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International Nannoplankton Association

ON THE COVER: INA19 logo created by Bridie Cheeseman (https://www.bridiecheeseman.com; Instagram @bridiecheeseman)

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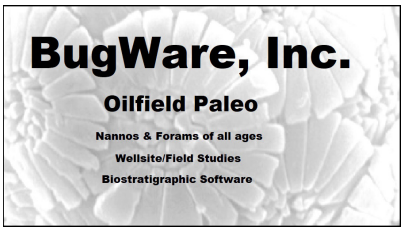

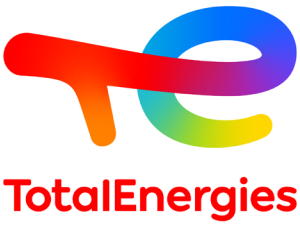

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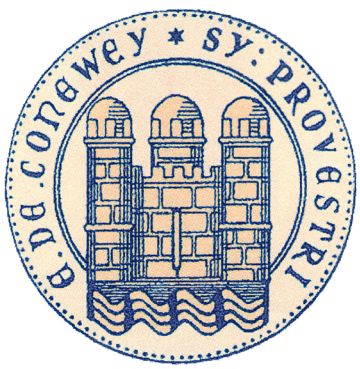

Croeso / Welcome to INA19 Conwy!
7th to 15th September 2024

Saturday 7th - Pre-conference field trip, Ynys Môn (Anglesey)
Sunday 8th - Ice breaker party hosted by PetroStrat at Conwy Castle
Monday 9th to Thursday 12th – Conference sessions, St George's Hotel, Llandudno
Friday 13th to Sunday 15th – Post-conference field trip, Eryri National Park (Snowdonia)

Left: Llandudno Promenade; right top, Conwy Castle; right bottom, Great Orme, Llandudno. Photo credit: Tamsin Lawrence (PetroStrat)

Croeso and Welcome to INA 19 Conwy!

We are delighted to be hosting the 19th International Nannoplankton Association meeting in North Wales, UK! This year's meeting will be taking place in the seaside town of Llandudno, and based in the St George's Hotel located on our stunning Victorian seafront. We look forward to welcoming over 100 participants from 27 countries!

The meeting will host talks over four days, focusing on biostratigraphy, methods and taxonomy, OAEs, hyperthermals, palaeoecology, and evolutionary history from the Jurassic to Recent. We will also be hosting a number of workshops and masterclasses, as well as software and microscope demonstrations. Finally, we look forward to welcoming sixth-form students from several local schools from Conwy County Borough, who will be introduced to the microscopic world of nannoplankton!

We have planned three field trips - to the mystical island of Anglesey (Ynys Môn), the Great Orme in Llandudno (Y Gogarth), and a two night residential trip to Snowdonia – the Eryri National Park. Our conference dinner will take place at Dylan's, a seafront restaurant in Llandudno which champions local, seasonal produce.

We look forward to showcasing the research of the nannoplankton community and welcome you all to beautiful North Wales! We very much hope you will enjoy the meeting and your time in Wales!

Diolch yn fawr!

Simon Cole & Tamsin Lawrence
INA19 Convenors
PetroStrat (UK)

PetroStrat
Integrated Geoscience Solutions

International Nannoplankton Association

INA19 Programme

Saturday 7th September 2024

08:30 – 18:00
Pre-conference field trip - Ynys Môn (Anglesey)
Stops include Menai Bridge Viewpoint; The Marquess of Anglesey's Column; Parys Mountain; Newborough/Llanddwyn Island; Llanfairpwllgwyngyllgogerychwyrndrobwllllantysiliogogogoch (Rob Crossley, GeoMôn/Viridien).

Sunday 8th September 2024

13:00 – 15:00
Masterclass:
Scientific Writing and Reviewing (Denise Kulhanek, Kiel University; Jean Self-Trail, USGS; Emma Sheldon, GEUS). Optional – sign up required.

13:00 – 16:00
Early Registration, St. George's Hotel

17:00 – 19:30
Ice Breaker Party, Conwy Castle
(Sponsored by PetroStrat)

Monday 9th September 2024

08:00 – 09:00
Late Registration – Conwy Suite, St Georges Hotel

09:00 – 09:30
Opening announcements
Simon Cole & Tamsin Lawrence, INA19 Conveyors; Emanuela Mattioli, INA President; Paul Cornick/ David Rutledge, PetroStrat Directors

Session One – "Life thru a lens" – Viewing the bigger picture through a microscope (continued)
Chairs: Odysseus Archontikis & Emma Sheldon

09:30 – 10:00
Keynote 1 (Talk 1): **Mike Simmons** – Biostratigraphy and the energy transition

10:00 – 10:15
Talk 2: **Young et al.** – Developing tools to compile and visualize nannofossil occurrence data

10:15 – 10:30
Talk 3: **Lassus et al.** – A YOLO model for coccolithophore identification using images from ocean water samples

Coffee Break 10:30 – 11:00

Session Two – "Life thru a lens" – Viewing the bigger picture through a microscope (continued)

11:00 – 11:15
Talk 4: **Varol** – Challenges of optical properties of calcareous nannofossils

11:15 – 11:30
Talk 5: **Beaufort** – Artificial intelligence used for automatic detection of calcareous nannofossils with SYRACO

11:30 – 11:45
Talk 6: **Stefanowicz et al.** – Nannofossil image searches using Scampi

11:45 – 12:00
Talk 7: **Hanson et al.** (**Tom Dunkley Jones** presenting) – Size-fraction coccolith stable isotopes and Sr/Ca from the Miocene to Recent

Flash talks for poster session 12:00 – 12:30

Lunch break (lunch provided) 12:30 – 13:30

Session Three – "Life thru a lens" – Viewing the bigger picture through a microscope (continued)
Chairs: Matthew Hampton & Yi Zhang

13:30 – 14:00
Keynote 2 (Talk 8): **Lawrence & Sheldon** – Nannofossil biostratigraphy in industry; female pioneers in nannopaleontology and a story of life on the rigs

Session Three (continued) – Nannos in the Age of the Dinosaurs – Jurassic

14:00 – 14:15
Talk 9: **Rutledge** - Application of nannofossils (the missing piece of the puzzle) from offshore New-

foundland: Upgrading the regional stratigraphy via an integrated multidisciplinary approach

14:15 – 14:30
Talk 10: **Chaumeil Rodríguez et al.** – New biostratigraphic data for the Lower–Middle Jurassic Los Molles Formation in the Picún Leufú area, Argentina

14:30 – 14:45
Talk 11: **Fraguas et al.** – New insights on calcareous nannofossil biostratigraphy and paleoecology around the Pliensbachian/Toarcian boundary in the South Iberian paleomargin

14:45 – 15:00
Talk 12: **Jeremiah & Schwartz** – Nannofossil abundance and diversity changes – a reaction to changing paleoenvironments in the late Tithonian of the Flemish Pass Basin, offshore Newfoundland

15:00 – 15:15
Talk 13: **Chowdhury et al.** – The microscale exoskeletal reconstruction of the genus *Nannoconus* – taxonomic insights

Coffee Break 15:15 – 15:45

Session Four – Nannos in the Age of the Dinosaurs (continued) – Cretaceous

15:45 – 16:00
Talk 14: **Aubry et al.** – From alkenones to Cretaceous marine Isochrysidales to coccoliths

16:00 – 16:15
Talk 15: **Anton & Melinte-Dobrinescu** – Calcareous nannofossils of the Valanginian/Hauterivian boundary interval in the Romanian Carpathians

16:15 – 16:30
Talk 16: **Bottini et al.** – Aptian–Albian calcareous nannofossils from the South Atlantic Ocean: Implications for paleoclimate and paleogeography

16:30 – 16:45
Talk 17: **Lamm et al.** – Calcareous nannofossils from the Poggio le Guaine core (Umbria-Marche Basin, central Italy): Biostratigraphy and discussion of Aptian–Albian bioevents

16:45 – 17:00
Talk 18: **Granero et al.** – Morphometric analysis of the calcareous nannofossil group *Aspidolithus* in the lower Campanian: Implications for taxonomy

17:00 – 17:15
Talk 19: **Howe** – Ultrastructure and taxonomy of the Order Watznauriales

Day 1 Closing remarks 17:15 – 17:30

Tuesday 10th September 2024

Session One – "Who stole all the oxygen?" (Cretaceous Nannos and the OAEs)

Chairs: Denise Kulhanek & Alessandro Menini

09:00 – 09:15
Talk 20: **Zhang et al.** – Reconstructing Cretaceous climate: Insights from a new calcareous nannofossil occurrence database

09:15 – 09:30
Talk 21: **Self-Trail et al.** – Calcareous nannofossils, Oceanic Anoxic Event 2, and the Cenomanian/Turonian boundary in cores from eastern Louisiana, USA

09:30 – 09:45
Talk 22: **Schueth et al.** – Unusual calcareous nannofossil assemblages from the Cenomanian–Turonian (93.9 Ma) of North America: Implications for nannofloral response to Oceanic Anoxic Event 2

09:45 – 10:00
Talk 23: **Tungo et al.** – Morphometric analyses of *Eprolithus floralis* from Oceanic Anoxic Event 2 in the Eastbourne section

10:00 – 10:15
Talk 24: **Godet et al.** – Using extraterrestrial ^{3}He to reconstruct terrigenous fluxes and their impacts on marine primary productivity and carbon burial during OAE2 in the Vocontian Basin (SE France)

10:15 – 10:30
Talk 25: **Erba et al.** – Calcareous nannofossil palaeoceanography across Oceanic Anoxic Event 3: From local to global perturbations

Coffee Break 10:30 – 11:00

Session Two – Nannos in the Age of the Dinosaurs – Cretaceous (continued)

11:00 – 11:15
Talk 26: **Tangunan et al.** – Multivariate evaluation rubric for assessing the reliability of Cretaceous nannofossil index taxa and bioevents

11:15 – 11:30
Talk 27: **Miniati et al.** – Revised calcareous nannofossil biostratigraphy and chemostratigraphy for the late Turonian–early Campanian at Seaford Head (southern England)

11:30 – 11:45
Talk 28: **Marconato et al.** – Orbitally paced bottom-water acidification episodes linked to the late Maastrichtian warming event: Calcareous nannofossil evidence in the Hor Hahar section, Israel

11:45 – 12:00
Talk 29: **Chira et al.** – Integrated biostratigraphy of the Upper Cretaceous–Eocene deposits from Poiana Botizei-Botiza (Maramures, Romania)

12:00 – 12:15
Talk 30: **Wang et al.** – Cretaceous–Paleogene calcareous nannofossils and their biostratigraphic and paleoceanographic implications in southern Tibet

12:15 – 12:30
Talk 31: **Vallejo-Hincapié** – Cretaceous and Cenozoic calcareous nannofossil biostratigraphy of the northwestern inland basins of Colombia

Lunch break (lunch provided) 12:30 – 13:30

Session Three – "Hwyl Fawr T-Rex; Bore Da Paleogene" – Paleogene Nannos
Chairs: Boris Karatsolis & Andrea Pardon

13:30 – 14:00
Keynote 3 (Talk 32): **Bown et al.** – What drove nannoplankton evolution and community dynamics through the Paleogene?

14:00 – 14:15
Talk 33: **Chouar et al.** – Stratigraphy of the lower Danian in the Danish Basin: Perspectives from calcareous nannofossils and stable isotopes

14:15 – 14:30
Talk 34: **Wang** – Late Paleocene eastern Tethys paleoenvironmental reconstruction using calcareous nannofossils in the Patala Formation, Salt Range, Pakistan

14:30 – 14:45
Talk 35: **Pige et al.** – Temperature-dependent calcareous nannofossil exported productivity during early Paleogene hyperthermals

14:45 – 15:00
Talk 36: **Utsunomiya et al.** – Evolutionary change in crystallographic orientation and morphology of Cenozoic coccoliths: Insights from *Toweius*, *Reticulofenestra*, and *Umbilicosphaera*

Coffee Break 15:00 – 15:30

Workshops 15:30 – 17:30 (four options – sign up required)
1. **Biostratigraphy Software – StrataBugs** (Paul Britton, StrataData) & **BugWin** (Mitch Covington, BugWare)
2. **Jurassic Nannofossils** (Fabienne Giraud, Université Grenoble Alpes; Jason Jeremiah, Viridien; Emanuela Mattioli, Université Claude Bernard Lyon 1)
3. **Extant Coccolithophore Biogeography** (Jeremy Young, University College London)
4. **Geochemical Proxies from Coccoliths** (Tom Dunkley Jones, University of Birmingham)

Mid-Conference Fieldtrip (1) 18:00 – 20:00
Mini field trip to The Great Orme, Llandudno (Peter Lucas, PetroStrat)

Wednesday 11th September 2024

Session One – "Everyone say wayo – E–O" – Oligocene to Miocene Nannos
Chairs: Luc Beaufort & Deborah Tangunan

09:00 – 09:15
Talk 37: **Viganò & Agnini** – Unlocking the mystery of *Clausicoccus subdistichus* across the Eocene–Oligocene transition

09:15 – 09:30
Talk 38: **Jordan et al.** – The search for fossil siliceous haptophytes

09:30 – 09:45
Talk 39: **Routledge et al.** – Evaluating Oligocene calcareous nannoplankton diversity and community dynamics

09:45 – 10:00
Talk 40: **Su et al.** – Calcareous nannofossil changes in reddish-brown sediments in the abyssal South China Sea during the Oligocene–Miocene

10:00 – 10:15
Talk 41: **Karatsolis et al.** – Oligocene to Recent North Atlantic biostratigraphy and calcareous nannofossil assemblages (IODP Expedition 395)

10:15 – 10:30
Talk 42: **Holcová & Scheiner** – Calcareous nannoplankton and εNd as paleogeographic proxies: A case study from the Langhian junction of the Indian Ocean, the Mediterranean, and the Paratethys

10:30 – 10:45
Talk 43: **Puentes-Jorge et al.** – Middle to Late Miocene calcareous nannoplankton biostratigraphy and paleoecology at Broken Ridge, eastern Indian Ocean (ODP Site 752)

Coffee Break 10:45 – 11:15

Session Two – "Take a Chill Pill" – Neogene Nannos

11:15 – 11:45
Keynote 5 (Talk 44): **Bendif** – Comparative genomics of the Isochrysidales

11:45 – 12:00
Talk 45: **Skampa et al.** – Early Pliocene calcareous nannofossils contribute to the paleoceanographic reconstruction of the Cretan Basin (southern Aegean Sea, NE Mediterranean)

12:00 – 12:15
Talk 46: **Lancis et al.** – Structural developments within the Family Ceratolithaceae

12:15 – 12:30
Talk 47: **De Kaenel** – A revision of Quaternary species of the genus *Scyphosphaera*

Lunch break (lunch not provided) 12:30 – 14:00

Schools outreach session 13:00 – 15:00
(Running concurrently with poster session)
4×10–15 minute talks, microscope demonstration, posters, talk to scientists

Poster Session (1) 14:00 – 15:30
(Running concurrently with schools outreach session)

Coffee Break 15:00 – 15:30

Workshops 15:30 – 17:30 (four options – sign up required)
1. **Cretaceous Nannofossils** (Paul Bown, University College London; Matthew Hampton, Network Stratigraphic; Richard Howe, Ellington Geological Services)
2. **Public Outreach** (Mario Cachão, Universidade de Lisboa; Micaela Chaumeil Rodriguez, Instituto de Investigación en Paleobiología y Geología; Mariem Saavedra-Pellitero, University of Portsmouth; Deborah Tangunan, University College London)
3. **Understanding Molecular Genetic Data** – (El Mahdi Bendif, Université du Québec à Rimouski)
4. **AI (Artificial Intelligence) and Automated Coccolith Identification** (Luc Beaufort, CEREGE)

Conference Dinner 18:00 – 23:59
3-course dinner at Dylan's Llandudno followed by dancing (Twmpath band – Twmpathology)

Thursday 12th September 2024

Session One – "Blowing hot and cold" – Nannos in the Ice Age
Chairs: Alyssa Peleo-Alampay & Masayuki Utsonomiya

09:00 – 09:30
Keynote 4 (Talk 48): **Bolton et al.** – Last glacial to Holocene sedimentation patterns and coccolithophore dynamics in the northwestern Bay of Bengal in response to South Asian monsoon strengthening

09:30 – 09:45
Talk 49: **Razmjooei et al.** – Improving Arctic Quaternary geochronology and paleoceanographic reconstructions using calcareous nannofossils

09:45 – 10:00
Talk 50: **Wang et al.** – Impact of the biological carbon pump on atmospheric pCO_2 over the past 800,000 years

10:00 – 10:15
Talk 51: **Pedrão et al.** – Coccolith dynamic distribution in the western tropical Atlantic during the last 300,000 years: Toward a better understanding of oceanic current dynamics

10:15 – 10:30
Talk 52: **Saavedra-Pellitero et al.** – Particulate inorganic carbon in the Pacific sector of the South-

ern Ocean: Satellite measurements versus coccolithophore estimates

Coffee Break & Poster Session (2) 10:30 – 11:30

Session Two – "Life on the Ocean Wave" – Extant Nannos

11:30 – 11:45
Talk 53: **Bronzo et al.** – Paleoclimatic reconstruction of the past 28 kyr BP based on calcareous nannofossil assemblages in the Ligurian Sea

11:45 – 12:00
Talk 54: **Frada et al.** – Phosphate-limiting conditions induce cell volume increase in natural coccolithophore populations

12:00 – 12:15
Talk 55: **González-Martín et al.** – Environmental influences on coccolithophore distribution and abundance in the water column of the western Iberian margin (August 2022)

12:15 – 12:30
Talk 56: **Wang et al.** – Calcification response of *Emiliania huxleyi* to temperature and pH variations under calcitic and aragonitic sea conditions

12:30 – 12:45
Talk 57: **Bianco et al.** – When CO_2 increases, how does *Helicosphaera carteri* respond?

Lunch break (lunch provided) 12:45 – 13:45

Session Three – Tessellation, identification, calcification, precipitation

Chairs: Jelena Godrijan & Mohammad Razmjooei

13:45 – 14:15
Keynote 6 (Talk 58) **Hagino** – Recent progress in the studies of *Braarudosphaera bigelowii*

14:15 – 14:30
Talk 59: **Bazzicalupo et al.** – Coccolithophore response to marine alkalinization: The results of ocean alkalinity enhancement exposure

14:30 – 14:45
Talk 60: **Wheeler** – Understanding the specialised cellular mechanisms that support calcification in coccolithophores

14:45 – 15:00
Talk 61: **Padre et al.** – Spatio-temporal variability of alkenone and calcareous nannofossil abundance records across the southeastern Philippines: Insights on alkenone production and paleoceanographic reconstructions

15:00 – 15:15
Talk 62: **Cachão & Carvalho** – Not a source of atmospheric CO_2…

Coffee Break 15:15 – 15:45

Session Four – Awards, INA business/AGM

Chairs: Simon Cole & Emanuela Mattioli

15:45 – 17:45
Including INA20 (2026) bids and votes. Close.

Mid-Conference Fieldtrip (2) 18:00 – 20:00
Mini field trip to The Great Orme, Llandudno (Peter Lucas, PetroStrat)

Friday 13th to Sunday 15th September 2024

Post-conference field trip - Snowdonia (Eryri) – 2 nights residential (Barmouth)

Friday – Slate; Llanberis, Zip World Deep Mine Tour (Llechwedd), (Jonathan Wilkins, X-ray Mineral Services [retired]).

Saturday – North Wales Nannofossils & Gold (Clogau); Harlech, Mochras Borehole and Mawddach Estuary (Dylan Roberts & Hannah Torrance, PetroStrat).

Sunday – Barmouth; Porthmadog (Portmeirion Village/Ffestiniog Railways); Caernarfon Castle.

