Ca ratio analyses to document temperature and salinity variation (considering the linear correlation between the sea water $\delta^{18}O$ and salinity, it is represented by $\delta^{18}O_{sw}$) of surface water in the centre of western Pacific warm pool over the last 30 kyr. The comparison of vertical temperature and salinity change amplitudes suggests that the BL was strengthened during the last deglacial. This is compatible with the maritime continent's increasing precipitation. Increased rainfall in the warm pool during the deglaciation period may have produced in higher vertical salt stratification in the surface water, resulting in BL thicknessening. It might provide positive feedbacks to the La Niña-like condition that existed during the deglacial period. Earlier in the Holocene, the BL is thinner and associated with an El Niño-like condition. Moreover, 169 $\delta^{18}O_{sw}$ measurements gathered throughout the whole western Pacific suggest that rainfall in the western

section of the warm pool rose while rainfall in the eastern part of the warm pool declined. This rain band's westward migration may have contributed to the BL's thinning. Our data give fresh light on the dynamics of ENSO-like events during the latest deglaciation.

Pliensbachian–Aalenian (Jurassic) palaeobiogeographical patterns of the Neotethyan benthic foraminifera

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In the last more than 160 years, many taxonomic works have been published on benthic foraminiferal assemblages of the late Pliensbachian–Bajocian interval in Western European carbonate–siliciclastic ramps and the deposits of the former carbonate platforms. In the last 25 years, the Hungarian assemblages of the same age, but with different facies, representing the former pelagic regions, have also been studied. Thus, we had the opportunity to evaluate the paleobiogeography of benthic foraminifera.

In the Early–Middle Jurassic of the Neotethyan Realm, we designated two foraminiferal bioprovinces, the Tethyan Carbonate Platform Province and the Boreal-Atlantic-Caucasian Province, whose composition differs from each other at the genus level, so they have no common species. Agglutinated larger benthic foraminifera are characteristic of the former, while benthic smaller benthic foraminifera with mostly calcareous skeletons are characteristic of the latter.

According to the low ratio of endemism based on the Provinciality Index of Johnson, Jaccard and Simpson similarity coefficients, and taxa–area relationship, no further biogeographical subdivisions (biochores) can be separated within the territory of the provinces. Within the Boreal-Atlantic-Caucasian Province, the generic and species composition of the assemblage is similar in different environments, but the individual groups occur in different proportions.

Based on these, it can be divided into different biomes. Biomes are different communities of living areas in contiguous areas, but endemism is not assumed. The shallower assemblages of the siliciclastic-carbonate ramp of the Neotethys, closer to the coast (e.g., Lusitanian basin) were classified into the Boreal-Atlantic Biome, and the pelagic assemblages of its predominantly carbonate, condensed formations (e.g., Apennines, Transdanubian Central Mountains – Hungary) were classified into the Mediterranean Biome. In the Pliensbachian–Bajocian, the Neotethys was connected to the Arctic Ocean in the northwest, from where many species crossed into the Boreal-Atlantic Biome. The Mediterranean Biome was presumably populated from the Boreal-Atlantic Biome, since the foraminiferal assemblages are less diverse and there are very few endemic species (e.g., *Nodosaria szentgali*), most species are found in both biomes.

The Pliensbachian in the Boreal-Atlantic Biome is characterized by the high frequency and variety of shallow-deep endobenthic lenticulinids, smooth-walled and ornamented specimens lenticular in shape occurred in a similar proportion to elongated forms. In the early Toarcian, the proportion of the endobenthic *Eoguttulina*, the ribbed *Paralingulina* and the smooth *Prodentalina* increased, and then the *Lenticulina* became the majority again until the late Aalenian–early Bajocian, when the *Spirillina* became common (e.g., Lusitanian Basin, Iberian-Cordillera).

During the late Pliensbachian, the Mediterranean Biome was characterized by assemblages dominated by the epibenthic *Glomospira–Ammodiscus*, in addition to the similarly common shallow endobenthic, ornamented *Ichthyolaria*, *Paralingulina* and the smooth-walled *Lenticulina* (e.g., Umbria-Marche-Apennines, Transdanubian Central Mountains). These were replaced by less diverse assemblages with a majority of *Eoguttulina–Spirillina* from the early Toarcian, and then from the middle–late Toarcian to the Bajocian, the *Spirillina* mostly dominated alone, and the diversity continues to decrease (e.g., Transdanubian Central Mountains).