Posters

P-01: **Álvarez et al.** – Changes in productivity in the Guaymas Basin over the last 22,000 years: Insights from coccolithophores in sediments from IODP Site U1549

P-02: **Archontikis et al.** – Recovery and diversification of coccolithophores after the Cretaceous/Paleogene boundary mass extinction, IODP Expedition 392, the Agulhas Plateau

P-03: **Argenio et al.** – Paleoceanographic and paleoclimatic changes during the Quaternary at IODP Site U1586, Iberian margin

P-04: **Asanbe & Henderiks** – Biometric analysis of the genus *Toweius* across the Early Eocene Climatic Optimum (EECO, ~53–49 Ma) at ODP Site 1258, Demerara Rise

P-05: **Bonatelli et al.** – The uncultivated side of coccolithophores: Digging into the organic matter

P-06: **Bronzo et al.** – Calcareous nannofossil assemblages as evidence of shifts in the Arctic/Polar Fronts during the past 24 kyr BP along the West Spitsbergen margin

P-07: **Calvelo et al.** – Preliminary results of calcareous nannofossil analyses of Neogene and Quaternary units in northwestern Pangasinan, Philippines

P-08: **Catelli et al.** – Gradual phyletic evolution of *Reticulofenestra oamaruensis* from *Reticulofenestra clatrata*: A rare example of calcareous nannoplankton microevolution preserved in the sedimentary record at IODP Site U1553 (southern Pacific Ocean)

P-09: **Chouar & Thibault** – Biometric analysis of Maastrichtian *Arkhangelskiella* group in the Indian Ocean (ODP Hole 762C): Taxonomy and evolution

P-10: **Ćorić et al.** – Calcareous nannofossils at the Cretaceous/Paleogene boundary of the Northern Calcareous Alps (Wasserfallgraben section, Germany; Nussdorf section, Austria)

P-11: **Fujiyama et al.** – Early Miocene microfossils from Marmorito (Italy)

P-12: **Gholamifard et al.** – Early Aptian Oceanic Anoxic Event 1a (OAE1a): Evidence based on calcareous nannofossils in the Qaleh Zoo section, centra Kopet Dagh, Iran

P-13: **González-Martín et al.** – Coccolithophore assemblages and paleoceanographic dynamics at IODP Site U1385: Insights from the Pliocene–Pleistocene transition (western Iberian margin)

P-14: **Howe** – Ultrastructure and taxonomy of the Families Axopodorhabdaceae and Cretarhabdaceae

P-15: **Howe** – Ultrastructure and taxonomy of the Order Arkhangelskiales

P-16: **Jin & Liu** – Estimating the coccolithophore ratio of particular inorganic carbon to particulate organic carbon from the geometry of living cells

P-17: **Jordan et al.** – The search for fossil siliceous haptophytes

P-18: **Lancis et al.** – Ceratolithaceae biostratigraphy of ODP Hole 999A, Caribbean Sea

P-19: **Lancis et al.** – Ceratolithaceae biostratigraphy of ODP Site 1237, equatorial Pacific

P-20: **Liu & Sun** – The relationship between the carbonate counter pump and seawater CO_2 in the middle Miocene

P-21: **Ma & Liu** – A decreased carbonate pump during the Oligocene–Miocene transition: Regulating the oceanic buffer capacity

P-22: **Mahanipour et al.** – Evidence of the mid-Valanginian Weissert Event in the Zagros Basin in Iran based on calcareous nannofossils and carbon isotope data

P-23: **Mahanipour & Nejadsahebi** – Evidence of *Discoaster multiradiatus* size variation in the late Paleocene–early Eocene of the Zagros Basin (SW Iran)

P-24: **Malavolta et al.** – Distribution and diversity of coccolithophore communities living in the tropical and subtropical South Atlantic: Preliminary results from AMT28

P-25: **Malinverno et al.** – Coccolithophore seasonal export production and fluxes in the Ionian Sea, eastern Mediterranean (June 2004–September 2005)

P-26: **Marconato et al.** – Size and morphological changes in *Coccolithus pelagicus* across the Danian and their link to environmental recovery from the K/Pg mass extinction in the SE Tethys, Israel

P-27: **Martín-García et al.** – Reconstruction of the ocean surface dynamics of the Iberian margin in the Miocene–Pliocene using calcareous nannofossil assemblages

P-28: **Murphy et al.** – Drivers of Neogene coccolithophore macroevolution

P-29: **Palandri et al.** – Leveling the gap between different counting techniques in coccolithophore cultures

P-30: **Penales et al.** – Coccolithophore assemblage dynamics and *Emiliania huxleyi* morphological patterns during the years 2017–2019 in the Aegean Sea (Greece, NE Mediterranean)

P-31: **Pérez Panera et al.** – Insights into the last glacial–interglacial shift: Microfossils and geochemical evidence from the Argentine Continental Margin

P-32: **Righi et al.** – Study of the paleoclimatic transition from Greenhouse to Icehouse conditions by means of calcareous nannofossils in the Southern, Atlantic, Pacific, and Indian Oceans

P-33: **Rigual Hernández et al.** – Evolution of coccolithophore communities in the Atlantic Iberian margin during the Common Era

P-34: **Rigual Hernández et al.** – Response of the coccolithophore *Calcidiscus leptoporus* to environmental change during the industrial era in the Subantarctic Southern Ocean

P-35: **Rivas et al.** – Pleistocene–Holocene calcareous nannofossils and foraminifera from the Argentine Continental Margin, southwest Atlantic Ocean

P-36: **Routledge et al.** – Calcareous nannofossils from the Paleocene–Eocene Thermal Maximum, IODP Site U1557, South Atlantic Ocean

P-37: **Self-Trail et al.** – Preliminary biostratigraphy of the lower Cenomanian Buda Limestone from the U.S. Geological Survey GC-3 and GC-5 cores, Texas, USA

P-38: **Sheldon et al.** – Early to Middle Miocene nannofossils from the Valhall–Hod area, Norwegian North Sea

P-39: **Srivastava et al.** – Responses of calcareous nannoplankton to mid-Pliocene dynamics between climate and the carbon cycle in the North Atlantic

P-40: **Stoykova & Ivanov** – Early Eocene hyperthermals in northern Bulgaria (SE Europe): New nannofossil and stable isotope data

P-41: **Stoykova et al.** – Calcareous nannofossil response to the early Oligocene Rhodope volcanic eruptions in some central and eastern Paratethyan basins: A comparison

P-42: **Triantaphyllou et al.** – Investigating the size variability and coccolith mass of *Emiliania huxleyi* in the Aegean Sea (NE Mediterranean): 20 years of evidence on modern assemblages compared to the last two thousand years

P-43: **Utsunomiya et al.** – Paleocene–Eocene cal-

careous nannofossil biostratigraphy of the Surprise Hill core from Virginia, USA

P-44: **Viganò & Agnini** – Mediterranean marine sediment core database: Unlocking paleoclimate signals for the last 20,000 years

P-45: **Visentin et al.** – Early and Middle Jurassic Tethyan calcareous nannofossil zonation: Taxonomic updates and biostratigraphic improvements

P-46: **Vitsou et al.** – Confocal laser imaging of calcareous nannofossils

P-47: **Winter et al.** – A high-resolution depth profile of coccolithophores from oligotrophic waters in the North Atlantic Gyre (part 2)

P-48: **Xi et al.** – Paleocene to Eocene calcareous nannofossil zonation in the western Tarim Basin, Central Asia

Changes in productivity in the Guaymas Basin over the last 22,000 years: Insights from coccolithophores in sediments from IODP Site U1549

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The Guaymas Basin in the central Gulf of California is a very productive area with high chlorophyll *a* concentrations in some parts of the basin. Coastal upwelling, which develops yearly on the eastern coast, is strong, and the resulting eddy circulation promotes phytoplankton growth throughout the gulf. These processes are induced by the atmospheric dynamics of the Gulf of California and the prevailing northern winds blowing along the continental coast during spring-winter. Coccolith abundance and net primary productivity (NPP) have been reconstructed for the last 22,000 years, using sediment samples that were retrieved from International Ocean Discovery Program (IODP) Expedition 385 Hole U1549A (27˚28.33167'N, 111˚28.7844'W). Site U1549 was drilled at a water depth of 1840 m aboard the R/V *JOIDES Resolution*, with Hole U1549A drilled to a total depth of 168.0 m below the seafloor, recovering 166.89 m of core, of which the uppermost 40 m were studied.

The coccolith assemblage from the cores of Hole U1549A is dominated (>50%) by *Gephyrocapsa* >3 μm and the reconstructed NPP is high with values ranging from 944.66 to 1288.25 mg C/m^2/day. Variations in the coccolith abundance and the NPP allowed us to identify four scenarios.

(1) Cold and productive: The highest NPP values were recorded during the Last Glacial Maximum and Heinrich Event 1 (H1). The genus *Gephyrocapsa* >3 μm showed its highest abundances and *Coccolithus pelagicus* subsp. *braarudii* was present in relatively high numbers. Both taxa developed well under upwelling conditions with cool water temperatures.

(2) Intermittent stratification: A stepwise decrease of NPP occurred in the Bølling-Allerød Interstadial (BA) and Younger Dryas (YD). *Coccolithus pelagicus* subsp. *braarudii* showed a decline in abundance, whereas *Florisphaera profunda* showed an increase. Variability and intermittent stratification characterized these intervals. Minimum values in total abundance, NPP, and most of the taxa were reached at 11,707 cal yr BP.

(3) Warm conditions with occasional stratification: At the beginning of the Holocene Climatic Optimum, *C. pelagicus* subsp. *braarudii* disappeared, and abundant warm-water taxa dominated. After this abundance peak, a decrease in NPP took place, and stratification events are suggested by the presence of *F. profunda*.

(4) Stratified waters: There was a general progressive decrease in NPP that characterized the modern part of the record, and the variable presence of *F. profunda* revealed stratification in the surface waters.

Calcareous nannofossils of the Valanginian/Hauterivian boundary interval in the Romanian Carpathians

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We studied the Cretaceous calcareous nannofossils in a succession of 15 m-thick dark gray to black marlstones, interbedded with centimeter- to decimeter-thick calcareous sandstones, that crop out in the Romanian Carpathian bend area. Forty-five samples were investigated qualitatively and semiquantitively. The calcareous nannofossil assemblages were assigned to the NC4 nannofossil zone of Roth (1983), including Subzones NC4a and NC4b of Bralower et al. (1995), which were separated on the basis of the first occurrence (FO) of *Lithraphidites bollii*.

The calcareous nannofossil preservation is moderate to good, which is supported by the abundance of *Watznaueria barnesiae* that reaches up to 28% of the total assemblage. Nannoconids are the second most abundant nannofossil taxa (up to 20%), and they show significant species diversity that includes *Nannoconus bermudezii*, *N. bonetii*, *N. bronnimannii*, and *N. steinmannii*. In addition to *W. barnesiae* and the nannoconids, commonly identified taxa are *Micrantholithus hoschulzii*, *M. obtusus*, *Retecapsa* spp., *Cretarhabdus* spp., *Conusphaera* spp., *Biscutum constans*, *Discorhabdus ignotus*, *Manivitella pemmatoidea*, *Staurolithites stradneri*, *Cruciellipsis cuvillieri*, *Cyclagelosphaera brezae*, *C. margerelii*, *C. deflandrei*, *Zeugrhabdotus embergeri*, and *Haqius circumradiatus*. In the studied section, several nannofossil events were encountered that are listed in stratigraphic succession: last occurrences (LO) of *Rucinolithus wisei*, *R. pinnatus*, and *Eiffellithus windii*, FOs of *Diloma galiciense*, *L. bollii*, and *Tegulalithus septentrionalis*. The calcareous nannofossil assemblages in the studied succession exhibit similarities with the La Charce section, Vocontian Basin, SE France, which is the Global Boundary Stratotype Section and Point (GSSP) for the base of the Hauterivian Stage (Mutterlose et al., 2021), where the last four above-mentioned events were found in the lowermost Hauterivian, whereas the LO of *R. wisei*, followed by the LO of *R. pinnatus*, occur in the uppermost Valanginian.

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Recovery and diversification of coccolithophores after the Cretaceous/Paleogene boundary mass extinction, IODP Expedition 392, the Agulhas Plateau

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The Cretaceous/Paleogene (K/Pg) boundary (66 Ma) was a pivotal moment in Earth's history when one of the most severe mass extinction events occurred. The bolide impact that triggered this event not only affected terrestrial ecosystems but also had profound effects on the marine biota, biological pump, and global carbon cycle, as is evidenced by community data, diversity records, and geochemical proxies. Calcareous nannoplankton are a key component of the modern global carbon cycle and one of the most important groups of marine primary producers with a key role in sediment formation that stretches back 200 million years. The K/Pg event is associated with the eradication of approximately 90% of Cretaceous nannoplankton species, and post-extinction lineages are characterized by their remarkably small sizes (<3 μm coccolith length) and mixotrophic strategies (Gibbs et al., 2020).

Here, we present data on high-latitude fossil coccolithophore assemblages across a recently recovered K/Pg section that was collected at International Ocean Discovery Program (IODP) Site U1579, drilled on the central Agulhas Plateau during IODP Expedition 392 (Uenzelmann-Neben et al., 2023). The K/Pg interval was initially identified during the expedition by a change in sediment color, magnetic susceptibility, and diagnostic calcareous nannofossil assemblages. We conducted quantitative abundance analyses on the post-K/Pg newly originated calcareous nannofossil lineages, including those that form a series of acmes (genera *Praeprinsius*, *Prinsius*, and *Toweius*), and determined the tempo of Paleocene coccolithophore evolutionary dynamics in the high latitudes. In addition, we used high-resolution calcareous nannofossil biostratigraphy to confirm the presence of the K/Pg boundary interval and bulk carbon and oxygen isotope records to provide a refined age model for correlation with other published Paleocene nannofossil records. These new data provide additional insights into the processes of Danian plankton recovery, biogeographic trends in the high latitudes, and the establishment of marine ecological niches after the mass extinction.

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Paleoceanographic and paleoclimatic changes during the Quaternary at IODP Site U1586, Iberian margin

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This study presents calcareous nannoplankton data from the North Atlantic area. Many climate studies currently focus on this region, particularly on the Iberian margin. Due to its high sedimentation rate, sedimentary records offer the possibility to perform high-fidelity and high-resolution climate variability studies along the Iberian margin. Our analyses are centered on Site U1586 (37°37.283'N, 10°42.628'W; 4691 m below sea level), which was drilled during the International Ocean Discovery Program (IODP) Expedition 397 along the SW Iberian margin. The CEX dissolution index was calculated, and it suggests good preservation for the coccolith assemblages. Abundance percentage variability of selected coccoliths is also provided to highlight paleoproductivity and paleotemperature changes. The main results provide information on global climate evolution and changes in paleoceanography and coccolithophore productivity related to upwelling strength fluctuations in surface-water masses and subtropical gyre dynamics.

Biometric analysis of the genus *Toweius* across the Early Eocene Climatic Optimum (EECO, ~53–49 Ma) at ODP Site 1258, Demerara Rise

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The genus *Toweius* represents a prominent group of coccolithophores during the late Paleocene and early Eocene that is known for its evolutionary linkage and abundance turnover to *Reticulofenestra* during the Early Eocene Climatic Optimum (EECO). Typically, *Toweius* coccoliths exhibit elliptical to circular shapes with a central area comprising conjunct nets or bars and a distinctive architecture that features three concentric tubes (inner, middle, and outer) along with proximal and distal shields. However, the discovery of a small morphotype (termed herein *Toweius* sp. II) from the tropics, which lacks the typical inner and middle R-units, raises important questions about the origin and evolutionary significance of this taxon.

This study investigated the biometric and morphological variation in *Toweius* across the EECO at Ocean Drilling Program (ODP) Site 1258, focusing on defining the small morphotype and exploring its relationship with other *Toweius* species. Observations using light microscopy (LM) and scanning electron microscopy (SEM) revealed that the absence of a central tube, along with a circular shape and wide central opening, was present in nearly all specimens of *Toweius* sp. II. A biometric analysis indicated that *Toweius* sp. II exhibits a unimodal size distribution with a range of 2.25–3.4 µm and an average of 2.65 µm, distinctly smaller than the medium-sized *Toweius* (3.2–5.4 µm) that dominated early EECO assemblages. Similarly, other metrics, such as coccolith aspect ratio, central diameter to total length ratio, and circularity index, further distinguish *Toweius* sp. II from other members of the genus.

While the observed biometric disparity could be attributed to a preservation bias, *Toweius* sp. II likely derived from a *Toweius* species of similar size. The consistent presence of this taxon throughout early and peak EECO times suggests that dissolution may not have been significant. As such, this taxon probably represents either a state of malformation in calcification or an actual ecophenotypical variant of *Toweius* with a restricted occurrence in the tropics. In conclusion, the distinct biometric features and lower coccolith mass of *Toweius* sp. II point to decreased calcification and possibly an ecological adaptation that may have facilitated its persistence much longer within the EECO than other *Toweius* species.

From alkenones to Cretaceous marine Isochrysidales to coccoliths

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Living coccolithophore communities are dominated by a small group of marine species of the genera *Emiliania* and *Gephyrocapsa*. They have an unambiguous marine record back to the early Eocene when *Reticulofenestra* evolved. All three genera belong to the Family Noelaerhabdaceae in the Order Isochrysidales. The current consensus among the nannoplankton community is that there were no calcifying marine Isochrysidales in the Mesozoic (Henderiks et al., 2022), despite taxonomic evidence (Black, 1975; Covington & Wise, 1987), molecular evidence (Medlin et al., 2008; Liu et al., 2010), and alkenone data (Brassell, 2014; Hasegawa & Goto, 2024) suggestive of Cretaceous occurrences. Of these three sources of information, the biomarker is structurally unique and stable over geological time, and it holds the best potential for an unambiguous demonstration of the presence of alkenones in Cretaceous sediments identical to those known from Holocene coretop sediments, as well as cultures of *Emiliania huxleyi* and *Gephyrocapsa oceanica*. Thus, it can be used as a fingerprint for identifying the occurrence of Isochrysidales in marine sediments even if the calcite skeleton is not produced or not preserved. The molecular profile of alkenones can also be lineage-specific and provide clues of Isochrysidales evolution.

Our recent investigation (Si et al., 2024) of hemipelagic sediments from the Hauterivian through Santonian (130–80 Ma) that are broadly distributed in the Atlantic Basin has yielded abundant and diverse alkenones among which are those specific to marine Isochrysidales. From this we have concluded that mostly unsuspected coccolith-bearing species in this order synthesized alkenones already by ~132 Ma. This has important implications. From an evolutionary perspective, this implies that the Cenozoic Family Noelaerhabdaceae is directly rooted in a genetic stock of Mesozoic Isochrysidales ancestors. We have undertaken a search for these ancestral coccoliths, based on the structural and optical characters found in Noelaerhabdaceae, aware that these early morphotypes may depart markedly from the crown taxa,

and focused our attention on the genera *Repagulum* and *Pickelhaube*. From a paleoclimatic perspective, the association of alkenone C37:2 and inferred Isochrysidales species has led us to an estimated pCO_2 in the range of 548–4090 ppm (median of 908 ppm) during the warm Cretaceous.

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Coccolithophore response to marine alkalinization: The results of ocean alkalinity enhancement exposure

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Understanding phytoplankton adaptation to changing ocean conditions is paramount when investigating both fossil and present-day assemblages. Ocean alkalinity enhancement (OAE) is carbon dioxide removal (CDR) technology aimed at increasing the ocean's CO_2 uptake capability by dispersing alkaline substances (e.g., Ca-hydroxide) on the ocean surface. Investigating the response of coccolithophores to this technology within an OAE mesocosm experiment has seldom been done, despite their potential effects on the ocean trophic chain and carbonate cycle.

Two sets of experiments were conducted where mesocosms were exposed to increasing concentrations of Ca-hydroxide slurry with two different trophic conditions and coccolithophore presences. These experiments took place at the CIM-ECIMAT (Marine Research Centre of the University of Vigo, CIM UVIGO) and CretaCosmos (Hellenic Centre for Marine Research, Crete) facilities. Coccolithophore assemblage composition and abundances were assessed through optical microscopic analysis of filtered mesocosms seawater. The results indicate that there is coccolithophore sensitivity to mesocosm confinement. Interestingly, a slightly positive correlation to low slurry concentration was observed, whereas a high slurry concentration was detrimental to coccolithophore abundance. The same kind of response was observed in diatoms in experiments conducted in Crete, and a comparison with the diatom abundance patterns shows a similarity between the two groups. Finally, a tentative coccolithophore morphological analysis was performed on some samples. These findings could provide a baseline for understanding the potential adaptation of coccolithophores to changes in ocean alkalinity.

Artificial intelligence used for automatic detection of calcareous nannofossils with SYRACO

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Coccoliths are often found in great abundance in sediments, and a single microscopic field typically contains over 50 individuals. Biostratigraphic studies are facilitated when rare but diagnostic taxa can be observed. However, a few species often dominate an assemblage, which complicates accurate counting. Achieving comprehensive counts presents challenges, including the risk of overlooking specimens or counting them multiple times. To obtain statistically significant counts of entire coccolith assemblages, thousands of specimens must often be tallied. This makes the process impractical if rare species need to be included in the statistics. To address this issue, some researchers restrict their counts to select taxa or use intricate logarithmic counting methods. Another solution is to develop an automated counting system. Artificial Intelligence (AI) aims to streamline the counting process, improve accuracy, and provide a more efficient means of obtaining reliable data for coccolith analysis. Additionally, automated counting facilitates the cropping of coccolith images for morphometric analyses of individual specimens.

In the mid-1990s, SYRACO (SYstème de Reconnaissance Automatique de COccolithes), an artificial coccolith classifier, was developed and has been used routinely for over twenty years. During this period of time, numerous advancements have occurred, both in the software, with the evolution of neural network architectures, and in the hardware, with the increasing power and speed of computers that enable the processing of higher resolution images. There has also been an improvement in the resolution and quality of digital cameras and optical methods that are used to capture coccolith images. The emergence of polarization techniques now allows for cross-free and calibrated images, and the ability to routinely capture multi-focus images. I will describe the evolution of these techniques and outline the current effective protocol that can be rapidly implemented in laboratories for robust pattern recognition of the 28 coccolith classes most abundantly found in Pliocene–Pleistocene sediments.

Comparative genomics of the Isochrysidales

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Coccolithophores constitute one of the ecologically important phytoplankton groups, yet their evolutionary and diversity patterns remain unclear due to limited observations. This is particularly true for the Order Isochrysidales, despite it containing several ecologically and economically key taxa, such as *Gephyrocapsa huxleyi* and *Tisochrysis lutea*. This study provides a triptych overview of the relationships between Isochrysidales species by examining their macroevolutionary phylogenetic context and conducting finer scale studies of intraspecific morphogenetic variability and biogeographic structuring, as inferred from comparative genomics. First, obtaining a stable phylogenetic tree for all haptophytes using single-gene phylogenies remains very challenging. Despite extensive sequencing efforts, several deep branches in the haptophyte phylogenetic tree remain unresolved and statistically unsupported. For example, do the Isochrysidales form an independent and basal divergence, or do they cluster with the Zygodiscales in the Calcihaptophycideae? To address this, I propose employing a phylogenomic approach based on a large transcriptomic dataset that covers most of the haptophyte groups, although this may not necessarily resolve all nodes of haptophyte phylogeny. Second, the integration of Isochrysidales diversity with recent genomic research has been successfully linked to the fossil record. This linkage has been well demonstrated for the genus *Gephyrocapsa*, particularly at a fine scale for the species *G. huxleyi*. Such studies have provided insights into the evolutionary history and adaptive strategies of these organisms over geological timescales. Can similar analyses be extended to *G. oceanica* to uncover comparable patterns? Specifically, can we identify evolutionary events in *G. oceanica* that correspond to changes observed in the fossil record? Additionally, what can these findings reveal about the environmental factors that have influenced the evolution of *G. oceanica*, and how do these factors compare to those affecting *G. huxleyi*? Third, to what extent do both *G. oceanica* and *G. huxleyi* differ in terms of adaptability conferred by their genetic features? This question aims to explore the genetic basis of their adaptability to varying environmental conditions. What specific genes or genetic mechanisms contribute to the resilience or vulnerability of each species in different habitats? How do these genetic features influence their capacity to respond to environmental stressors such as ocean acidification, temperature fluctuations, and nutrient availability? Moreover, are there differences in the ploidy levels or gene content between *G. oceanica* and *G. huxleyi* that explain their distinct adaptive strategies? Understanding these genetic differences can provide deeper insights into the evolutionary processes that shaped the diversity and ecological success of these key phytoplankton species. Overall, this study sheds light on the biocomplexity and microevolution of phytoplankton and highlights the importance of considering microdiversity when studying their ecological and biogeochemical roles in the global ecosystem.

When CO_2 increases, how does *Helicosphaera carteri* respond?

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Beginning in the 1960s, human activities have led to an increase in atmospheric CO_2 concentration 100 times faster than with previous natural increases. Approximately 30% of anthropogenic CO_2 is absorbed by the oceans, leading to changes in ocean chemistry termed ocean acidification (OA). Several studies have focused on the effects of increasing CO_2 on calcifying organisms, including coccolithophores. Responses of coccolithophores to OA appear to be species specific, but only a few species (from approximately 250 living species) have been studied, which warrants further studies. *Helicosphaera carteri* is a common coccolithophore species. It is considered a major contributor to carbon uptake and $CaCO_3$ storage in deep-sea sediments due to its large size and higher rates of organic carbon fixation and calcite production compared to smaller species. Despite its important role, only a few studies have been conducted on living *H. carteri* under experimental conditions, and none have considered the effects of rising CO_2.

In this work, we study for the first time the response of *H. carteri* (Strain RCC1323, Roscoff Culture Collection) to varying CO_2 (295, 444, 600 ppm) by analyzing its variations in morphology, growth rate, and particulate organic carbon (POC) and inorganic carbon (PIC) production. Our results show that *H. carteri* is not very sensitive to pH/CO_2 variations. From a morphological point of view, there is only a 10% increase in slightly malformed coccoliths and <1% of collapsed coccospheres when CO_2 amounts are increased from 295 to 600 ppm.

A preliminary comparison of malformed coccoliths of *H. carteri* with another heavily calcified species, *Calcidiscus leptoporus*, (grown under experimentally controlled conditions at CO_2 levels close to 600 ppm), shows that the percentage of malformed coccoliths in *C. leptoporus* is higher than that in our *H. carteri* experiments, and with a greater amount of malformation (Langer et al., 2006; Diner et al., 2015). This indicates that *H. carteri* has a greater resilience than *C. leptoporus* to CO_2 variation. However, there was a decrease in PIC production (-26%) and the PIC:POC ratio (-29.6%) with increasing CO_2 levels, showing that *H. carteri* is sensitive to ocean acidification.

Moreover, a decrease in *H. carteri* growth rate (μ) occurred at the lowest (295 ppm; 0.36 μ/day, decrease of 18%) and highest (600 ppm; 0.40 μ/day, decrease of 9%) CO_2 concentrations compared to the control culture (444 ppm; 0.44 μ/day), indicating a possible influence of CO_2 limitation (295 ppm) and H^+ inhibition (600 ppm), respectively. However, this decrease is not related to a decrease in POC production, as previously was observed by other authors in association to these two limiting factors (e.g., Bach et al., 2011). Indeed, POC production does not change significantly from 295 to 444 ppm, and contrary to the growth rate, it increases from the intermediate CO_2 level to the highest. Our results highlight the complexity of coccolithophore responses to increased CO_2 and underscore the need to collect extensive data from different species.

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Last glacial to Holocene sedimentation patterns and coccolithophore dynamics in the northwestern Bay of Bengal in response to South Asian monsoon strengthening

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In the modern northern Indian Ocean, biological productivity is intimately linked to near-surface, ocean–atmosphere dynamics forced by the South Asian monsoon (SAM). The interplay between monsoon winds and precipitation, ocean carbon cycle feedbacks, and climate forcing mechanisms in the oceanographically heterogeneous Bay of Bengal remains poorly understood. In the southern Bay of Bengal, seasonally reversing winds are the dominant control on mixing that brings nutrients into the mixed layer, thus stimulating productivity. However, in the northern Bay of Bengal, monsoon precipitation and runoff that peaks during the late summer–early autumn strongly influences upper water column structure, inducing strong stratification that may inhibit phytoplankton productivity.

Here, we present new high-resolution records of past biogenic sediment mass accumulation rates, coccolith assemblages, coccolith $CaCO_3$ export, and coccolith morphology that span the period from the Last Glacial Maximum to the Holocene (the last ~26 kyr). We examined samples from International Ocean Discovery Program (IODP) Site U1446 in the Mahanadi Basin (NW Bay of Bengal), a region strongly impacted by monsoon runoff. During the Last Glacial Maximum and the following deglaciation, we found that an increase in the relative abundance of upper photic zone coccolithophore species coincided with reduced stratification and runoff, which potentially increased nutrients as a result of a weaker SAM. In contrast, the lower photic zone species *Florisphaera profunda* displayed a higher relative abundance during the Holocene (up to 80%) due to strong salinity stratification that can be linked with increased precipitation and runoff that was the result of a stronger Indian Summer Monsoon (ISM). Throughout the study interval, and in particular under conditions of maximum stratification in the Holocene, *F. profunda* coccoliths dominated coccolith absolute abundances and mass accumulation rates, highlighting the importance of deep photic zone species in coccolith $CaCO_3$ and potentially organic C export into certain environments. Within the reticulofenestrid coccoliths, smaller morphotypes dominated during the strongly stratified Holocene, whereas larger reticulofenestrid coccoliths were more abundant during the glacial and deglaciation. Within the <3 μm reticulofenestrid coccolith group, mean coccolith mass decreased from the glacial to the Holocene, suggesting that more stratified and/or fresher conditions favored smaller and more lightly calcified morphotypes.

The uncultivated side of coccolithophores: Digging into the organic matter

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The calcium carbonate production from coccolithophores has been widely studied because of its important contribution to global biogeochemical cycles and long-term carbon fluxes. On the other hand, the organic fraction of coccolithophores is still poorly studied, despite its importance in carbon transfer among different oceanic reservoirs. To date, only the species *Emiliania huxleyi* has been studied in detail for its organic composition (Aveiro et al., 2020): >50% $CaCO_3$, 20% lipids, 15% proteins, and 4% carbohydrates. Specific studies on other species of coccolithophores are necessary to differentiate their organic fraction production.

To increase the knowledge of the organic compounds involved in coccolithophore physiology, *Helicosphaera carteri* was chosen as the target species. The analysis was carried out at a lower resolution with easily accessible instruments (e.g., benchtop Fourier Transform Infrared (FTIR) Spectroscope). This species' relatively large cell size (15 µm), as compared to *E. huxleyi*, makes possible a more detailed analysis at the single cell level, exploiting the higher brightness of the synchrotron source. Here, the IR spectra obtained from both entire coccospheres and decalcified cells are compared to data (10 µm spatial resolution) that were collected at the Synchrotron Infrared Source for Spectroscopy and Imaging (SISSI-Bio) beamline at Elettra Sincrotrone Trieste (Italy), during the beamtime #20235227, on single naked cells and coccoliths detached through both mechanical and chemical treatments.

The data acquired on entire coccospheres (3 replicates) with laboratory FTIR were recorded using only 5 mg of freeze-dried residue of *H. carteri*. At first, we detected weak peaks of lipids, proteins, carbohydrates, and nucleic acids because the presence of $CaCO_3$, which returned a strong signal at ~1410/cm, masked the peaks of the organic compounds. After a HCl 1M treatment, the spectra at FTIR on decalcified cells documented the presence of stronger peaks of the above-mentioned organic compounds and returned a clearer overview of the organic composition. The analysis at SISSI-Bio was performed on decalcified single cells stored in acid Lugol's solution and single coccoliths of *H. carteri.* We analyzed 100 naked cells and coccoliths that were both mechanically and chemically separated for a total of 300 different spectra. The data showed a clearer signal of the individual organic macromolecules such as proteins, polysaccharides, and lipids compared to the previous FTIR data. Moreover, at the SISSI-Bio, the analysis of organic matter on individual coccoliths obtained by mechanical separation documented the occurrence of weak signals of polysaccharides and proteins, in contrast to those chemically treated with Triton-X, bleach, and hydrogen peroxide, where only the peaks of $CaCO_3$ are evident. Multivariate analysis will be used to highlight more subtle differences between the treatments and provide more detail on protein conformation and lipid order.

In conclusion, our work draws attention once again to the importance of sample preparation and documents the pos-

sibility of performing FTIR analyses in the laboratory with good results even when having microquantities of residue available. Moreover, our data underline the importance of using innovative, high-resolution techniques for a better characterization of the organic matter produced by coccolithophores during their life cycle. This is critical for a better understanding of their physiology and thus the role that different organic compounds might play in coccolithogenesis and biocalcification.

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Aptian–Albian calcareous nannofossils from the South Atlantic Ocean: Implications for paleoclimate and paleogeography

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Calcareous nannofossil assemblages indicate marked changes in surface-water temperature and fertility across the Aptian–Albian transition. However, most records are from the northern hemisphere, and less is known about the response of calcareous nannoplankton in the southern hemisphere. Here, we focus on two locations in the South Atlantic Ocean, namely Deep Sea Drilling Project (DSDP) Site 364 (Kwanza Basin) and DSDP Site 511 (Falkland Plateau), to analyze the paleoceanographic and paleoclimatic changes in the Southern Ocean during the Aptian–Albian transition interval.

Calcareous nannofossils were investigated to refine the biostratigraphy, obtain relative abundances, and document size variations of *Watznaueria barnesiae* and *Biscutum constans*. A comparison with the Tethyan record (Cismon and Piobbico cores) allowed for the differentiation between local and global factors such as paleotemperature and paleofertility. Notably, some similarities in the temperature trends were observed, but there was evidence of cooler conditions at DSDP Site 511, possibly indicative of latitudinal gradients that were established during the Aptian–Albian transition. A moderate change occurred in the calcareous nannofossil assemblage composition with the appearance of abundant cold-water species such as *Repagulum parvidentatum* and more abundant surface-water fertility taxa such as *B. constans* and *Zeugrhabdotus erectus* in the early late Albian at DSDP Site 511. Paleofertility exhibited more localized changes except during the Aptian/Albian boundary interval, which is marked by a temperature rise and increased fertility, aligning with observations in the western Tethyan Ocean. This serves as evidence of the global nature of the warming phase associated with this interval, likely triggered by volcanism from the Kerguelen Plateau Large Igneous Province.

Morphometric analyses of *W. barnesiae* and *B. constans* revealed similar responses and trends to those identified in the Tethys but with larger average coccolith length and width values in the South Atlantic. *Watznaueria barnesiae* is confirmed to display a much less pronounced size change compared to *B. constans*, which is now confirmed to be more sensitive to paleoenvironmental changes.

What drove nannoplankton evolution and community dynamics through the Paleogene?

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Cenozoic calcareous nannoplankton records reveal profound changes in diversity, morphology, and community composition, but what were the primary controls on these parameters through time since the dramatic taxonomic reset at the Cretaceous/Paleogene mass extinction 66 million years ago? Here we will examine the evolution of nannoplankton through the first 44 million years of the Cenozoic (Danian to Aquitanian), using a range of approaches that include biometry (liths and coccospheres) and long time series community analyses. Our dataset spans the time interval that saw recovery of nannoplankton communities following the devastating mass extinction and their co-evolution alongside profound extrinsic changes as the Earth system shifted from warm early Paleogene greenhouse climates to cooler temperatures of the Oligocene coolhouse (~33 Ma). We will show that in the first two million years after the mass extinction there was exceptional community variability, predominantly in small lith and cell sizes, and unusual trophic strategies, most notably mixotrophy in the most widespread and dominant taxa. A rapid regime change occurred after this, associated with rising species richness, rapidly increasing cell sizes, diversifying trophic strategies, and the emergence of a stable background community state. These biotic shifts were reflected in broader biogeochemical changes, such as recovery of biological pump function and increasing food web complexity. Our subsequent time-series community records demonstrate an enduring stability and resilience despite long-term changes in climate, but this stability was punctuated by ephemeral excursions of above background levels of disruption, associated with both warming (e.g., the early Eocene hyperthermals) and cooling events (e.g., the Eocene–Oligocene transition and several Oligocene glaciations). These transient community perturbations show threshold behavior that can be linked to magnitudes of temperature change, and they scale with environmental parameters, in particular rising and falling temperature. These relationships hold for plankton communities through the entire Paleocene to Early Miocene record with temperature being the primary driver, modulating communities in a similar way regardless of the greenhouse or icehouse background climate state.

Paleoclimatic reconstruction of the past 28 kyr BP based on calcareous nannofossil assemblages in the Ligurian Sea

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The climatic events that marked the last 28 kyr (e.g., Heinrich Stadials [HS], Last Glacial Maximum, Younger Dryas, and Bølling-Allerød) have been identified and described in the Mediterranean Sea. Nevertheless, some of its areas, such as the northern Tyrrhenian Sea, are still poorly investigated and lack data and paleorecords. The core NDT_22 was collected from 436 m of water in the Ligurian Sea and consists of 320 cm of greenish to greyish fine sentiments. The age model is based on 14 radiocarbon (^{14}C) accelerator mass spectrometry (AMS) measurements on the planktonic foraminifera *Globigerina bulloides* and dates the bottom of the core at 27.4 kyr BP. Calcareous nannofossil assemblages were studied at a resolution of 170 yr/sample. The distribution of calcareous nannofossils was investigated by considering the calcareous nannofossil accumulation rate (NAR) and their relative abundance (%).

In general, abundance of the warm-water group (*Calciosolenia* spp., *Discosphaera tubifera*, *Oolithothus fragilis*, *Rhabdosphaera* spp., *Umbellosphaera* spp., and *Umbilicosphaera* spp.) increased from the onset of the Bølling-Allerød interval (~14.4–12.8 kyr BP), peaking during the early Holocene (between 10.3 and 9 kyr BP). Conversely, the cold-water group (*Coccolithus pelagicus*, *Emiliania huxleyi* >4 μm, and *Gephyrocapsa muellerae*) showed higher values throughout the Late Pleistocene, decreasing after the Younger Dryas (~12.8–11.7 kyr BP). *Florisphaera profunda* increased from the Bølling-Allerød and reached significant values during the Holocene, marking the development of seasonal stratification. Higher values of reworked coccoliths and the presence of *Helicosphaera carteri* highlighted enhanced runoff during HS2 (26.1–23.7 kyr BP) and HS1 (17.2–14.4 kyr BP).

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Calcareous nannofossil assemblages as evidence of shifts in the Arctic/Polar Fronts during the past 24 kyr BP along the West Spitsbergen margin

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The study of well-preserved Arctic marine sedimentary deposits is pivotal to understanding the impact of climate changes on ecological and sedimentary scales. From the Last Glacial Maximum to the onset of the Holocene, the climate underwent abrupt changes that caused Heinrich events and episodes of rapid sea level rise known as meltwater pulses (MWPs). To unravel the effects of these events on thermohaline ocean circulation in the Arctic region, a multiproxy-based approach is essential. Here, we investigated calcareous nannofossil assemblages, and coupled the results with X-ray fluorescence (XRF) and Greenland ice core $\delta^{18}O$ data.

The piston core IRIDYA-02PC was collected on the Bellsund Drift crest along the West Spitsbergen margin. The core was sampled at a water depth of 1724 m, and it recovered 4.87 m of sediments that are distinguished by bioturbated and laminated sediments with sparse to massive ice-rafted debris and oxidized layers. The age model is based on three radiocarbon ages and on the reconstruction of a high-resolution relative paleointensity and paleosecular variation of the geomagnetic field record for the last 24 kyr BP. The calcareous nannofossil content of the IRIDYA-02PC core was investigated with a 240 yr/sample resolution.

Oscillations in total nannofossil abundance and reworked coccoliths (both expressed as number of nannofossils per gram of sediment) were compared with Ca/Ti and Zr/Rb, indicating oscillations in marine biogenic carbonate content and sediment grain size, respectively. The logarithmic ratio between the warm-water group (*Emiliania huxleyi*, *Gephyrocapsa oceanica*, small *Gephyrocapsa*, and *Calcidiscus leptoporus*) and the cold-water group (*E. huxleyi* >4 μm, *Gephyrocapsa muellerae*, and *Coccolithus pelagicus pelagicus*) (log[WWG/CWG]) was calculated to evidence shifts in the Polar Front along the West Spitsbergen margin.

During the Late Pleistocene, a decrease in abundance of both total and reworked coccoliths highlights Heinrich-like (H2, H1), Younger Dryas, and MWP-1A abrupt events that correspond to peaks in Zr/Rb values. In contrast, their slight increase in abundance is evidence of the Last Glacial Maximum and the Allerød episode with the log(WWG/CWG), suggesting the formation of a seasonal sea-ice cover over the study site. From 11.2 kyr BP, a sharp increase in total nannofossil abundance indicates the development of Holocene warmer conditions as evidenced by the log(WWG/CWG), which points to a prominent retreat of the Polar Front.

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Not a source of atmospheric CO_2...

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Many authors refer to the precipitation of calcium carbonate from sea water expressed by equation [1], either by purely chemical mechanisms (e.g., an increase in sea surface temperature [SST]) or mediated by organisms such as coccolithophores (biomineralization) as a source of $CO_{2(g)}$ degassing back to the atmosphere (e.g., Hutchins, 2011).

$$Ca^{2+} + 2\ HCO_3^- \ <=>\ CaCO_{3(s)} + H_2O + CO_{2(g)} \qquad [1]$$

However, there are four reasons why the precipitation of calcium carbonate from seawater does not contribute to atmospheric $CO_{2(g)}$:

Reason #1 – The overall cycle. Equation [1] does not take into consideration the entire geochemical process, starting with the weathering (hydrolysis in acidic conditions) of crustal rocks rich in calcium silicates, such as a metamorphic rock rich in the inosilicate Wollastonite ($CaSiO_3$) or a magmatic mafic rock with plagioclase anorthite ($CaAl_2Si_2O_8$). In this last case, the hydrolysis of the feldspar occurs according to equation [2].

$$CaAl_2Si_2O_8 + 8\ H^+ <=>\ Ca^{2+} + 2\ A1^{3+} + 2\ SiO_2\ (aq.) + 4\ H_2O \qquad [2]$$

The main supplier of H^+ is the $CO_{2(g)}$, according to equations [3] and [4]. To maintain the bivalent calcium in solution, two molecules of $CO_{2(g)}$ are needed to produce the two negative bicarbonate ions on the left side of equation [1] promoting acidic conditions, i.e., with two protons (H^+) in excess.

$$2\ CO_{2(g)} + 2\ H_2O\ <=>\ 2\ H_2CO_3 \qquad [3]$$
$$2\ H_2CO_3\ <=>\ 2\ HCO_3^- + 2\ H^+ \qquad [4]$$

Thus, the overall balance of this mechanism ([3] + [4] + [2] + [1]) indicates that this mechanism is a sink and not a source of $CO_{2(g)}$. On the other hand, if instead of siliceous magmatic or metamorphic rocks, one considers the weathering (karstification) of sedimentary Ca-rich rocks such as limestone or marble, the overall process is neutral (neither a sink nor a source) for $CO_{2(g)}$ because in this case the solubilization of the calcium only requires one molecule of carbon dioxide (equation [1] from right to left), which is "released" by the precipitation of calcium carbonate (equation [1] from left to right). Many may argue that these geological processes occur at much longer time scales, but we will present a study on weathering of monuments in Lisbon that demonstrates that this is not the case.

Reason #2 – There is no addition of $[CO_2]$. Equation [1], as in any other chemical balance equation, indicates that both sides are equivalent in terms of mass and so, the molecule CO_2 that appears on the right side is already in the medium, i.e., there is no addition of dissolved inorganic carbon (DIC) to the system due to precipitation of $CaCO_3$ itself.

Reason #3 – Part is used to produce sugars. Significant amounts of CO_2 are absorbed by coccolithophores and other photosynthetic organisms to produce carbohydrates and other forms of organic carbon. While some of this organic carbon may be remineralized in the water column or due to resuspension (Smeaton & Austin, 2022), for example, an estimated 266 Gt of organic carbon is incorporated only within the top 1 meter of sediment of the continental shelves

worldwide (Atwood et al., 2020).

Reason #4 – The pH factor. When the alkaline ion Ca^{2+} is incorporated into the seawater solution from river discharges, it increases the ocean's alkalinity, which in turn promotes the dissolved inorganic carbon (DIC) chemical species on the right side of equation [4], releasing H^+ and thus diminishing the ocean's pH.

$$HCO_3^- \; <=> \; CO_3^{2-} \; + \; H^+ \qquad [5]$$

As with most calcifying organisms, coccolithophores preferentially uptake DIC in the form of HCO_3^- mainly because it is the dominant chemical species in current pH oceanic conditions (Glotter et al., 2014). In coccolithophores, the buildup of protons from equation [5] led to the appearance of mechanisms designed to eliminate H^+ in excess while promoting the uptake of the bivalent ion calcium via solute carrier 4 (SLC4) family, a Ca^{2+}/H^+ exchanger of the CAX family of exchangers and a vacuolar H^+- ATPase (Mackinder et al., 2011; Brownlee et al., 2021).

Thus, for sea water with pH around 8, equation [1] should be rewritten as:

$$Ca^{2+} + 2\ HCO_3^- \; <-> \; CaCO_3 + H^+ + HCO_3^- \qquad (aq.) \qquad [6]$$

As well as, in lower concentrations:

$$Ca^{2+} + 2\ HCO_3^- \; <-> \; CaCO_3 + 2\ H^+ + CO_3^{2-} \qquad (aq.) \qquad [7]$$

We will present results from modeling the forced precipitation of $CaCO_3$ due to the (bio)mineralization of calcite as coccoliths from seawater at a pH of around 8, showing that the remaining DIC always tends to stay in solution according to equations [6] and [7] (Parkhurst & Appelo, 1999). Therefore, the precipitation of $CaCO_3$ does not serve as a source of CO_2 as a gas for the sea water and much less for the atmosphere.

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Preliminary results of calcareous nannofossil analyses of Neogene and Quaternary units in northwestern Pangasinan, Philippines

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This study presents the preliminary results of a calcareous nannofossil analysis of samples collected from exposed Neogene and possible Quaternary marine sequences in northwestern Pangasinan, Philippines. The study was conducted to refine the ages and distribution of previously mapped lithostratigraphic units, as well as refine understanding of the geology and stratigraphy of the region.

Samples that were collected from a mass transport deposit were assigned to nannofossil Zone NN10 (early Late Miocene) or older based on the occurrence of *Cyclicargolithus floridanus*, *Reticulofenestra pseudoumbilicus*, *Catinaster calyculus*, and *C. coalitus*. An intercalated calcareous siltstone and limestone unit, assigned to Zones NN8–10 (early Late Miocene), overlies these deposits, and this unit was tentatively assigned to the Cabaluan Formation, which was previously dated Middle–Late Miocene on the basis of planktonic foraminiferal assemblages. Limestones, fine- to very fine-grained sandstones, and finer grained clastic rocks, which are widely distributed in the study area, were dated early Late Miocene to late Early Pliocene (nannofossil Zones NN10–16) based on the occurrences of *Amaurolithus delicatus, Ceratolithus cristatus*, *Discoaster pentaradiatus*, *D. quinqueramus*, *D. surculus*, *D. triradiatus*, *Helicosphaera orientalis*, *H. pacifica*, *H. stalis*, *Reticulofenestra pseudoumbilicus*, *R. haqii*, *R. minuta*, *R. rotaria*, *Pseudoemiliania lacunosa*, and small gephyrocapsids. These units are tentatively assigned to the Santa Cruz Formation, which was previously dated late Late Miocene.

Ongoing geological fieldwork and mapping, including petrographic, structural, and microfacies analyses, will determine whether these Pliocene units belong to the Santa Cruz Formation, Bolinao Limestone (Pliocene–Pleistocene), or a previously unmapped lithostratigraphic unit.