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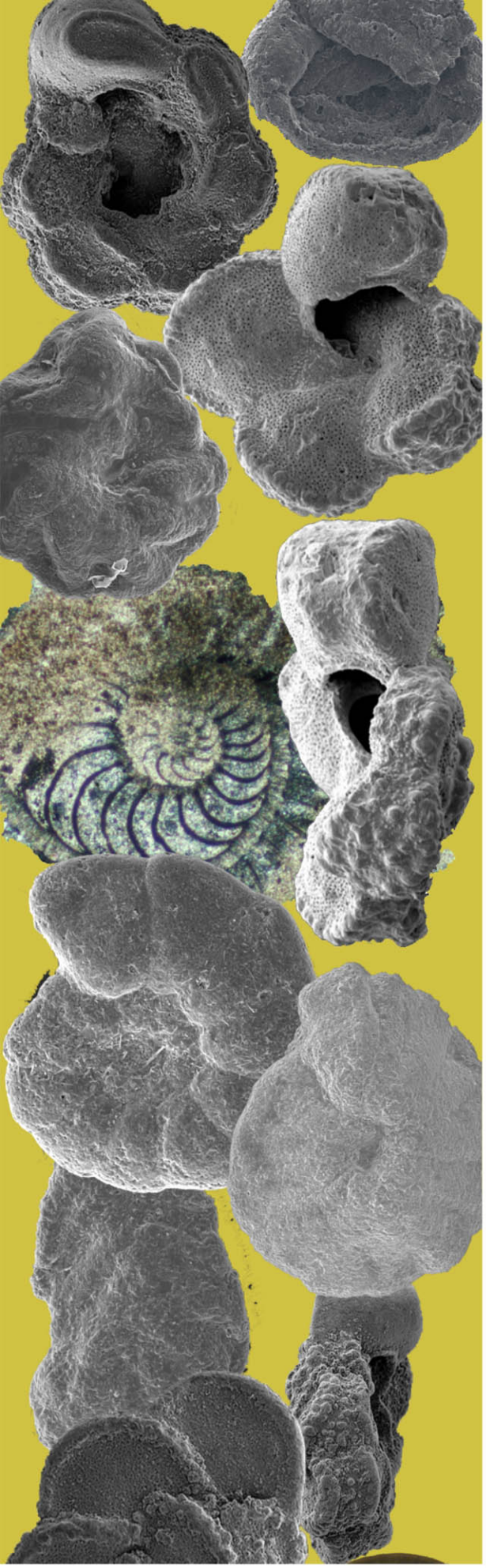

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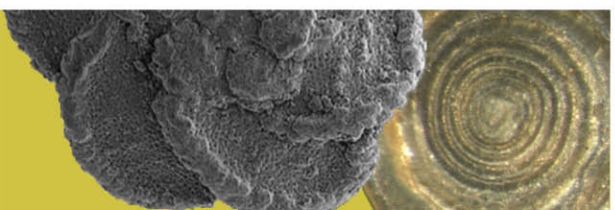

FORAMS 2023

June 26th–30th, 2023 - Perugia, Italy

FORAMS 2023 continues the tradition of the highly successful meetings previously held in Halifax (Benthos '75), Pau (Benthos '81), Geneva (Benthos '86), Sendai (Benthos '90), Berkeley (FORAMS'94), Monterrey (FORAMS '98), Perth (FORAMS 2002), Natal (FORAMS 2006), Bonn (FORAMS 2010), Concepción (FORAMS 2014), and Edinburgh (FORAMS 2018). During the last meeting in Scotland, the general assembly voted to hold the next meeting, FORAMS 2022 (now FORAMS 2023), in Perugia, Italy.

It is with great pleasure and honour that Perugia hosts this important scientific event, which certainly will contribute to spread even further the knowledge and the science among all countries represented at the meeting.

FORAMS 2023 will see 223 oral presentations and 162 poster presentations hosted into 25 scientific sessions, with more than 330 participants. Two of the proposed field trips were activated to visit the Carso area (near Trieste, pre-congress) and the world-famous Bottaccione section (close to Gubbio, post-congress).

The presentations will cover any topics related to extant and fossil foraminifera, including biostratigraphy, taxonomy, evolution, mass extinctions, paleoclimatology, paleoceanography, paleogeography, geochemistry, biology, ecology, symbiosis, biomineralization, environmental monitoring, extreme environments, polar environments, automated recognition, molecular systematics, from all over the world.

We thank all the participants hoping this conference will be again an enjoyable place to exchange scientific knowledge, to stimulate younger researchers to build new collaborations, and to demonstrate the vitality of our scientific community.

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