Gradual phyletic evolution of *Reticulofenestra oamaruensis* from *Reticulofenestra clatrata*: A rare example of calcareous nannoplankton microevolution preserved in the sedimentary record at IODP Site U1553 (southern Pacific Ocean)

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Persico et al. (2014) first proposed a possible gradual phyletic evolution of *Reticulofenestra oamaruensis* from *R. clatrata* during the study of Ocean Drilling Program (ODP) Sites 738, 748, 744 (Kerguelen Plateau), and 689 (Maud Rise). International Ocean Discovery Program (IODP) Expedition 378 Site U1553, drilled in the Southern Ocean (Campbell Plateau), recovered a continuously cored, multiple-hole (U1553A–U1553E) Paleogene sedimentary section (Röhl et al., 2022). The good preservation of calcareous nannofossils in these cores made possible a study of the origin of *R. oamaruensis* and its intraspecific variability, as well as its biostratigraphic distribution in the middle–late Eocene. The original description of this transition only considered samples with sizes of 13.8–17 µm, but our biometric analyses and morphological investigations suggest including transitional morphotypes of *R. oamaruensis* (10–14 µm). Morphometric quantitative studies allowed us to recognize an intraspecific evolutionary trend that is characterized by a gradual increase in size of small specimens of *R. clatrata* (8–10 µm), which are present from the base of the stratigraphic sequence (263.81 m core composite depth below seafloor [CCSF]) (Raffi et al., submitted), to large specimens of *R. oamaruensis* (>14 µm). Intermediate specimens were placed into two size categories (10–12 µm and 12–14 µm). All "morphotypes", including species with sizes defined in the original descriptions, disappear simultaneously during the Eocene–Oligocene transition (Raffi et al., submitted). Intermediate morphotypes appear as distinct and stratigraphically identifiable events, suggesting a potential "lineage zone" that is useful in Southern Ocean biostratigraphy. The morphological homology, the continuity in the stratigraphic distribution, the same geographical distribution area, and the presence of a gradually increasing size trend from *R. clatrata* to *R. oamaruensis* represent a possible phyletic lineage that is endemic to high southern latitudes where *R. clatrata* represents the archetype.

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New biostratigraphic data for the Lower–Middle Jurassic Los Molles Formation in the Picún Leufú area, Argentina

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The Los Molles Formation in the Neuquén Basin, Argentina, is one of the few southern latitude locations that can shed light on the diversity of Early–Middle Jurassic calcareous nannofossil assemblages. The recent establishment of a biostratigraphic framework based upon nannofossils allows us to evaluate the response of southern hemisphere environments to global changes, such as the early Toarcian Oceanic Anoxic Event (T-OAE) or the turnover in the nannoplankton community through the Early to Middle Jurassic, which occurred along with stable carbon isotope perturbations. Previous investigations examined the expression of the T-OAE in the northern part of the basin and illustrated well-preserved calcareous nannofossil assemblages in the south where there is a continuous record from the Pliensbachian to the Aalenian.

The new Kalemen section in the Picún Leufú area, near the already known El Matuasto section, was studied for calcareous nannofossils and geochemical analyses, including elemental composition, stable carbon isotopes measured on organic matter, and total organic carbon (TOC) weight percent. Calcareous nannofossil assemblages show low diversity and abundance with some barren levels. However, identification of some events like the first occurrence (FO) of *Watznaueria britannica* suggests that this outcrop is late Toarcian–Aalenian in age. Total organic carbon values fluctuate and can attain values as high as 5% in the studied interval, despite the overall high siliciclastic input. The carbon isotope ratio that was measured on organic matter also has significant fluctuations, making it difficult to identify any clear trends. When compared to El Matuasto, Kalemen represents a deeper depositional environment with turbidite deposits. Our approach adds a new piece to the paleoenvironmental puzzle of the Los Molles Formation, revealing important variations in sedimentation zones in close proximity to each other.

Integrated biostratigraphy of the Upper Cretaceous–Eocene deposits from Poiana Botizei-Botiza (Maramureș, Romania)

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In the present study, detailed analyses of the Upper Cretaceous–Eocene deposits from Poiana Botizei and Botiza (Maramureș County, northwest Romania) focused mainly on calcareous nannofossils with some additional examination of foraminifera and ichnofossils. The Poiana Botizei Klippen Zone is part of the Pienide units in Romania and is a southeastward extension of the Pieniny Klippen Belt of the Western Carpathians. In the study area, the outcropping formations are included into several south-vergent tectonic scales mainly consisting of "red beds" and "hieroglyphic beds". The "red beds" (Cretaceous–Paleocene) are predominantly marls with facies variations similar to the analogous "Puchow marls" in Slovakia and Poland. The color of the marls, although dominantly reddish, varies vertically and laterally depending upon physical, chemical, and biotic parameters. The depositional environment was probably bathyal with limited and episodic input of fine-grained sedimentary clastic material. Because of the prevalence of quartz grains and the absence of lithic fragments, the main source area of the clastics could be external to the East European Craton or the inner Dacides.

The middle–upper Eocene succession consists of thin-bedded calcareous turbidites with predominantly Tc–e and Td–e Bouma intervals. Cross and convolute laminations, scour marks (groove and flute casts), and vertical burrows and trails are common in some beds. Studies on provenance of clastic supply, based on orientation of sedimentary structures, show the primary direction of sediment influx was from south to north. The turbiditic depositional system can be considered one of transition from middle to outer fan into a well-oxygenated environment.

The foraminiferal samples were quite difficult to process in the laboratory due to their marly nature, but where present, benthic specimens dominated (agglutinated genera *Bathysiphon*, *Placentammina*, *Haplophragmoides*, *Lituotub*a, and *Recurvoides* and some calcareous benthics of the genus *Eponides*). Planktonic foraminifera occurred in low percentages (consisting only of *Heterohelix* sp.). The foraminiferal assemblage indicates a bathyal environment above the carbonate compensation depth.

At Botiza, the calcareous nannofossil assemblages contained very frequent *Lucianorhabdus maleformis*, *Micula murus*, *M. staurophora*, *M. cubiformis*, and *Watznaueria barnesiae*, along with lower numbers of *Broinsonia parca*, *Cribrosphaerella ehrenbergii*, and *Microrhabdulus decoratus*. Entire coccospheres were rarely present. In the lowest part of the Poiana Botizei section, the "red marls" contain abundant and diversified calcareous nannofossils: *Arkhangelskiella cymbiformis*, *A. maastrichtiensis*, *Micula staurophora*, *M. prinsii*, *M. murus*, *Ceratolithoides aculeus*, *Eiffellithus*

turriseiffelii, *E. eximius*, *Prediscosphaera cretacea*, *Placozygus fibuliformis*, *B. parca*, *Lithraphidites carniolensis*, *M. decoratus*, *C. ehrenbergii*, and sometimes entire coccospheres. The calcareous nannofossil assemblages from the "red marls", both at Botiza and Poiana Botizei, indicate a Late Cretaceous (Maastrichtian) age.

The oldest Paleocene calcareous nannofossils are small coccoliths, *Cruciplacolithus* spp., *Ericsonia* spp., *Markalius* spp., *Biantholithus sparsus*, and *Zeugrhabdotus sigmoides*, along with reworked Cretaceous taxa. Eocene calcareous nannofossils include discoasters, *Coccolithus pelagicus*, and *Reticulofenestra* cf. *dictyoda*. A few samples were barren of calcareous nannofossils.

The trace fossils were grouped toponomically into hypichnia, epichnia, and endichnia. Ethologically, the genera were mixed domichnia–fodinichnia (*Ophiomorpha*, *Thalassinoides*, *Arenicolites*), fodinichnia (*Rhizocorallium*, *Planolites*, *Taenidium*), repichnia (*Scolicia*), and cubichnia (*Lockeia*) forms. These trace fossils suggest a *Cruziana* ichnofacies. The turbiditic depositional system was a transition from mid- to outer fan into a well-oxygenated environment.

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Biometric analysis of the Maastrichtian *Arkhangelskiella* group in the Indian Ocean (ODP Hole 762C): Taxonomy and evolution

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The Late Cretaceous genus *Arkhangelskiella* has been the object of numerous biometric studies due to its large variation in size and rim width throughout its stratigraphic range. Coincident with becoming a more significant component of the nannofossil assemblage in the late Campanian of the North Atlantic, the genus significantly increased in size. While some authors advocated against the presence of several morphotypes of the unique species *Arkhangelskiella cymbiformis*, others have identified three variants of this species in the North Sea (var. NT, var. N, and var. W), based on the thickness of the rim and suggested dominance of these variants in distinct stratigraphic intervals of the Campanian–Maastrichtian. The definition of these variants was later emended based on variation in the length of the coccolith, and they were elevated to species: *A. cymbiformis* sensu lato (var. NT), *A. confuse* (var. N), and *A. maastrichtiensis* (var. W). In the Danish Basin, these morphotypes strongly overlap across all measured biometric parameters. The different variants have been valued in terms of stratigraphy in the Danish Basin with var. N rising to dominance in the early Maastrichtian and var. W dominant in the late Maastrichtian. It was also deemed necessary to introduce a fourth variant (var. SW) of average size and relatively thick rim that constitutes a transitional Maastrichtian form between var. N and var. W. Variant NT was then considered a separate ancestor lineage, dominant in the Campanian.

In our study, morphological variations in *A. cymbiformis* were studied across the Maastrichtian within sedimentary deposits of Ocean Drilling Program (ODP) Hole 762C (Indian Ocean), which has excellent stratigraphic constraints. We measured coccolith length and width, rim width, and central area length and width on 1876 specimens from 32 samples. Coccolith length ranges from 7 µm to a staggering maximum of 18 µm. The results confirm that the length, rim width, and central area opening are primary parameters for distinguishing between *Arkhangelskiella* variants. The study confirms the presence of four overlapping variants with distinct stratigraphic occurrences: var. N, a small variant of <10 µm with relatively thick rim that is dominant in the early Maastrichtian; var. W, a large variant of >12 µm that is dominant in the late Maastrichtian; and var. NT, of 8–14 µm, which bears a thin rim and wide-open central area and is present throughout the Maastrichtian. The transitional *A. cymbiformis* var. SW is needed to explain the overall stratigraphic evolution of these forms. While this evolutionary pattern and the upper limits in rim width and central opening size are similar to those found in the Danish Basin, the upper limits in coccolith length are significantly larger by +2 µm, highlighting the difficulty in defining clear globally applied rules for the distinction of morphospecies. Comparison between the percentage of the four variants and global climatic trends suggests that while the rise in dominance of the small (var. N) and very large (var. W) variants were favored during the early and late Maastrichtian cooling episodes, the transitional var. SW dominated during the mid-Maastrichtian and late Maastrichtian warm episodes.

Stratigraphy of the lower Danian in the Danish Basin: Perspectives from calcareous nannofossils and stable isotopes

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The Danian Stage is characterized primarily by ecological recovery from the mass extinction at the Cretaceous/Paleogene boundary (K/Pg), as well as several enigmatic climatic events such as the Dan-C2 hyperthermal event and other potential short environmental perturbations from Deccan volcanism. However, the Danian Stage remains poorly studied in the Boreal Realm. In this study, two Danian sections in the Danish Basin (onshore Denmark) are examined: Nye Kløv (NW Jylland) and the recently drilled BH-01 core (north of Næstved, Sjælland). Isotopic records from both localities allowed application of an age model via carbon isotope stratigraphy.

For the Danian of the Nye Kløv section, calcareous nannofossil quantitative abundance was integrated with previously established isotopic and biotic records. For the BH-01 core, new nannofossil biostratigraphy and carbon and oxygen isotope records on bulk carbonate were obtained. Correlation of the nannofossil recovery pattern and carbon isotope records at Nye Kløv revealed a delayed recovery of the assemblages, with the increase of emergent species possibly linked to the early Danian Dan-C2 hyperthermal event. The new nannofossil biostratigraphy of the BH-01 core links the lower Danian deposits at the classic locality of Stevns Klint to the middle Danian limestones at Faxe Quarry, eastern Sjælland. This study, incorporating the absolute abundance of reworked Cretaceous species, Cretaceous survivor taxa, and Danian emergent species, indicates a probable full recovery of the nannoplankton assemblages within 1 Myr following the K/Pg boundary in the Danish Basin.

The microscale exoskeletal reconstruction of the genus *Nannoconus* - taxonomic insights

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Among calcareous nannofossils, the genus *Nannoconus* was the major biocarbonate producer of Early Cretaceous seas (~152 to ~120 Ma). With its heavy calcitic exoskeleton (~200–1100 picograms), it produced massive carbonate accumulations for approximately 30 million years. However, its taxonomic position and biological affinity are not well known. A better understanding of the calcification process from the microstructural arrangement of the exoskeleton can help to close this gap. The *Nannoconus* skeleton is physically characterized by the interlocking arrangement of calcitic laminae (length ~0.5–1 µm, thickness ~100–500 nm) around a central canal. This arrangement results from sets of laminae with two different angles of inclination. Different morphogroups of *Nannoconus* have been classified based on the variability of these angles. A set of ptychography X-ray computed tomography (PXCT) and synchrotron radiation at SWING Beamline of SOLEIL (French synchrotron) was applied to several well-preserved *Nannoconus* skeletons in order to understand the microstructural arrangement at the nanometer level (finer than the thickness of an individual lamina).

The result of the experiment was a series of tomographic image slices (3D resolution ~30 nm) for the exoskeleton of each specimen. One lamina for each species of *Nannoconus* was virtually separated from the image slices using ORS-Dragonfly software. This lamina was used again to reconstruct virtually the entire exoskeleton of *Nannoconus* in the same software. Based on these results, we propose two different models of construction:

Model 1: Two separate layers of plates are formed. The laminae in each layer have a specific inclination. The entire exoskeleton is built by alternatively placing these two layers one above the other.

Model 2: One segment of laminae is created. Each segment is formed by alternately stacking laminae of two different inclinations. The exoskeleton is built by joining several such segments.

Both models show that the exoskeleton was formed by the arrangement of laminae, but each model has a unique growth pattern during calcification. However, model 2, in which segments constitute the building blocks of *Nannoconus*, agrees with scanning electron microscope (SEM) illustrations and descriptions of the structure of *Nannoconus*

and other homococcoliths in the Order Braarudosphaerales, which includes the genus *Braarudosphaera*. Calcification in the latter genus thus provides a good model for the calcification of *Nannoconus* on an external organic template. In the case of *Braarudosphaera*, the template for each segment has a pentagonal shape and the laminae form on vertical columnar stacks. In the case of *Nannoconus*, the template for each segment is of triangular shape and the segments slant in a sinistral direction.

Calcareous nannofossils at the Cretaceous/Paleogene boundary of the Northern Calcareous Alps (Wasserfallgraben section, Germany; Nussdorf section, Austria)

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The Cretaceous/Paleogene (K/Pg) mass extinction is one of the five large mass extinctions that have occurred in Earth's history and the only major mass extinction event known so far to be connected to a major meteorite impact and simultaneously occurring flood basalt eruptions. The Wasserfallgraben section is the type section of the Campanian to Paleocene Nierental Formation, which belongs to the upper part of the Gosau Group of the Northern Calcareous Alps and consists of deep-marine, hemipelagic, and turbiditic sediments. The Nierental Formation was deposited in a deep-water environment that was the result of rapid subsidence due to subduction and tectonic erosion at the front of the Austro-Alpine microplate.

The transition from the Maastrichtian to the Danian in the Nierental Formation can be documented by changes in the calcareous nannofossil assemblage. Occurrences of *Micula prinsii*, *Cribrosphaerella daniae*, and other Late Cretaceous nannofossils occur in the lower two meters of the Wasserfallgraben section, allowing placement in the upper part of the uppermost Maastrichtian nannofossil Subzone UC20d (equivalent to Subzone CC26b). *Micula prinsii* and *C. daniae* were identified in all samples from the lowermost sample (profile height 200 cm) up to the K/Pg boundary (profile height 0 cm). Blooms of the genus *Thoracosphaera* (calcareous dinoflagellates), beginning with sample 32 (profile height 0 cm), document the massive change in the nannofossil assemblage in the lowermost part of the Paleocene sediments. Sediments from this part of the section contain *Biantholithus sparsus*, *Cyclagelosphaera alta*, *Prinsius tenuiculus*, and *Neobiscutum parvulum*. Based on the occurrences of these species and the absence of *Cruciplacolithus tenuis*, this part of the succession can be attributed to nannofossil Zone NP1 (CP1a). A short bloom of *Braarudosphaera bigelowii* and *Braarudosphaera pentagonica*, which were observed in sample 14 (profile height 68–80 cm), characterizes the lowermost part of the Danian.

Additionally, 33 samples were quantitatively investigated for calcareous nannofossils from the Nussdorf section in Austria, with 81 species identified within the Cretaceous part. Although they are not abundant, the marker species restricted to the Maastrichtian are *Ceratolithoides kamptneri*, *Chiastozygus antiquus*, *Lithraphidites quadratus*, *Micula murus*, *M. prinsii*, and *Russellia bukryi*. A total of 26 calcareous nannofossil species were identified in the five Paleogene samples. The calcareous dinoflagellates were counted separately under the *Thoracosphaera* spp. group, which includes *Calciodinellum albatrosianum*, *Cervisiella operculata*, *Thoracosphaera heimii*, *Pernambugia tuberosa*, and *Thoracosphaera* spp. The most abundant species in the Paleocene samples are *Thoracosphaera* spp. (77.10%), followed by C*yclagelosphaera* cf. *alta* (13.03%), which combined represent 90.13% of the assemblage.

A revision of Quaternary species of the genus *Scyphosphaera*

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The genus *Scyphosphaera* is perhaps one of the most understudied groups of coccolithophores due to its relative scarcity in many stratigraphic sections. Polymorphism is one important feature of the scyphosphaerids as illustrated by Lohmann (1902) in his drawings of the type species *S. apsteinii*. Siesser (1998) indicated that 53 species had been described from lower Eocene to Upper Pleistocene sediments. Many Quaternary *Scyphosphaera* species have been described in the literature, but some may belong to the same coccosphere. To clarify the ranges of Quaternary *Scyphosphaera* and the biostratigraphic value of some of these species, I undertook a detailed analysis of sediments from Ocean Drilling Program (ODP) Leg 154 sites in the tropical Atlantic Ocean. I observed a total of 39 *Scyphosphaera* species in the Leg 154 Quaternary sediments. This degree of variation of forms is similar to that observed in Miocene or Pliocene sediments. I found no decrease in the number of *Scyphosphaera* species for the Late Pliocene (Subzone NN16B) or the Early Pleistocene (Zone NN17 to Subzone NN19A). Based on this assessment, the number of Quaternary *Scyphosphaera* species has so far been underestimated. All 39 species survived the early Quaternary cooling between 2.588 and 1.727 Ma (De Kaenel et al., 2024) and disappeared in the late Early Pleistocene (Calabrian). Only nine species are recorded in the Holocene, and the youngest sample examined (1000 years) contained all nine: *S. antilleana*, *S. apsteinii*, *S. aranta*, *S. cohenii*, *S. elegans*, *S. galeana*, *S. magma*, *S. porosa*, and *S. recurvata.*

I identified a total of nine *Scyphosphaera* groups (GR) in the Quaternary based on morphologic criteria and extinction levels. Species that disappear at the same time are placed in the same group and are thought to represent forms (*formae*) belonging to the same coccosphere and so to one unique species. The extinction of these groups occurs between Subzones NN19B and NN21A with two groups surviving until today: the *S. apsteinii* group (GR1) and the *S. porosa* group (GR2). The *S. hemirana* group (GR3) disappeared at 0.128 Ma (NN21B), the *S. recta* group (GR4) at 0.525 Ma (NN19F), the *S. globulosa* group (GR5) at 0.699 Ma (NN19F), the *S. aequatorialis* (GR6) at 0.731 Ma (NN19F), the *S. pulcherrima* group (GR7) at 0.966 Ma (NN19F), the *S. campanula* group (GR8) at 1.318 Ma (NN19D), and the *S. lagena* group (GR9) at 1.643 Ma (NN19B). Each group of *Scyphosphaera* consists of lopadoliths of the same structure with some morphological variations in the shape of the margin or of the neck. A lopadolith with a neck was never observed in a group of lopadoliths without a neck. GR1 to GR5 include lopadoliths without a neck, and GR6 to GR9 lopadoliths have necks. The highest occurrence of *Scyphosphaera* with a neck (GR6 at 0.731 Ma) occurs at the base of the Middle Pleistocene, just above the Matuyama/Brunhes magnetochron boundary, and divides the Quaternary into two main intervals (Early Pleistocene and Middle–Late Pleistocene). The other six Pleistocene groups provide useful additional biohorizons to subdivide the Quaternary calcareous nannofossil zonation.

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Calcareous nannofossil paleoceanography across Oceanic Anoxic Event 3: From local to global perturbations

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The Late Cretaceous was punctuated by several periods of global perturbations in the climate–ocean system that led to widespread deposition of organic carbon-rich marine black shales known as oceanic anoxic events (OAEs). The OAE3, which represents the youngest Cretaceous episode of anoxia and is in the Coniacian–Santonian, was confined to the equatorial Atlantic Ocean and adjacent basins rather than being global in scale. We focused on nannofossil paleoceanography of the late Turonian to early Campanian time interval and applied quantitative analyses to assess the response of calcareous nannoplankton to paleoenvironmental changes across OAE3. The study was conducted on sites from the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) situated in the equatorial and southern Atlantic Ocean and the Indian Ocean, as well as land sections from the Anglo-Paris Basin. A detailed, revised, and high-resolution nannofossil biostratigraphy of the selected sites enabled correlations at a supra-regional scale.

Quantitative analyses allowed us to characterize paleotemperature and nutrient changes before, during, and after OAE3. Nannofossil-based paleotemperatures varied depending upon the cool-water taxa considered. However, warm conditions that were interrupted by brief cooling episodes in the Coniacian–early Santonian interval were followed by a generalized and longer term cooling that began in the middle Santonian. Regarding paleofertility, the nannofossil assemblages exhibit very different patterns at the various sites, suggesting that OAE3 was not characterized by a global fertilization episode.

We identified relatively large fluctuations in abundance of the genera *Micula* and *Marthasterites*, which correlate with coeval peaks described in the literature, albeit with different abundance values at various sites and sections. Discrete *Marthasterites* (*M. furcatus*) and *Micula* (*M. staurophora*) "acmes" were identified across OAE3. The paleoecological affinities of *Micula* and *Marthasterites* remain elusive, but their distinctive fluctuations indicate that there were profound paleoceanographic changes at specific times. The onset of OAE3 coincides with a major increase in abundance (and local dominance) of *M. furcatus*, suggesting the rapid establishment of new and peculiar paleoceanographic conditions at a widespread to global scale. The most altered paleoceanographic conditions occurred during the core of OAE3 as characterized by the synchronous maximum abundance (climax) of *M. staurophora* on a global scale. In addition to their value for paleoenvironmental reconstructions, the *Micula* and *Marthasterites* "acmes" are useful for the biostratigraphic characterization of the Turonian/Coniacian, Coniacian/Santonian, and Santonian/Campanian boundaries. These "acmes" might be introduced as additional events in future nannofossil zonations for the Late Cretaceous.

Phosphate-limiting conditions induce cell volume increase in natural coccolithophore populations

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Coccolithophores are a key functional phytoplankton group that produce distinctive minute calcite plates (coccoliths) covering the cell surface. Calcification and subsequent export of coccoliths reduce alkalinity in the surface ocean and cause a net release of CO_2 into the atmosphere, counteracting the CO_2 drawdown by photosynthesis, thus constituting an important pathway of the global carbon cycle. Experiments in vitro indicate that the coccosphere size and coccolith length of *Gephyrocapsa huxleyi* increase when phosphate (P) is limited and decrease when nitrogen (N) is limited, relative to exponential cell growth in nutrient-replete conditions. However, variations occur between natural and experimental conditions. To test whether coccosphere size variations that occur in nature relate to nutrient availability, we examined coccolithophore communities in two oligotrophic ecosystems with marked seasonal variability: the Gulf of Aqaba (GoA) in the northern Red Sea and the Eastern Mediterranean (EM). In the GoA, we found that *G. huxleyi* cells are larger during the summer in the stratified layer, whereas winter cells are smaller in the mixed layer. Bioassays indicate that during the summer, cells are primarily P-limited, whereas nutrient limitation in the winter is absent or weak. Critically, no correlation between coccosphere size and coccolith length was detected. Similar size variations were detected for the similar species *Gephyrocapsa ericsonii*. The seasonal pattern in *G. huxleyi* size was the opposite in the EM. Coccospheres were larger in the mixed layer during winter and smaller during the stratified summer, which coincides with the prevalent pattern of limitation. The EM is permanently P-limited across all seasons, but during the summer, N limitation often predominates over P limitation. These results indicate that nutrient availability is a major regulator of coccolithophore size in marine ecosystems.

New insights on calcareous nannofossil biostratigraphy and paleoecology around the Pliensbachian/Toarcian boundary in the South Iberian paleomargin

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Calcareous nannofossils have proved to be one of the most useful tools for dating Mesozoic marine rocks, especially in those areas where ammonites are very scarce or absent. This is the case for two stratigraphic sections in the Betic External Zone: Sierra Pelada (PEL) in the median Subbetic and Guarrumbre (G) in the external Subbetic. The uppermost Pliensbachian–lower Toarcian, pre-Jenkyns Event materials from these sections have been dated with precision with calcareous nannofossils using the biostratigraphic scheme of Ferrerira et al. (2019) for the western Tethys. In the PEL section, the boundary between Subzones NJT5b and NJT5c was established based on the first occurrence (FO) of *Zeugrhabdotus erectus*, which also enabled the approximation of the Pliensbachian/Toarcian boundary. At the G section, Subzones NJT5a, NJT5b, NJT5c, and NJT6a were identified using the FOs of *Lotharingius crucicentralis* (latest Pliensbachian), *Z. erectus*, and *Carinolithus superbus* (early Toarcian).

The results of the quantitative analysis performed on calcareous nannofossils from the PEL and G sections can help us decipher their paleoecological affinities around the Pliensbachian/Toarcian boundary, a time interval marked by environmental and climatic changes with an increase in temperature and a negative carbon isotope excursion (CIE). Coinciding with the negative CIE, there was a decrease in the relative abundance of *Calcivascularis jansae*, which probably thrived under relatively cool temperatures and oligotrophic conditions (Fraguas et al., 2021) and can be observed in both sections. Furthermore, a sharp increase in the relative abundances of *Mitrolithus lenticularis* and *Crepidolithus crucifer*, which could thrive under warm and mesotrophic conditions, was noticed only at PEL, which was located in a more distal paleogeographic position than G with respect to the South Iberian paleomargin. According to Peti & Thibault (2022), these two species thrived predominantly in open-ocean settings. In both sections, the opportunistic taxon *Lotharingius hauffii*, together with other species of the genus *Lotharingius* and the recovered *C. jansae*, dominated the nannofossil assemblages above the negative CIE and the Pliensbachian/Toarcian boundary.

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Early Miocene microfossils from Marmorito (Italy)

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In previous studies, the Marmorito sediments in northwest Italy were determined to be Early Miocene (Aquitanian–Burdigalian) in age, based on foraminifera and diatoms. However, there have been few investigations on other microfossil groups. Samples from 28 diatomaceous layers were obtained in February 2019 and prepared as permanent mounts for the light microscope (LM) and stubs for the scanning electron microscope (SEM). Observations on the calcareous nannofossils revealed the presence of coccospheres of *Tergestiella* sp., *Coccolithus pelagicus*, *Reticulofenestra minuta*, *R. haqii*, and *Cyclicargolithus floridanus*, which suggests that these species were deposited *in situ* (i.e., not reworked). However, the assemblages also include reworked Cretaceous and Paleogene forms. Siliceous scales of the putative haptophyte *Macrora stella* were encountered, particularly in the lower Burdigalian. Diverse silicoflagellate assemblages were comprised of *Naviculopsis*, *Mesocena* (*Bachmannocena*), *Corbisema*, *Distephanopsis*, *Dictyocha*, and *Stephanocha*, and they represent a time close to the extinctions of *Corbisema* and *Naviculopsis* and before the first appearance of *Caryocha.* Chrysophyte cysts were also observed and assumed to be associated with river outflow. Diatom assemblages contained a lot of *Chaetoceros* resting spores, as well as attached and benthic taxa, with few (if any) offshore taxa, which collectively suggests a shallow shelf assemblage. Sponge spicule assemblages were mainly composed of oxeas, styles, sigmas, and spherasters that seemingly originating from shallow- and deep-water sponges.

From this holistic approach, our microfossil data show that the Marmorito sediments were likely deposited on the continental slope, given the presence of deep-water (e.g., some of the sponges) and offshore (silicoflagellates) forms, but with significant input from river outflow (chrysophytes), as well as coastal and shelf assemblages (diatoms and some of the coccolithophorids). In addition, monospecific *Ethmodiscus* layers may suggest rapid deposition of seasonally stratified oligotrophic waters or selective preservation through sediment winnowing.

Early Aptian Oceanic Anoxic Event 1a (OAE1a): Evidence based on calcareous nannofossils in the Qaleh Zoo section, central Kopet Dagh, Iran

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This study examines a marine sedimentary succession from the middle part of the Sarcheshmeh Formation with the aim of recording the early Aptian Oceanic Anoxic Event (OAE) 1a in the Qaleh Zoo section in the central part of the Kopet Dagh Basin in northeastern Iran. The OAE1a was recorded on a global scale during the early Aptian in the nannofossil Subzone NC6B. In this study based on calcareous nannofossils, the interval from the uppermost part of Subzone NC6A to the lowermost part of Subzone NC7A (early Aptian) was examined in the Sarcheshmeh Formation. For the identification of OAE1a, calcareous nannofossil paleoecology and calcium carbonate content were analyzed. The rare presence or absence of nannoconids in Subzone NC6B, together with the lowest calcium carbonate values, indicates the presence of OAE1a in the Sarcheshmeh Formation (55–180 m in the studied interval). Considering the calcareous nannofossil data and the calcium carbonate content of the samples, OAE1a was placed in the middle part of the Sarcheshmeh Formation, which is equivalent to the event west of the Kopet Dagh Basin in the Takal Kuh section (Mahanipour et al., 2011).

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Using extraterrestrial ^{3}He to reconstruct terrigenous fluxes and their impacts on marine primary productivity and carbon burial during OAE2 in the Vocontian Basin (SE France)

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The Mesozoic was punctuated by several oceanic anoxic events (OAEs) that were characterized by widespread black shale deposition and global carbon cycle perturbations. Among them, OAE2, spanning the Cenomanian/Turonian boundary (~94 Ma), has been identified as one of the most severe OAEs of the Mesozoic. Lasting ~600 kyr, this event is marked by a global >2‰ positive excursion in the $\delta^{13}C$ signature of both carbonates and organic matter. This has been interpreted to reflect a massive burial of isotopically light organic carbon that was driven by deoxygenation of ocean bottom water. Previous models suggested that volcanism related to large igneous provinces (LIPs) increased atmospheric and oceanic CO_2 concentrations, thereby increasing nutrient input into the ocean, increasing marine primary production, and decreasing seawater oxygenation. This volcanism also disturbed the climate by increasing precipitation and thus weathering. However, the respective roles of weathering and detrital fluxes on marine primary productivity and organic carbon burial during OAE2 remain highly debated, mainly due to the lack of high-resolution chronologies. In this study, we performed new extraterrestrial ^{3}He ($^3He_{ET}$) measurements on hemipelagic marine samples from Pont d'Issole (Vocontian Basin, SE France) in order to reconstruct carbonate and organic carbon contents, and terrigenous sedimentation rates and fluxes across OAE2. Combined with organic matter content, trace metal concentrations, and nannofossil fluxes, this method allowed us to trace sources and variations of each of the three sedimentary components during the event.

Our results reveal that over 70% of the ^{3}He in the analyzed samples is extraterrestrial in origin. Assuming a constant flux of interplanetary dust particles, the $^3He_{ET}$ concentrations allowed us to reconstruct relative changes in sedimentation rates at an unprecedented high resolution (every 15 cm). Our preliminary results suggest that there were changes in the variability of terrigenous and carbonate depositional fluxes across OAE2. Indeed, prior to OAE2 and at its onset, sediments are characterized by constant terrigenous input across different carbonate-rich and carbonate-poor lithologies, whereas total sedimentation plummeted (from 17 to 2 g/cm²/kyr). The beginning of the event was thus marked by a collapse of carbonate net deposition. In contrast, sediments from the Plenus Cold Event (colder and more oxygenated period within early OAE2) and from the Cenomanian/Turonian boundary show variations in both terrigenous and carbonate fluxes (from 0.2 to 2 g/cm²/kyr and from 0.5 to 8 g/cm²/kyr, respectively). In both cases, reconstructed organic matter accumulation rates peaked during short-lived pulses. The implications of our new nannofossil and $^3He_{ET}$ data will be discussed in the context of the debated role of increased detrital input on marine primary productivity and organic carbon burial during OAE2.

Coccolithophore assemblages and paleoceanographic dynamics at IODP Site U1385: Insights from the Pliocene–Pleistocene transition (western Iberian margin)

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This study investigates coccolithophore assemblages from the Pliocene–Pleistocene transition in an ocean sediment core from International Ocean Discovery Program (IODP) Site U1385 (Expedition 397), located on the western Iberian margin and retrieved at a depth of 2590 meters below sea level (mbsl). The samples, which were collected over 109 meters (215.5–324.5 meters below seafloor [mbsf]) with an average sedimentation rate of 10 cm/kyr, should allow us to identify the most relevant signatures of astronomical cycles. Samples were prepared using the random sedimentation technique described by Flores & Sierro (1997), and a quantitative analysis was carried out on the entire assemblage.

Biostratigraphic events based on the quantitative distribution of several species of the genus *Discoaster* (highest occurrences of *D. pentaradiatus*, *D. surculus*, and *D. tamalis*) were recognized and used to establish a preliminary age model for the studied interval. The coccolithophore assemblage is mainly composed of small placoliths (<3 μm), followed by medium-sized placoliths (3–5 μm), and *Florisphaera profunda*. The abundances of small and medium placoliths show clear anti-correlation, which, together with the patterns of N ratio (*Reticulofenestra* spp./*Reticulofenestra* spp. + *F. profunda*) and total coccolith abundance, may provide information about paleoproductivity and nutricline variations through time. The overall results will provide insight into the most important variations of coccolithophore assemblage productivity and oceanographic conditions during the Pliocene–Pleistocene transition that was a crucial time for Earth climate changes.

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Environmental influences on coccolithophore distribution and abundance in the water column of the western Iberian margin (August 2022)

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This study investigates the abundance, composition, and biogeographical distribution of coccolithophores in the water column of the northwestern Iberian coastal upwelling system during late summer 2022. The coccolithophore data were compared with physical, chemical, and biological parameters measured *in situ* to evaluate the influence of the environment on coccolithophore distribution. Additionally, coccolithophore data were compared with satellite data (NASA Ocean Biogeochemical Model [NOBM] and NASA Moderate-Resolution Imaging Spectroradiometer [MODIS]) and the upwelling index (UI) in the study area. The results reveal a latitudinal and longitudinal gradient in coccolithophore abundance with peaks towards the north and east. This indicates that the stations closest to the coast (CA-7, CA-8, and CA-4) are most affected by coastal upwelling, with cooler surface temperatures and higher fluorescence and turbidity values. Moreover, our data suggest that the source of the upwelled water in the north (Eastern North Atlantic Central Waters of subpolar origin, ENACWsp) is different from that in the south (ENACW of subtropical origin [st]). The significant correlation between the upwelling index and the total abundance of coccoliths and coccospheres underlines the important role of upwelling mechanisms in controlling the abundance and spatial distribution of coccolithophores along the western Iberian margin. Furthermore, the significant correlation between coccolithophore abundance and fluorescence (Chl-*a*) and turbidity suggests that coccolithophores account for a substantial fraction of the primary production in the region.

The affinity of certain species to specific environmental conditions supports their use as paleoenvironmental indicators in the study area. In particular, the small Noelaerhabdaceae group (sum of the small *Gephyrocapsa* group and *Emiliania huxleyi*) is proposed as a proxy for primary productivity (PP) and enhanced upwelling intensity (UI > 0), whereas *Florisphaera profunda* appears to be associated with conditions of upwelling relaxation, stratified water column (deep thermocline), and low productivity in the upper photic zone. Discrepancies between our *in situ* observations and satellite data are attributed to the limited capacity of satellites to detect subsurface biological processes. In addition, this study supports the viability of using the N ratio in water column samples, as opposed to only in sediments as suggested by previous work. Overall, this research contributes to a deeper understanding of primary productivity on the western Iberian margin during the upwelling season and emphasizes the crucial role of coccolithophores in paleoenvironmental reconstructions.

Morphometric analysis of the calcareous nannofossil group *Aspidolithus* in the lower Campanian: Implications for taxonomy

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Changes in the coccolith morphometry of the *Aspidolithus parcus* group have been used to distinguish biostratigraphically relevant subspecies for the Late Cretaceous. However, insufficiently detailed morphometric analyses have hindered the establishment of statistical differentiation among the subspecies. Consequently, the taxonomic classification of this group remains ambiguous, which also affects the accuracy of biostratigraphic correlations. In this study, a morphometric analysis of samples from the lower Campanian of the Loibichl section (Rhenodanubian Flysch Zone, Austrian Alps) was performed that focused on the *Aspidolithus* group. Semi-quantitative analyses of the nannofossil assemblages allowed the calculation of paleoenvironmental indices. In addition, 1021 well-preserved specimens of the *Aspidolithus* group were measured for several key parameters: (1) the maximum coccolith length (L), (2) the maximum coccolith width (W), (3) the width of the outer rim versus the small diameter of the central area (b/a), and (4) the number and arrangement of perforations in the central area. The main objective was to identify significant differences between *Aspidolithus* morphotypes and to explore possible factors influencing size variation within this group. In addition, we analyzed $CaCO_3$ content and stable isotope ratios of $\delta^{13}C$ and $\delta^{18}O$ to aid stratigraphic and paleoecological interpretations.

Five distinct morphotypes were identified: *Aspidolithus enormis* subsp. 1, *A. enormis* subsp. 2, *A. parcus expansus*, *A. parcus parcus*, and *A. parcus constrictus*. Morphometric analyses revealed significant taxonomic differentiation between the "small" *A. enormis* (<8–8.5 µm in length) and the "large" *A. parcus* group (≥8–8.5 µm in length). However, the study found no clear patterns that naturally classify the "subspecies" (*A. parcus expansus*, *A. parcus parcus*, and *A. parcus constrictus*) within the *A. parcus* group. These morphotypes appear to be an evolutionary lineage, probably driven by the global cooling that began in the late Santonian. Moreover, it was observed that the dimensions of the central area, represented by the value of the ratio b/a, correlate with surface temperature values. An in-depth examination of global versus regional environmental influences is essential to fully understand these findings. Therefore, calcareous nannofossil samples from the Smoky Hill Member of the Niobrara Formation (Kansas, USA) are being analyzed to confirm this impact on size variation.

Recent progress in the studies of *Braarudosphaera bigelowii*

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Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre has long been considered a coastal–neritic dweller because pentaliths of *B. bigelowii* are usually found only from coastal–neritic marine sediments deposited on continental shelves. However, the discovery of a symbiotic relationship between an unidentified species, which is closely related to *B. bigelowii* in 18S rDNA sequence, and cosmopolitan nitrogen-fixing cyanobacterium UCYN-A (Thompson et al., 2012) suggests that extant *Braarudosphaera* specimens are widely distributed from coastal seas to open oceans, and *Braarudosphaera* plays an important role in the ocean nitrogen cycle. Moreover, a recent study on the established culture strain of *B. bigelowii* s.s. (18S rDNA genotype III) revealed that UCYN-A2 (one of the *nifH* genotypes of UCYN-A) has evolved beyond endosymbiosis and is in the early stages of developing into a N_2-fixing organelle (nitroplast) (Coale et al., 2024). This talk will review the progress in the studies of *B. bigelowii* and nitroplasts (UCYN-A) over a decade, discuss taxonomic issues of *Braarudosphaera*, and present the remaining challenges to be solved in *Braarudosphaera* research.

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Size-fraction coccolith stable isotopes and Sr/Ca from the Miocene to Recent

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The preservation of coccoliths in marine sediments makes them an excellent recorder of surface ocean environmental change through geologic time. Geochemical analyses of coccolith-rich sediment fractions have recently been the basis for determining biotic responses to paleoenvironmental change, most notably through $\delta^{13}C$ stable isotopic analysis of coccolith size-separated microfractions. A marked isotopic divergence, also known as vital effects, in coccolith $\delta^{13}C$ between small (<4 µm), lightly calcifying forms (e.g., *Gephyrocapsa oceanica* and *Emiliania huxleyi*) and large (~7–10 µm), heavily calcifying forms (*Calcidiscus leptoporus* and *Coccolithus pelagicus*) is noted in extant species in culture studies. This effect originated during the Late Miocene (7–5 million years ago) and has been linked to a decline in atmospheric CO_2, causing a reallocation of carbon from calcification to photosynthesis in the coccolithophore cell during coccolithogenesis that particularly affected larger cells.

To investigate how these isotopic divergences may have been influenced by climatic events and nannofossil evolutionary changes, we generated a long-term record of coccolith geochemistry, including oxygen and carbon isotopes and strontium/calcium, from the Miocene to Recent (~10 to 0.1 million years ago). All samples that capture the emergence of these vital effects come from International Ocean Discovery Program (IODP) Site U1482 (Expedition 363) on the northwest Australian continental margin. A further high-resolution record from the same site was generated that spans the Pliocene–Pleistocene transition (3.01 to 1.38 million years ago). A novel technique allows for the rapid separation of coccolith-rich sediments into very fine and very coarse fractions, allowing for the generation of high-resolution size-specific coccolith geochemistry records over the two time periods. Further honing of this method will enable the further use of coccolithophore isotopes, particularly when paired with the alkenone CO_2 proxy, which would allow us to study coccolithophore carbon limitation through time.

Calcareous nannoplankton and εNd as paleogeographic proxies: A case study from the Langhian junction of the Indian Ocean, the Mediterranean, and the Paratethys

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The location of marine seaways or gateways between the Mediterranean, the Paratethys, and the Indian Ocean from the late Burdigalian to the Serravallian is still a matter of scientific debate, although several paleogeographic reconstructions have attempted to assess this issue in recent decades (Popov et al., 2004; Bialik et al., 2019). Unfortunately, due to intensive tectonic activity and denudation of the Miocene sedimentary cover in the Eurasian area, only isolated relicts of the original marine basins, including those representing communication corridors, have been preserved. As a result, the only original record available is that of isolated relics, which in some areas are completely absent. However, various paleobiological proxies (e.g., migration paths of indicative species and distribution of indicative assemblages) can be used to partially reconstruct the paleogeographic setting. In addition, Nd isotope systematics can be helpful, as $^{143}Nd/^{144}Nd$ is one of the most prominent paleoceanographic proxies for tracing water masses (von Blanckenburg, 1999; Bialik et al., 2019).

In this context, our study aims to evaluate the contribution of calcareous nannofossil assemblage analysis together with the $^{143}Nd/^{144}Nd$ proxy to reconstruct communication corridors in the Early–Middle Miocene interval in the European region and the Middle East. All analyzed samples were dated using integrated biostratigraphy and chemostratigraphy (strontium isotope stratigraphy) to ensure maximum robustness of the stratigraphic correlations. In general, the variability in calcareous nannofossil assemblages reflects the quality of the surficial water masses. We focused on characteristics such as warm-water taxa ratios, diversity, dominance, and distribution of different assemblage types, all of which were subjected to multivariate statistical methods. These results were then compared with high precision εNd data. Although the distribution of calcareous nannoplankton in marginal areas is thought to be primarily related to the variance of surface water temperatures, which correspond to climatic zones and the presence of stress factors, when these data are combined with high precision $^{143}Nd/^{144}Nd$ data, they can significantly contribute to refining paleogeographic reconstructions of complex marine regions.

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Ultrastructure and taxonomy of the Families Axopodorhabdaceae and Cretarhabdaceae

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The Families Axopodorhabdaceae and Cretarhabdaceae are two placolith heterococcolith families that originated in the Early Jurassic and went extinct at the end of the Cretaceous. They are generally classified together in the Order Podorhabdales. However, although superficially similar, their ultrastructures are quite different (Figure 1). Both families have "conventional" placolith morphologies with an R-unit proximal shield, a V-unit distal shield, an R-unit tube cycle, and a central-area structure. However, the arrangements of the tube cycle and central-area structures are distinctly different between the two families, suggesting that they may not be as closely related as previously thought.

Electron microscope (EM) images of typical Axopodorhabdaceae species show a steeply inclined petaloid (i.e., non-imbricate) tube cycle lining the central area. Because the tube-cycle elements are steeply inclined and non-imbricate, they are generally bright in cross-polarized light (XPL) with a characteristic "beaded" appearance. The central-area structure grows inwards and upwards from the base of the tube cycle. Where a spine is present, it is always hollow with a distinct central cavity present the entire length of the spine. Because the central-area structure grows from the base of the tube cycle, it is referred to here as "low".

In EM images, typical Cretarhabdaceae species appear to have three shields, which has led to much confusion on their taxonomic position. However, what appears to be a distal third shield is actually the tube cycle. Unlike in the Axopodorhabdaceae, this tube cycle grows (sub)horizontally, fully or partly covering the top of the V-unit distal shield. Although it is composed of petaloid R-units, because the tube cycle is flat lying, its vertical thickness is low, resulting in relatively low birefringence in XPL. Because the tube cycle may fully (e.g., *Cruciellipsis*) or partly (e.g., *Cretarhabdus*) cover the distal shield, some species have an apparently unicyclic or bicyclic appearance under XPL. Where a spine is present, it is always solid, unlike the hollow spines of the Axopodorhabdaceae. The central-area structure is raised because the tube cycle is also raised up to cover the distal shield and is referred to here as "high".

With a clear understanding of the ultrastructure of the two families, it is possible to show that several species have been incorrectly assigned to either the Axopodorhabdaceae or the Cretarhabdaceae. It is essential to properly characterize the tube cycle, the relative height of the central area, and the nature of the spine to correctly assign taxa to either family.

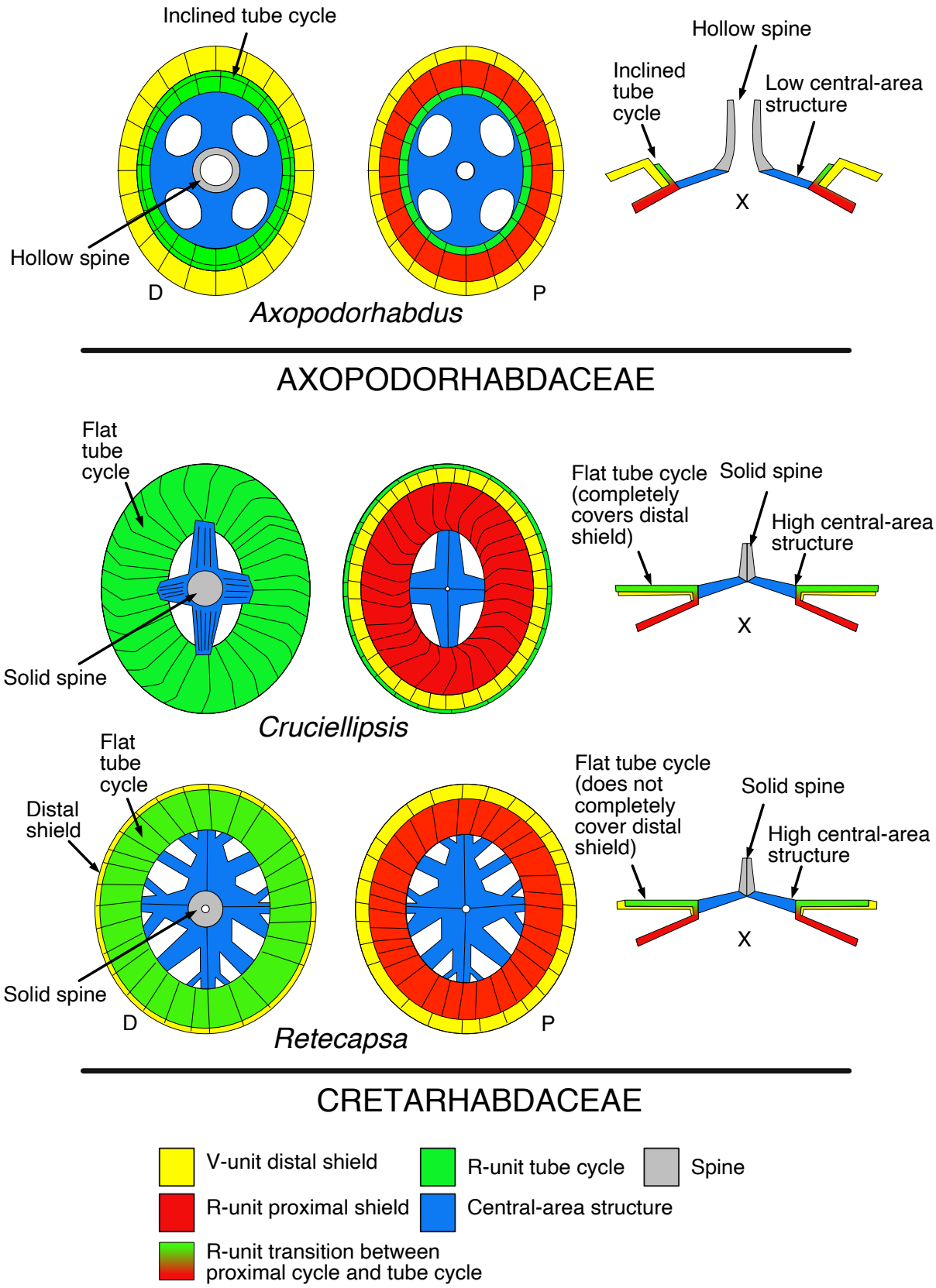

Figure 1. Schematic ultrastructure of the Axopodorhabdaceae and Cretarhabdaceae. D = distal side, P = proximal side, X = cross section.

Ultrastructure and taxonomy of the Order Arkhangelskiales

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The Order Arkhangelskiales is a group of Cretaceous heterococcoliths that are united by a common ultrastructure. They are muroliths with a thin and narrow R-unit proximal cycle, a tall and wide V-unit outer wall, an R-unit tube cycle, and a central-area structure (Figure 1). The key innovation that separates the Arkhangelskiales from other Cretaceous muroliths is that the outer wall is wide and grows inward of the tube cycle so that the tube-cycle elements grow upwards through the outer wall, which is not seen in any other group. This divides the outer wall into inner and outer sections, and results in a superficially complex ultrastructure. Another key feature of taxa in the order is the presence of lateral ridges that extend outward from the outer wall, resulting in a tiered appearance in lateral view that superficially resembles placolith morphology. It is unclear whether all taxa within this order have tiers, although most do. In most species, the inner and outer sections of the outer wall meet distally at a marginal suture. A central-area structure is present inside the inner section of the outer wall, usually with a perforate plate or axial cross, and it sometimes has accessory bars.

There are two families within the order, the Arkhangelskiellaceae and Kamptneriaceae. These two families have superficially different ultrastructures but clearly have a common origin because they share the key characteristics of the outer wall growing inward of the tube cycle and tiers being present on the outer wall. The evolutionary origin of the order is unclear. The first unambiguous member of the order is *Broinsonia* in the Arkhangelskiellaceae, which appeared in the early Albian. In *Broinsonia* and the closely related *Aspidolithus*, the tube cycle grows up through the outer wall and grows laterally on top of the distal surface of the outer wall where it shows a complex suture pattern between adjacent elements. Outside of the marginal suture, a narrow outer section of the outer wall is present on the distal surface. A single cycle of subcircular depressions is present on the distal surface of the tube cycle in many species of *Broinsonia* and *Aspidolithus*. *Arkhangelskiella* evolved from *Aspidolithus* in the Santonian–Campanian with the tube cycle growing laterally on the distal surface to cover the outer wall mostly or completely, and the complex tube-cycle sutures of *Aspidolithus* became simple radial sutures in *Arkhangelskiella.*

In the Albian–Cenomanian, the Kamptneriaceae evolved from *Broinsonia* through loss of the distal portion of the tube cycle, leaving the distal surface of the inner section of the outer wall exposed. The tube cycle in *Gartnerago* is much narrower than in *Broinsonia*, and on the distal surface it is completely covered by the outer wall, making it visible in the light microscope but not in the electron microscope. The marginal suture marks, where the inner and outer sections of the outer wall meet on the distal surface, completely cover the tube cycle. In *Kamptnerius*, the distal part of the outer section of the outer wall extends laterally to form an asymmetrical flange. The inner section of the outer wall is much wider than in *Gartnerago*, and the central plate is correspondingly reduced in width. The inner section of the outer wall may be perforate.

Correctly characterizing species in the Arkhangelskiales requires careful observation of the tube cycle, both the inner and outer sections of the outer wall, the position of the marginal suture, and the nature of the central-area structure.

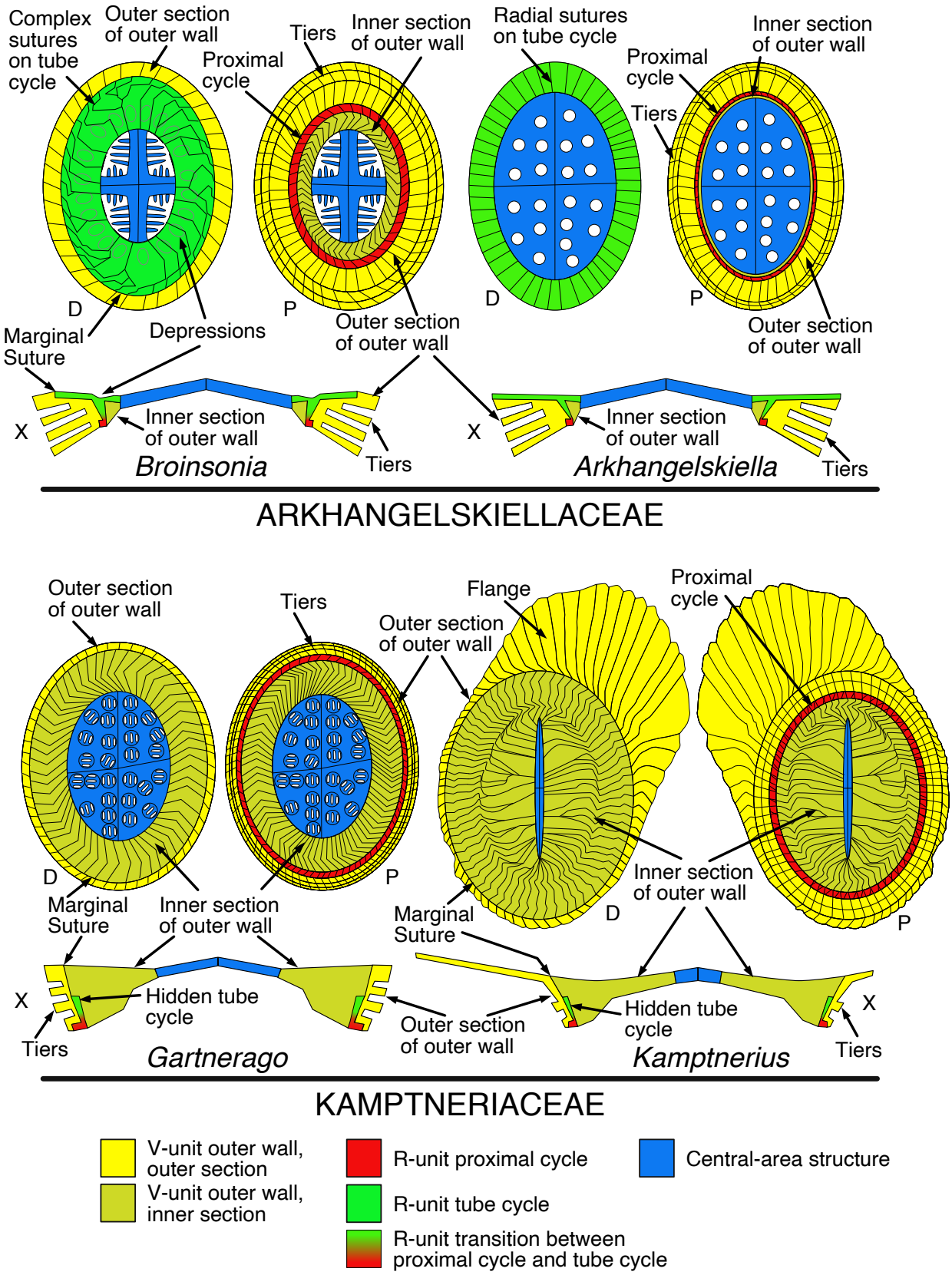

Figure 1. Schematic ultrastructure of the Order Arkhangelskiales. D = distal side, P = proximal side, X = cross section.

Ultrastructure and taxonomy of the Order Watznaueriales

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The Order Watznaueriales is a group of Early Jurassic to Recent placolith heterococcoliths that are united by a common ultrastructure. Either two or three shields are present, the lower two shields having R-unit elements, and the third shield, when present, having V-unit elements (Figure 1). An R-unit tube cycle is usually present, as well as a central-area structure that can include plates, axial crosses, transverse bars, or may be open. This ultrastructure is quite different from other placolith families, which usually have R-unit proximal shields and V-unit distal shields. Three families are placed within the Order Watznaueriales: Bussoniaceae, Ellipsagelosphaeraceae, and Noelaerhabdaceae. The Noelaerhabdaceae have generally been considered to have evolved from the Family Prinsiaceae (Order Isochrysidales). However, the ultrastructure of the Noelaerhabdaceae has much more in common with the Ellipsagelosphaeraceae.

The Watznaueriales appeared during the Early Jurassic with the evolution of the genus *Mazaganella* (Family Bussoniaceae) from the ancestral murolith genus *Crucirhabdus*. The key innovations in *Mazaganella* were a doubling of the R-unit proximal cycle and development of a lateral extension of both the proximal and distal cycles, resulting in a placolith morphology with two proximal shields and a raised distal shield. *Bussonius* then evolved from *Mazaganella* with the inception of imbrication in the shields. In a separate branch of the family, *Triscutum* evolved from *Mazaganella* through the development of a high non-imbricate distal shield.

The Family Ellipsagelosphaeraceae evolved with the appearance of *Lotharingius* in which the raised V-unit distal shield of *Bussonius* was reduced in height and width until it was close to level with the distal surface of the upper of the two proximal shields. This relict V-unit cycle is here referred to as the crown cycle. The upper of the two R-unit proximal shields in *Bussonius* became the distal shield in *Lotharingius.* The R-unit distal shield in *Lotharingius* and all subsequent descendants has no homology to the V-unit distal shield of the Bussoniaceae. The basic ultrastructure of *Lotharingius* continued through the Mesozoic with the appearance of *Ellipsagelosphaera*, *Watznaueria*, *Cyclagelosphaera*, and *Ansulasphaera*, all of which have a crown cycle and R-unit proximal and distal shields. Only *Cyclagelosphaera* survived the K/Pg boundary mass extinction, and it is still extant as *Tergestiella*.

In the Ypresian, *Cyclagelosphaera* gave rise to *Cyclicargolithus* in the Family Noelaerhabdaceae through the complete loss of the V-unit crown cycle. The Ellipsagelosphaeraceae and Noelaerhabdaceae have in common two R-unit shields, an ultrastructure not seen in any other placolith group, which is considered strong evidence of a very close relationship between the two families. The basic ultrastructure of *Cyclicargolithus* has been conserved from the Ypresian through Recent in *Reticulofenestra*, *Dictyococcites*, *Cribrocentrum*, *Crenalithus*, and *Pseudoemiliania*, and in the extant *Gephyrocapsa.*

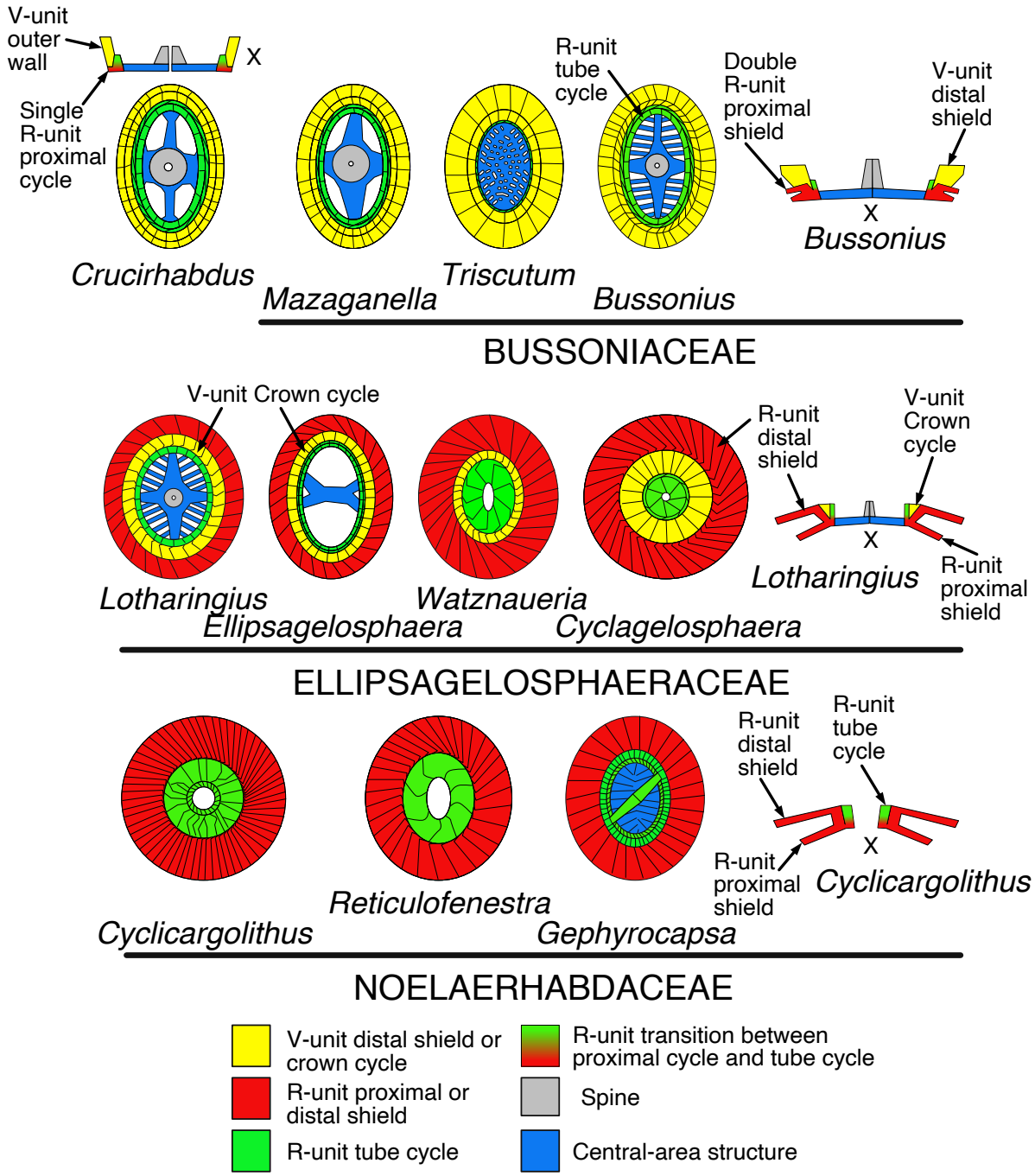

Figure 1. Schematic distal side ultrastructure of the Order Watznaueriales. X = cross section.

Nannofossil abundance and diversity changes – a reaction to changing paleoenvironments in the late Tithonian of the Flemish Pass Basin, offshore Newfoundland

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The Flemish Pass is a Mesozoic extensional basin located 500 km offshore of Newfoundland that contains multiple oil discovery areas operated by Equinor Canada Ltd. Reservoirs are of late Tithonian through early Berriasian age and are represented by a series of incised valleys that consist of fluvio-deltaic sandstones and intervening marine shales. Nannofossil analyses from cores and cuttings have been conducted to supplement sedimentological core observations, interpretations, and uncertainties. Here, we present an integrated sedimentological and nannofossil review from a core that details a unique set of lithofacies and nannofossil variations that demonstrate paleoenvironmental changes and the flooding of a late Tithonian delta system.

Three facies associations are interpreted across the Bay de Verde F-67Z cored interval between 3043 and 3053 m. The basal facies association 1 (FA1) is represented by rhythmic, finely laminated, dark gray organic mudstone, light gray siltstone, red-brown organic mudstone, and calcareous laminae, which lack bioturbation. It is gradationally overlain by facies association 2 (FA2) with variably crypto-bioturbated lithofacies, consisting of black organic mudstone, light gray calcareous to silty mudstone, and very fine-grained sandstone laminae. The youngest sediments are dominated by facies association 3 (FA3), which is predominantly comprised of calcareous mudstone and marl beds that are intensely bioturbated and contain a diverse ichnofabric.

The nannofossil assemblages are characteristic of the North Atlantic Tethyan Province with *Acadialithus valentinei*, *Nannoconus magnadiscus*, and *Polycostella senaria* prevalent. FA1 yields high-abundance, opportunistic nannofossil bloom assemblages that can be attributed to upwelling conditions and are located at the base of the prodelta slope. The calcareous laminae were found to yield prolific coccospheres. Benthic foraminiferal assemblages are absent, but there are isolated radiolarian influxes. FA2 contains increased nannoflora diversity. Anoxic through hypoxic bottom waters are prevalent with continued deposition of black, organic mudstone, but agglutinated foraminifera are present that indicate increased oxygenation in the substrate. FA3 yields highly bioturbated marls, which yield a diverse calcareous benthic foraminiferal assemblage in association with a high abundance and diversity of nannoflora that is typical of a fully oxygenated marine shelf.

Estimating the coccolithophore ratio of particulate inorganic carbon to particulate organic carbon from the geometry of living cells

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Marine biological calcification and photosynthesis can produce particulate inorganic and organic carbon (PIC and POC), which have opposite effects on seawater CO_2. Coccolithophores are marine unicellular algae that both photosynthesize and calcify, and their production of PIC and POC can influence the water column rain ratio as a dominant driver for Earth's carbon cycle. Thus, changes in ancient coccolithophore PIC:POC ratios can be important for paleoceanographic and paleoclimatic studies of carbon cycle modeling. However, ancient coccolithophore PIC:POC ratios are poorly constrained because of the limited occurrences of intact coccospheres in deep ocean sediments. Instead, detached coccoliths, the remnants of fossilized coccolithophores, are commonly found. Here, we carry out the biometric analysis of coccospheres and coccoliths from the living cells of *Emiliania huxleyi* and *Gephyrocapsa oceanica* in the South China Sea and confirm a significant correlation between the PIC:POC ratio and the lateral coccolith aspect ratio (ARL), which is here defined as the ratio of mean coccolith thickness with respect to coccolith length. A linear regression, PIC:POC = 15.023 × ARL - 0.083 (R^2 = 0.59, n = 121), for the reconstruction of ancient Noelaerhabdaceae coccolithophore PIC:POC ratio is based on individual coccoliths in marine sediments. Based on this equation, we can reconstruct ancient Noelaerhabdaceae coccolithophore PIC:POC ratios for the past 14 million years (Ma) using published coccolith data, which reveal a long-term decrease in PIC:POC ratios from 7 to 4 Ma. We suggest that such a change in coccolithophore physiology may be induced by a simultaneous long-term decline in the seawater calcium concentration.

The search for fossil siliceous haptophytes

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Almost twenty years ago, an enigmatic marine nannoplankton, *Hyalolithus neolepis*, was determined to be a haptophyte covered in siliceous scales. Subsequent research provided convincing evidence that another silica-scaled nannoplankton, *Petasaria heterolepis*, was also likely to be a haptophyte. Preliminary studies of the fossil record have recently revealed two species of *Hyalolithus, H. tumescens* (middle Eocene) and *H. didymus* (Late Miocene), and have proposed that two siliceous microfossil genera, *Macrora* (middle Eocene–Late Miocene) and *Clathropyxidella* (middle Eocene), could also be related. Given the large gaps in geological time between the three *Hyalolithus* spp., as well as the overlap between the three *Macrora* spp., we decided to make a sample request using the abundance charts and illustrations in the Deep Sea Drilling Project (DSDP), Ocean Drilling Program (ODP), and Integrated Ocean Drilling Program and International Ocean Discovery Program (collectively known as IODP) literature as a guide. As a consequence, we obtained 167 samples from various geographical regions, ranging from middle Eocene to Late Miocene/Pliocene in age, and prepared them for light microscope and scanning electron microscope examination. Outcrop samples were also reinvestigated, notably from Barbados (Caribbean), California (USA), Marmorito (Italy), Porcuna (Spain), and Israel. Our observations confirmed the presence of three species in middle Eocene samples: (1) *Macrora barbadensis* from DSDP Legs 4 (Venezuela Basin), 21 (Lord Howe Rise), and 95 (New Jersey Transect), and from Barbados; (2) *Macrora najae* from Barbados; and (3) *Clathropyxidella similis* from DSDP Legs 4 and 21 (Venezuela Basin and Lord Howe Rise). Upper Oligocene samples from ODP Leg 119 (Kerguelen Plateau), Lower Miocene samples from Marmorito (Italy), and Upper Miocene samples from Porcuna (Spain) contained *Macrora stella.*

Oligocene to Recent North Atlantic biostratigraphy and calcareous nannofossil assemblages (IODP Expedition 395)

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Low-latitude biozonation schemes of calcareous nannoplankton and planktonic foraminifera are hard to implement in higher latitudes due to the absence of warm-water species in temperate to cold water masses. Continuous records with well-preserved fossils are therefore crucial to build robust biostratigraphic schemes and explore calcareous nannofossil assemblage changes within the Cenozoic. International Ocean Discovery Program (IODP) Expeditions 384, 395C, and 395 drilled six sites in the North Atlantic at a latitude of ~60˚N, recovering sedimentary sequences from the Irminger and Iceland Basins that date back to the early Oligocene. Five Expedition 395 sites (U1554, U1555, U1562, U1563, and U1564) are located on a transect to the east of the North Atlantic mid-ocean ridge, and one site (U1602) is located to the west of the ridge. Integrated calcareous nannofossil, planktonic foraminiferal, and bolboform occurrences allowed for a robust reconstruction of biohorizons that are well correlated across sites.

Calcareous nannofossils are present to abundant in most samples, and their preservation is moderate to good, whereas intervals of very good preservation also occurred, primarily for the Pliocene and Pleistocene. Species that belong to the genera *Reticulofenestra* and *Coccolithus* are the most dominant across all sites and geological time intervals, whereas *Gephyrocapsa* species commonly dominate the Upper Pleistocene assemblages. Higher abundances of species affiliated with warmer waters, such as *Sphenolithus* sp., were observed in samples dated to the Early and Late Miocene, both to the east and west of the Mid-Atlantic Ridge.

Calcareous nannofossils from the Poggio le Guaine core (Umbria-Marche Basin, central Italy): Biostratigraphy and discussion of Aptian–Albian bioevents

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Calcareous nannofossil biostratigraphy of the Aptian–Albian interval has been developed and applied in recent decades. However, the shortage of complete and continuous outcropping marine sections, or even marine subsurface sections, has presented a significant challenge for stratigraphic studies of this interval. Taxonomic ambiguities, diachroneity, and reworking are additional challenges for calcareous nannofossil biostratigraphic studies of this interval. In contrast, the Poggio le Guaine (PLG) section of the Umbria-Marche Basin (central Italy) stands out by presenting a complete pelagic to hemipelagic marine sedimentary succession of the Aptian–Albian interval.

In this study, we (1) provide a detailed calcareous nannofossil biostratigraphy, (2) calibrate the results with previously published work, and (3) discuss some important bioevents of the Aptian–Albian interval that we identified in the PLG core. The following biozones of the calcareous nannofossil reference zonation for the Aptian–Albian interval were recognized: *Chiastozygus litterarius* Zone (NC6), *Rhagodiscus angustus* Zone (NC7), *Prediscosphaera columnata* Zone (NC8* and NC8), *Axopodorhabdus albianus* Zone (NC9), and *Eiffellithus turriseiffelii* Zone (NC10). The PLG core encompasses the chronostratigraphic interval from the Barremian/Aptian through the Albian/Cenomanian boundaries. Finally, we also recognized some important calcareous nannofossil bioevents within this interval: the first occurrence (FO) of *Hayesites irregularis*, FO of *Hayesites albiensis*, last occurrence (LO) of *Conusphaera rothii*, LO of *Micrantholithus hoschulzii*/*Micrantholithus obtusus*, FO of *Rhagodiscus achlyostaurion*, FO of *Prediscosphaera columnata*, FO of *Tranolithus orionatus*, and LO of *Assipetra* spp.

Ceratolithaceae biostratigraphy of ODP Hole 999A, Caribbean Sea

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Ocean Drilling Program (ODP) Hole 999A was drilling during Leg 165 and is located on a promontory nearly 1000 m above the relatively flat Colombian Plain (Caribbean Sea) at 2828 m water depth. A total of 102 smear slides were studied from this hole between 224.58 meters composite depth below seafloor (mcd) and 180.59 mcd. To determine the fine details of the nannofossil structures, 46 samples were prepared for scanning electron microscopy (SEM) using a technique of centrifugation/filtration. The focus of our work is from the lowest occurrence of *Amaurolithus primus* at 211.12 mcd in sample 999B-24X-1, 90 cm, to the highest occurrence of *Ceratolithus atlanticus* at 158.22 mcd in sample 999B-17H-6, 90 cm.

Amaurolithus delicatus, which evolved from *A. primus*, first appears at 209.06 mcd, followed by *Nicklithus amplificus*, which evolved from *Orthorhabdus rugosus* and appears at about 204.02 mcd. At 189.41 mcd, *A. primus* is no longer present, and at 181.93 mcd, *N. amplificus* is also absent. In the latest Messinian, a new ceratolith branch evolved from *O. rugosus*. The first species present is *Ceratolithus finifer* at 165.99 mcd. This sample also contains *A. delicatus*, the only species left from the previous ceratolith branch. Above the first appearance of *C. finifer*, the following species rapidly appear: *C. acutus* (165.56 mcd), *C.*? *atlanticus* (161.76 mcd), *C. larrymayeri* and *C.*? *tricorniculatus* (both at 160.91 mcd), *C. armatus* (160.50 mcd), and *C. cristatus* (159.65 mcd). The highest occurrences of *C. finifer* and *C.*? *atlanticus* are at 158.22 mcd. *Ceratolithus*? *atlanticus* is abundant, and it has a short range between 5.322 and 5.173 Ma (Lancis et al., 2024). *Ceratolithus*? *tricorniculatus* is scarce in the studied samples.

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Ceratolithaceae biostratigraphy of ODP Site 1237, equatorial Pacific

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Site 1237 was drilled during Ocean Drilling Program (ODP) Leg 202 in the equatorial Pacific at a water depth of 3212 m on the easternmost flank of the Nazca Ridge, approximately 140 km off the coast of Peru. Four boreholes were drilled: Holes 1237A, 1237B, 1237C, and 1237D. Forty-two smear slides were studied from Hole 1237B between 179.67 meters composite depth below seafloor (mcd) and 113.53 mcd. To determine the fine details of the nannofossil structures, 63 samples from Holes 1237B, 1237C, and 1237D were prepared for scanning electron microscopy (SEM) using a technique of centrifugation/filtration. The focus of our work is from the lowest occurrence of *Amaurolithus primus* at 149.86 mcd in sample 1237B-15H-6, 75 cm, which evolved from *Orthorhabdus rugosus*, to the highest occurrence of *Amaurolithus delicatus* at 54.49 mcd (sample 1237B-6H-4, 75 cm).

Amaurolithus delicatus, which evolved from *A. primus*, first appears at 143.81 mcd, followed by *Nicklithus amplificus*, which also evolved from *O. rugosus* and first occurs at about 135.22 mcd. At 124.84 mcd, *A. primus* is no longer present, and at 115.04 mcd, *N. amplificus* is also absent. In the latest Messinian, a new ceratolith branch evolved from *O. rugosus*. The first species to evolve is *Ceratolithus finifer*, which we found at 94.01 mcd. This sample also contains *A. delicatus,* the only species left from the previous ceratolith branch. After the appearance of *C. finifer*, the following species rapidly appear: *C. acutus* (90.67 mcd), *C. armatus* (87.71 mcd), *C.*? *tricorniculatus* (86.45 mcd), *C. larrymayeri* (86.34 mcd), *C.*? *atlanticus* (84.96 mcd), and *C. cristatus* (83.54 mcd). The highest occurrences of *C. armatus* (81.12 mcd), *C. acutus* (80.01 mcd), and *C. larrymayeri* and *C.*? *tricorniculatus* (both at 77.30 mcd) are found in close succession, whereas *A. delicatus* is present to 54.49 mcd. *Ceratolithus cristatus* is the only ceratolith present above 54.49 mcd. *Ceratolithus*? *atlanticus* is scarce in studied samples.

Structural developments within the Family Ceratolithaceae

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The horseshoe-shaped nannoliths, which are commonly known as ceratoliths, have unique calcite crystals that may or may not show birefringence, depending on how they settle into a stable position during smear slide preparation. Raffi et al. (1998) pointed out that the horseshoe structure evolved three different times from *Orthorhabdus rugosus*, which usually does not show any birefringence because in its most stable position it has a middle blade oriented straight up. The c-axis is perpendicular to the length of the nannolith and parallel to this median blade, and at both sides there are two blades in about the same plane (Lancis et al., 2022). This rod-shaped and bladed nannolith has two pointed ends. With the sharper end pointing away from the observer and the median blade face up, the blade to the right is the dextral blade and the one to the left the sinistral blade.

The first two horseshoe developments do not show any birefringence because in their most stable layouts the c-axis points upward and basically coincides with the median blade. Both ceratolith horseshoe structures were produced by the sinistral blade becoming the sinistral arm and the median and dextral blade becoming the dextral arm. The *Amaurolithus branch* started with *A. primus*, which then evolved into *A. delicatus*. *Amaurolithus primus* became extinct in the late Messinian, whereas *A. delicatus* continued into the Pliocene. The second branch consists of only one species, the short lived *Nicklithus amplificus*.

From the end of the Messinian to the early Pliocene, a new genus, *Ceratolithus*, evolved from *O. rugosus*. The *Ceratolithus* horseshoe structure is formed by the *O. rugosus* sinistral blade producing the sinistral arm, the dextral arm is formed from the median blade, and the dextral blade becomes reduced to a keel. The genus *Ceratolithus* shows birefringence because the median blade of *O. rugosus* rotated to the right during the evolution of *C. finifer* to be parallel to the most stable layout, thus showing birefringence when observed with cross-polarized light (Lancis et al., 2024). Older specimens of *C. finifer* commonly have low birefringence, whereas younger specimens have high birefringence. The more recent *C. finifer* form evolved into three branches: (1) *C. acutus*, *C. armatus*, *C. cristatus*, and *C. larrymayeri*, (2) *C.*? *atlanticus*, and (3) *C.*? *tricorniculatus*.

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A YOLO model for coccolithophore identification using images from ocean water samples

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Coccolithophores represent one of the major phytoplankton groups and have been extensively studied by scientists. Despite their small size (2–20 µm diameter), the use of polarized light facilitates their microscopic observation, thanks to the birefringent properties of their calcite composition. In 2002, the neural network SYRACO (SYstème de Reconnaissance Automatique de COccolithophores), developed since 1994 by Luc Beaufort and Denis Dollfus, was used to count and identify coccolithophores from different types of samples from deep-sea sediments to ocean water samples. Recent developments in artificial intelligence allow fast segmentation and classification that are fully adapted to oceanic samples. YOLO (« You Only Live Once »), a deep learning algorithm developed since 2016, is a rapid method (several minutes or hours) to train models for the detection of specific objects on images. Besides its precision and versatility, one of YOLO's most prominent features is its ability to instantly detect and identify objects after scanning an image once. It can also be used for image segmentation, and it is frequently updated with version 8 released in January 2023.

In order to train a model, a dataset comprised of artificially generated images was assembled by gathering a large number of segmented images of coccolithophores of various species and shapes. These images were then randomly pasted onto background images. Two training courses were tested: first, a single class model trained with 1950 instances of various species of coccolithophores that were distributed on approximately 150 images, and second, a multi-species model trained to identify 10 classes of coccolithophores, each containing 200 instances. We also created a third dataset by combining 320 images from water samples collected in the Caribbean Sea and eastern Pacific. Several models were generated with varying training parameters (image size, base model size, etc.). Each model was then tested by running a detection on the third dataset to measure and compare their efficiency (precision, recall, and F1-Score), thus allowing an assessment of the best training parameters. The best neural network was then applied to coccolithophores from samples collected in the southern tropical Pacific in a transect going from the Marquesas Islands to Chile during the cruise BIOSOPE in 2005. The results were compared with published SYRACO coccosphere counts and unpublished human counts. The quality of the YOLOv8 model will be evaluated through this comparison.

Nannofossil biostratigraphy in industry; female pioneers in nannopaleontology and a story of life on the rigs

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The applied biostratigraphy community would like to pay tribute to contributions made to the advancement of nannofossil biostratigraphy in an offshore setting by Donata Zucchi, whose life was tragically cut short by her untimely death in 2021.

A large proportion of work on offshore oil and gas installations can be characterized by hard physical labor in occasionally dangerous, dirty conditions and uncomfortable weather conditions from the extremes of the North Sea to the heat, humidity, and hurricane season in the Gulf of Mexico. The offshore industry has been traditionally male dominated and estimates from 2021 indicate that only around 3–5% of offshore workers globally are female. From the late 1970s, when women infrequently began to work at wellsites, to the present day, the majority of female offshore workers have been employed in the catering, cleaning, medical, and administrative divisions. In the North Sea by the mid-1980s, women occasionally began to work offshore in other positions, for example, as biostratigraphy technicians. By the mid-1990s, biostratigrapher, wellsite geologist, mud-logger, and data engineer roles began to be filled by women. Today, positions traditionally filled by men, such as driller, crane operator, and roughneck, are now beginning to be occupied by women.

Biostratigraphy has been used in real-time offshore hydrocarbon exploration for approximately five decades. Initially, microfossil (mainly foraminifera) biostratigraphy was utilized, paving the way for expansion into the use of nannofossil biostratigraphy, which was routinely used in North Sea exploration and the development of Cretaceous and Paleogene chalk oil and gas fields. Today, applied, real-time nannofossil biostratigraphy has global applications and covers the stratigraphic column from the Jurassic to the Recent. The use of biostratigraphy on offshore oil and gas installations is one of the pioneering jobs that introduced women into the offshore world on an equal footing, a world that has changed significantly since the 1970s and 1980s!

Donata Zucchi embraced the changes and challenges of offshore life with enthusiasm, good humor, and intelligence in a career spanning 25 years “in the field”, which often took her to extremely challenging environments, including West Africa, Mexico, and the northernmost extremes of the North Sea. We are extremely grateful to her for her pioneering efforts.

The relationship between the carbonate counter pump and seawater CO_2 in the Middle Miocene

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To understand the relationship between the carbonate counter pump and seawater CO_2 in the Middle Miocene between 15 and 12 Ma, samples from International Ocean Discovery Program (IODP) Site U1505 in the South China Sea were analyzed for calcareous nannofossils and organic geochemistry. These included statistical analysis of the absolute abundance of calcareous nannofossils, morphological parameter measurements of Noelaerhabdaceae, alkenone and glycerol dialkyl glycerol tetraether (GDGT) lipid content, and alkenone stable carbon isotope composition. The conclusions are as follows:

(1) The length, thickness, and mass of Noelaerhabdaceae, *Helicosphaera* spp., and *Coccolithus pelagicus* show relatively similar variation trends. There is a significant correlation between the length and thickness of Noelaerhabdaceae coccoliths. The calcification index calculated by morphological parameters shows that the calcification of coccoliths experienced three peaks starting from 15.2 Ma that reached a maximum value at the end of the Middle Miocene Climate Transition (MMCT).

(2) The stable carbon isotope composition of alkenones in our samples and the calculated fraction value εp of coccolith photosynthesis decreased significantly during the MMCT. These two values are generally greater before the MMCT than after the MMCT, which is the same trend found in benthic foraminiferal oxygen isotopes and global sea level change. The pCO_2 reconstruction using alkenones ranges from 429 to 598 ppm between 15 and 12 Ma. Overall, the pCO_2 values fluctuated but also showed a decrease of about 120 ppm across the MMCT.

(3) The relationship between calcification of coccolithophores and seawater CO_2 was inconsistent before and after the MMCT. Between 15 and 13.9 Ma, coccolith calcification changes correlate with CO_2 values, whereas from 13.9 to 12 Ma, coccolith calcification changes are inversely related to CO_2 values, suggesting that CO_2 is not the main driver of coccolithophore calcification. On the other hand, the mass accumulation rate of coccoliths is an indicator of the strength of the coccolith carbonate pump, and the deposition of coccoliths can affect regional seawater CO_2 values. Calcification and abundance of Noelaerhabdaceae and benthic foraminiferal carbon isotopes change synchronously. Coccolithophore blooms correspond to high values in benthic foraminiferal carbon isotopes, when the marine surface biological pump was weak. This may indicate that there was competition for ecological niches between coccolithophores and diatoms or other algae.

A decreased carbonate pump during the Oligocene–Miocene transition: Regulating the oceanic buffering capacity

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The ocean carbonate pump plays a crucial role in the buffering effect by regulating the ocean total alkalinity (TA) and dissolved inorganic carbon (DIC). Recent studies suggest that through the Cenozoic the TA and DIC inventory remained relatively constant despite significant changes in continental weathering and pCO_2 variations. Nevertheless, this conclusion is under debate because biogenic calcification (e.g., coccoliths) may have controlled the carbonate precipitation more than the seawater saturation state. During the late Oligocene to the Early Miocene, a decline in pCO_2 is thought to be responsible for Antarctic glaciation, possibly through a threshold effect of ~400 ppm, a level we are approaching today. The mechanism(s) that caused this long-term decline in pCO_2 during this period remain(s) an open topic in which fluctuations in the carbonate pump are rarely discussed.

Coccolithophores contribute as much as 90% of the carbonate production and over half of the carbonate sedimentation in the modern ocean. We reconstructed the changes in volume and flux of pelagic carbonate, specifically using Noelaerhabdaceae coccoliths. Our investigation spanned the transition from the Paleogene to the Neogene (~24–20.5 Ma), using marine sediment samples retrieved from International Ocean Discovery Program (IODP) Sites U1501 and U1505 located in the western tropical Pacific Ocean. A circular polarized light microscope was used to measure the thickness/volume of the calcite crystals. Our results show that coccolith thickness or k_s (= volume/length^3) decreased from ~0.09 during the late Oligocene to ~0.06 in the Early Miocene. The k_s value is positively correlated with the bulk sediment carbonate content ($p < 0.01$, $R^2 = 0.5$). We also found that the fine fraction (<10 μm) carbonate stable carbon and oxygen isotopes indicate that there was maximized primary productivity and carbonate dissolution at around 23.5–22.5 Ma. We estimate that coccolith production was ~0.15–0.50 g carbonate/kyr/cm^2, which corresponds to ~15–56% total carbonate flux at the study sites. Scanning electron microscope (SEM) observations revealed that ~5–30% of coccolith carbonate was dissolved during sinking. The concurrent peaks of primary productivity and carbonate dissolution intensity indicate that organic carbon respiration may have enhanced coccolith dissolution. We propose that the decline in the carbonate pump weakened the removal of TA from the ocean's surface to its depths. Consequently, the enhanced buffering capacity of the ocean likely played a role in the drawdown of pCO_2 from the late Oligocene to the Early Miocene.

Evidence of the mid-Valanginian Weissert Event in the Zagros Basin in Iran based on calcareous nannofossils and carbon isotope data

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The mid-Valanginian Weissert Oceanic Anoxic Event is one of the most important paleoceanographic events of the Early Cretaceous that is characterized by a positive excursion in the carbon isotope data, crisis in the nannoplankton association, and climate changes. In this study, calcareous nannofossils and carbon isotope data were investigated from the lower part of the Garau Formation in the Kabir-Kuh anticline, and they confirm the presence of the Weissert Event in the Zagros Basin in western Iran (central Tethys). Two positive excursions in the carbon isotope data (2.8‰ and 2.4‰) were recorded from the middle part of nannofossil Subzone NK3a and the middle part of the Subzone NK3b–NC4a transition that are comparable to placement in other parts of the Tethyan Realm: the Vocontian Basin in France (e.g., Duchamp-Alphonse et al., 2007), the Umbria-Marche Basin in central Italy, and the Subbetic Basin in Spain and SW Morocco, as well as in the Weddell Sea Basin in Antarctica.

In the Zagros Basin, we recorded a simultaneous increase in the relative abundance of warm and eutrophic taxa like *Diazomatolithus lehmanii*, *Rhagodiscus asper*, and *Cyclagelosphaera margerelii*, which might be related to the Paraná-Etendeka volcanism. An increase in the relative abundance of *D. lehmanii* was also recorded from other parts of the Tethyan Realm (e.g., Erba et al., 2004). A low relative abundance of nannoconids (less than 5%) was recorded except for in a few samples. This assemblage was followed by a high relative abundance of *Discorhabdus ignotus* in the early Hauterivian, which indicates cool surface water conditions (e.g., Mattioli et al., 2014). These data are accompanied by a decrease in the carbon isotope data to 0.7‰. The Weissert Oceanic Anoxic Event has now been confirmed in the central Tethys in the Zagros Basin in Iran, which further supports a wide paleoceanographic distribution for this event.

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Evidence of *Discoaster multiradiatus* size variation in the late Paleocene–early Eocene of the Zagros Basin (SW Iran)

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The Paleocene/Eocene boundary is associated with an abrupt global warming known as the Paleocene–Eocene Thermal Maximum (PETM) that occurred at about 55 Ma and coincided with a negative carbon isotope excursion in all ocean basins. At the PETM, there were also changes in calcareous nannofossils assemblages, such as an increase in abundance of the genera *Rhomboaster* and *Discoaster*. In the current study, calcareous nannofossils were investigated at the Gurpi anticline in the Zagros Basin in SW Iran (central Tethys). A morphometric analysis of *Discoaster multiradiatus* indicates a remarkable increase in the size of this species in the upper part of Biozone CNP11/NP9 within the PETM. The top of Zone CNP11 is marked by the disappearance of the *Fasciculithus richardii* group. The extinction of this group is regarded as a marker for the beginning of the PETM at the Paleocene/Eocene boundary in the Atlantic, Pacific, and Tethyan Oceans. In other parts of the world, the PETM has been recorded in the upper part of Biozone CNP11/NP9.

Within the studied interval from Zagros Basin, there was a reversed trend in the relative abundance of *Toweius* spp. and *Coccolithus pelagicus*, followed by a decreasing trend in the relative abundance of these two groups of taxa. An increase and subsequent decrease in the relative abundance of *Fasciculithus* spp. was also identified before their disappearance and extinction in the PETM and post-PETM interval. Warm and oligotrophic conditions were recorded during the PETM of the studied interval where an increase in the size of *D. multiradiatus* was recorded. According to Tremolada et al. (2008), an increase in the size of *D. multiradiatus* correlates with oligotrophic conditions under enhanced stratification rather than nitrification.

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Distribution and diversity of coccolithophore communities living in the tropical and subtropical South Atlantic: Preliminary results from AMT28

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Coccolithophores, a group of unicellular nannophytoplankton chromists belonging to the Division Haptophyta, play a crucial role in oceanic ecosystems and global biogeochemical cycles. These communities are affected by changes in seawater temperature, nutrient availability, and sunlight conditions linked to the meridional variations of the mixed layer dynamics. Here, we present new data on coccolithophore communities living in the tropical and subtropical South Atlantic based on biological and hydrological data collected along a meridional transect (AMT28) of 16 stations extending from the equatorial region to the Tropic of Capricorn (0–30°S). The aim of this study is to gather information on how variations in environmental parameters influence the distribution and diversity of coccolithophores living in this heavily stratified region. This information is critical for understanding how these important primary producers are likely to respond to ongoing and future climate changes, and their associated impacts on the biogeochemical cycles that they influence.

Our preliminary results identified a total of 54 taxa, of which 42 contributed to >5% of the assemblage in at least one of the samples studied. Taxa contributing <5% of all studied samples on average were 1% of the studied coccolithophore community. The identified taxa were subsequently grouped into 19 taxonomic categories (by genus and/or ecological similarity) to facilitate exploration of the data and focus on the most abundant taxa. The region of highest coccolithophore abundance (coccospheres/liter) was the South Atlantic equatorial region (0–8˚S). To the south of the equatorial area, abundances became much lower in the upper photic zone, particularly in the region where the deep chlorophyll maximum (DCM) was deeper along the gyre, despite slightly increasing again around 24–27˚S. The Shannon-Wiener diversity index was higher to the south of the equatorial region but did not show a clear distribution pattern along the transect. Enhanced species diversity was noticed along the entire photic zone in the region where the DCM was deeper along the gyre, and slightly more bound to the DCM to the south (24–25˚S) and to the north (7–12˚S) of the gyre center.

Emiliania huxleyi was more abundant near the surface in the equatorial region (3–7˚S) but clearly bound to the DCM to the south of this area. *Umbellosphaera* spp. were clearly more abundant in the upper photic zone to the south of the equatorial region, whereas *Florisphaera profunda* was most abundant along and below the DCM across the transect, particularly along 2–25°S. Finally, *Oolithotus* spp. were clearly more abundant along the DCM in the northern part of the studied transect (2–12°S). The next step in this ongoing study will be to compare the newly obtained ecological data with environmental parameters measured along the photic zone during the cruise, and with previous coccolithophore studies from the Atlantic Ocean, including the North Atlantic region, which was also sampled during the same AMT28 cruise.

Coccolithophore seasonal export production and fluxes in the Ionian Sea, eastern Mediterranean (June 2004–September 2005)

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Coccolithophores are a major phytoplankton group in the oligotrophic eastern Mediterranean and make a significant contribution to the biogenic sediments on the seafloor. The vertical stratification and seasonal succession of species, as well as the alternation of haplo–diploid phases of their life cycle, allow coccolithophores to exploit different ecological niches year-round. Understanding these patterns and the subsequent mechanisms of settling through the water column is key to unravelling the role of coccolithophore species as paleoceanographic proxies.

Here we present a 15-month (June 2004–September 2005) time series of coccolithophore export production and fluxes from sediment trap samples at 500, 1500, and 3000 m water depths with the aims of linking the seasonal export of species to the seasonal oceanographic and external forcing and tracing the sinking speed and the modifications of the export flux with depth. The peak in total mass and coccolithophore fluxes occurred in early summer. *Emiliania huxleyi* dominated the coccolith and coccosphere fluxes for most of the year and displayed the highest relative abundance in March, whereas the deep-dwelling *Florisphaera profunda* made a higher contribution during late summer and early autumn. Minor species that occur year-round in the flux were represented by *Syracosphaera pulchra*, *Umbellosphaera tenuis*, *Rhabdosphaera clavigera*, *Umbilicosphaera foliosa*, *Helicosphaera carteri*, and *Calcidiscus leptoporus*. Other minor species and the holococcolithophore phases only occurred during the summer peak of flux.

Size and morphological changes in *Coccolithus pelagicus* across the Danian and their link to environmental recovery from the K/Pg mass extinction in the SE Tethys, Israel

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Coccolithus pelagicus has been the object of numerous biometric studies of Recent and Neogene nannoplankton assemblages. However, so far, despite several biometric studies pointing at a significant increase in size of emergent Danian lineages in the early Paleogene, there has not been any studies assessing morphological changes in *C. pelagicus* during its early evolutionary history. To perform this study, 50 specimens per sample of *C. pelagicus* were counted and measured with the image software ImageJ across the first 26 m of the Danian of the Hor Hahar section, Zin Basin, (30˚49'46.96"N, 35˚3'22.40"E, 160 m above sea level). For the first time, we report a distinction between distinctly circular and broadly elliptical lineages. Moreover, our preliminary results suggest that not less than six morphotypes co-existed in the Danian of Hor Hahar with a dominant elliptical morphotype ranging between 5 and 10 µm. We also observed a constant increase in the length and width of the whole lineage through the Danian, as was previously documented in the tropical Atlantic Ocean and which probably indicates the progressive establishment of more stable paleoenvironmental conditions.

Orbitally paced bottom-water acidification episodes linked to the late Maastrichtian warming event: Calcareous nannofossil evidence in the Hor Hahar section, Israel

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The late Maastrichtian was characterized by a pronounced abrupt global warming of 3–4˚C from 66.3 to 66.1 Ma and by episodes of Deccan flood volcanism. A number of previous studies also observed a large increase in fragmentation of planktonic foraminifera, accompanied by a decrease in species richness of calcareous planktonic microfossils, which are related to a “dissolution” event in the late Maastrichtian. These observations have been tentatively linked to a significant lowering of seawater alkalinity in sea surface waters.

Here, we report new results on absolute and relative abundances of late Maastrichtian calcareous nannofossils from the Hor Hahar section in the Zin Basin, Negev Desert (30˚49'46.96"N, 35˚3'22.40"E, 160 m above sea level). A cyclostratigraphic study, which was performed on high-resolution elemental data acquired by X-ray fluorescence, constrains the section to the last ~410 kyr of the Maastrichtian, hence spanning the final Maastrichtian Deccan episodes and the late Maastrichtian warming event. Our high-resolution study of nannofossils, performed on 126 samples, revealed that the most abundant taxa are members of the highly solution-resistant group *Micula* spp., which, in some cases, constitute up to 80% of the whole assemblage. We observed a trend of increasing dissolution and high-frequency oscillations in the relative abundance of “robust” recrystallized specimens of *Micula staurophora*. These oscillations exhibit an out-of-phase relationship to a precession filter output obtained from the Si signal, attesting to an orbital pacing of early diagenetic phenomena, which is only possible if sediment pore waters, and hence bottom waters, were regularly affected by episodes of low alkalinity, possibly at insolation maxima. The timing of the first occurrence of recrystallized *Micula*, and an associated drop in the solution-susceptible species *Biscutum constans*, at 280 kyr before the Cretaceous/Paleogene boundary, nearly coincides with the onset of the Deccan greenhouse warming.

Reconstruction of the ocean surface dynamics of the Iberian margin in the Miocene–Pliocene using calcareous nannofossil assemblages

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The Iberian margin is a unique location on our planet. It has a shallow continental shelf that is delimited by deep submarine canyons. Portugal's continental shelf rapidly transports sediments through rivers to the ocean floor of the Iberian margin where it records continental climate signals and changes in ocean dynamics. Previous studies of marine sediments in the region have shown that sedimentary records, which can be correlated with terrestrial and ice volume global records from Greenland and Antarctica, are related to astronomical (orbital) cyclicity.

Using Miocene–Pliocene sedimentary material recovered from the International Ocean Discovery Program (IODP) Site U1587, located in the southwest of the Iberian margin, calcareous nannofossil assemblages were analyzed to reconstruct changes in surface-water masses and environmental parameters, such as temperature and surface-water productivity. Calcareous nannofossils were used to illustrate the effect of astronomical dynamics on the marine-continental relationship at the Miocene/Pliocene boundary.

The studied sedimentary sequence contains alternations of dark and lighter materials, reflecting a cyclicity linked to the astronomical response. The calcareous nannofossil assemblages also respond to these patterns, as evidenced by the abundance of *Coccolithus pelagicus* (cold water species) with respect to *Discoaster* (warm water taxa). Moreover, the abundance of total nannoliths per gram of sediment is also affected by this trend. In addition, intervals have been identified that contain an increase in the number of *Reticulofenestra* morphotypes with a closed central area. This has been observed in all sizes of Noelaerhabdaceae: smallest sizes (<5 μm), medium sizes (between 5 and 7 μm), and larger sizes (>7 μm). This observation could be related to high calcification intervals in the surface water of the ocean. In this succession, darker colored sediment intervals are consistent with a scenario of maximum insolation: wet intervals with increased continental rainfall and a resulting increased supply of detrital material being deposited in the basin. Lighter colored sediment levels are consistent with a scenario of minimum insolation: less rainfall, higher planktonic production, and more continental aridity. However, other global or regional processes, particularly some related to dynamics of the subtropical gyre, could interfere and modify the pattern.

Revised calcareous nannofossil biostratigraphy and chemostratigraphy for the late Turonian–early Campanian at Seaford Head (southern England)

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The Seaford Head section is exposed along the sea cliffs on the south coast of England between Brighton and Eastbourne in the county of Sussex (50.7644˚N, 0.1087˚E; 50.7561˚N, 0.1388˚E). The succession comprises upper Turonian–lower Campanian white nannofossil chalk with a large number of named marls, flint layers, and fossil-rich beds, which provide excellent marker beds that can be traced through the Anglo-Paris Basin. The available stratigraphic framework consists of lithostratigraphy, chemostratigraphy, and biostratigraphy that is based on macrofossils, microcrinoids, and microfossils (calcareous nannofossils and benthic foraminifera).

This study aims to revise the calcareous nannofossil biostratigraphy of the late Turonian–early Campanian interval and calibrate it to a new high-resolution carbonate $\delta^{13}C$ record that spans the upper Turonian–middle Santonian of the Seaford Head section. A total of 68 samples (1 sample/2 m) were analyzed for calcareous nannofossil content, and 712 samples (1 sample/10 cm) were measured for stable carbon isotopes. Changes in calcareous nannofossil assemblages were evaluated both in terms of semiquantitative and quantitative data with at least 300 specimens counted in each slide. Four different types of biohorizons were coded as follows: Base (B), Top (T), Base common (Bc), and Top common (Tc) occurrences.

We applied the available calcareous nannofossil biozonations for the Late Cretaceous (CC zones, the integrated NC* zones, UC zones, and the Boreal UCi subzones). The calcareous nannofossil biostratigraphy was then integrated with the new stable carbon isotope chemostratigraphy. Absolute abundance patterns of marker taxa allow for a more accurate overview of the biohorizons and the definition of a revised, high-resolution calcareous nannofossil biostratigraphic framework for the Seaford Head section. This approach proves to be particularly useful in chalk sea deposits where processes of reworking and redeposition of sediments commonly occur.

Drivers of Neogene coccolithophore macroevolution

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This study aims to investigate the driving mechanisms of macroevolutionary changes in Neogene nannofossil communities. We provide a global perspective into the macroevolutionary drivers that have influenced coccolithophore communities over the last 15 million years during Neogene cooling. Two datasets are analyzed: (1) a low-resolution (~2.5 Myr sample spacing) global comparison of nine sites spanning the Atlantic, Indian, Pacific, and Southern Ocean basins and (2) a high-resolution (200 kyr sample spacing) dataset from International Ocean Discovery Program (IODP) Expedition 363, Site U1482 (7.7–1.7 Ma) that document the critical Late Miocene to Early Pleistocene interval. These high-resolution data are from a representative tropical, high-diversity succession with apparent continuous recovery through this key interval. The Family Noelaerhabdaceae were greatly impacted by declining pCO_2 with an overall decrease in *Reticulofenestra* coccolith size beginning in the Late Miocene. In contrast, *Gephyrocapsa* spp. increased in abundance concurrently, signifying that multiple controlling factors were influencing nannoplankton communities by the end of the Miocene. New evidence demonstrates that the role of a deepened nutricline prompted macroevolution of coccolithophores and was a greater forcing influence than pCO_2 alone. The following adaptive changes within communities were recognized: the decline of *Reticulofenestra* coccolith size, the extinction of *Discoaster* spp. in the Early Pleistocene, and the increased abundance of *Florisphaera profunda*, a deep-photic zone taxon.

Spatio-temporal variability of alkenone and calcareous nannofossil abundance records across the southeastern Philippines: Insights on alkenone production and paleoceanographic reconstructions

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Southeastern Philippines is located near the center of the Western Pacific Warm Pool (WPWP), a large, oceanic warm-water mass located in the tropical western Pacific with a characteristic mean sea surface temperature of >28˚C. Several water masses meet in this area as part of the global thermohaline circulation that distributes mass and heat throughout the world. Study of the oceanographic variability in this area has aided understanding of the role that the tropics play in heat and mass transfer and subsequent climate change. Recent studies have proposed the use of coastal basin areas with high sedimentation rates as potential sites of high-resolution records that can be used to reconstruct centennial, decadal, and interannual scales of climate variability over the recent past.

Alkenones are long-chain organic compounds produced by haptophytes in the Order Isochrysidales that are primarily produced in the marine realm by the coccolithophorid species *Emiliania huxleyi* and *Gephyrocapsa oceanica*. The degree of unsaturation of these compounds, based on the ratio of di- and tri-unsaturated alkenone compounds as expressed by the alkenone unsaturation index ($U^{K'}_{37}$), provides a correlation to mean annual sea surface temperature, whereas alkenone concentrations have been considered to correlate with surface productivity. There is a large potential for correlating alkenone concentration with calcareous nannofossil abundance proxy records to provide a broader, multiproxy approach in reconstructing past oceanographic conditions, particularly in sites of high sedimentation rates.

Here, we present downcore results from three multicore sites across the southeastern Philippines (eastern Mindanao and the Davao Gulf) that were used to explore the potential of determining sea surface temperature and productivity reconstructions during the Holocene using alkenone and calcareous nannofossil abundance proxy records. Preliminary results show that *Florisphaera profunda* dominates the assemblage, followed by *Gephyrocapsa oceanica* and *Emiliania huxleyi*. Coccolith abundance, species diversity, and net primary productivity indices decrease across all sites, coinciding with an alkenone-derived decrease in sea surface temperature. In terms of alkenone production and dominant haptophyte assemblages, there is a higher positive correlation between *G. oceanica* abundances and $U^{K'}_{37}$ values than *E. huxleyi*. Due to constraints with age dating results, we can only provide age-dated variability for one site, which faces the Philippine Sea. The overall variation shows a slight warming trend over the last 2000 years, accompanied by a decreasing trend of net surface primary productivity.

Leveling the gap between different counting techniques in coccolithophore cultures

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Monospecific cultures of coccolithophores are fundamental to exploring species-specific response to various controlling parameters (temperature, pH, CO_2, etc.). Acquiring the most accurate values for cell counting is fundamental to correctly quantifying the maximum cellular density and growth rate, which are pivotal for studying the culture response, especially when it comes to comparing the results among different laboratories. We tested two of the most commonly used cell counting methods to identify which approach has the highest accuracy and speed for evaluating a culture's cellular density (cells/mL): Sedgewick Rafter chamber or Bürker counting chamber. Moreover, because manual cell counts are time consuming, we compared them with the culture absorbance (i.e., optical density [OD]) measured with a spectrophotometer, a poorly used method for coccolithophores but extremely useful for high density cultures and to speed up the counting process. These methodologies were tested on three different species of coccolithophores: *Helicosphaera carteri*, *Chrysotila carterae*, and *Emiliania huxleyi* (from Roscoff Culture Collection) that cover a wide range in cellular densities and cell sizes, from lower cell density (~3×10^5 cells/mL) and larger size (20 µm) for *H. carteri* to higher cellular density (>5×10^6 cells/mL) and smaller size (5 µm) for *E. huxleyi*.

The preliminary data document that the Sedgewick Rafter chamber can be confidently used from very low cellular densities (e.g., 500 cells/mL) to higher counts (~3×10^5 cells/mL), maintaining a low standard deviation among the replicates. Above this upper limit, culture dilution is necessary when using the Sedgewick Rafter chamber to avoid increasing errors from the human operator. Dilution at higher cellular densities can be avoided using the Bürker chamber, which also returns good results with low standard deviations for cellular densities above 10^6 cells/mL and for small-sized species. Indeed, small-sized species, such as *E. huxleyi*, can make the manual counting more difficult with the Sedgewick Rafter chamber, which has fewer guide grids compared to the Bürker chamber. All the above-mentioned counts can be linearly correlated with OD measurements at a specific wavelength (750 nm) according to the Lambert-Beer law within the validity range of 0.1–1. Both manual counting methods provided good coefficients of determination (>0.9 when correlated with the OD), indicating that the number of cells is well described by OD in the selected range.

Our data show that the Sedgewick Rafter chamber is an effective method for physiological studies, where lower cellular densities are commonly used. On the other hand, the Bürker chamber is more suitable for higher cellular densities required for biotechnological studies. Finally, although the OD is not commonly used for monitoring coccolithophore growth, we recommend the use of OD measurements to speed up data collection, particularly for high cell density studies that focus on coccolithophore productivity for practical applications.

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Coccolith dynamic distribution in the western tropical Atlantic during the last 300,000 years: Toward a better understanding of oceanic current dynamics

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In tropical regions, trade winds related to the Intertropical Convergence Zone (ITCZ) shape ocean surface circulation with a significant impact on latitudinal heat transport. This is particularly the case in the western tropical Atlantic (WTA) that is characterized by several surface currents: the South Equatorial Current, the Brazil Current, and the North Brazil Current, which contribute to a unique northward, cross-equatorial transport of heat and salt. The dynamics of these currents in the geologic past remains unclear, preventing us from having a clear overview of how they may have affected cross-equatorial flow and the associated heat transport.

In this study based on coccolith assemblage analyses of marine sediment core GL-1180 retrieved in the WTA (8°27'18"S, 33°32'53"W, 1037 m water depth), we explore productivity patterns over the past 300,000 years to track variations in the expansion of the nutrient-rich South Atlantic Central Water (SACW) at orbital scales and try to understand how it may impact the Brazil Current system. In addition, based on total coccolith abundance (TCA) and proportions of lower photic zone (LPZ) species, such as *Florisphaera profunda* and *Gladiolithus flabellatus*, together with subsurface temperature data, we aim to trace nutricline dynamics and interpret them in terms of stratification versus mixing of the upper to intermediate water column.

Preliminary results show that ~90% of the coccolith assemblages were represented by *F. profunda*, *Gephyrocapsa* spp., *Emiliania huxleyi*, and *G. flabellatus*. Subtropical species, such as *Umbellosphaera* spp., *Syracosphaera* spp., *Discosphaera tubifera*, and *Umbilicosphaera* spp., were also observed, but altogether, they did not exceed 15% of the assemblage. The coccoliths had moderate to excellent preservation. The LPZ species *F. profunda* and *G. flabellatus* dominated the assemblages when precession was low, suggesting a relatively deep nutricline, stratified waters, and probable oligotrophic conditions in the upper photic zone. *Gephyrocapsa* spp. only dominated during the high precession periods of Marine Isotope Stages 8 and 9, which might indicate a shallower nutricline and higher paleoproductivity when meso-eutrophic conditions prevailed. Higher *Gephyrocapsa* spp. abundances were concomitant with higher TCA and lower subsurface temperatures, whereas higher LPZ species abundances were associated with lower TCA and higher subsurface temperatures. It is probable that heat accumulated in the study area during low precession periods, which are associated with a weakening of the North Brazil Current and a southward migration of the ITCZ prevented any influence of the SACW and, hence, hampered nutrient input into the photic zone. In contrast, we likely observed an influence of intermediate SACW for periods of high precession.

Coccolithophore assemblage dynamics and *Emiliania huxleyi* morphological patterns during the years 2017–2019 in the Aegean Sea (Greece, NE Mediterranean)

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This study describes the species composition of living coccolithophore communities and the morphological features of *Emiliania huxleyi* from samples collected during expeditions in March 2017, March 2019, and August 2019 in the Aegean Sea. We investigated spatial and temporal variations using samples collected across six sampling stations to monitor the coccolithophore assemblages after the exceptionally cold December 2016, which resulted in winter heat loss and newly produced dense waters that ventilated the Aegean deep basins (Velaoras et al., 2017). Coccolithophores in the area were relatively diverse, and a total of 51 species were identified using the scanning electron microscope (SEM). The recorded total cell density in the 2017 winter sampling (maximum 17.8×10^3 cells/L in mid- to lower water depths) was much lower than the 2019 cold sampling period (up to 27.7×10^3 cells/L documented at 20 m depth). A notable corroded/malformed morphology of many specimens was observed in the studied samples for winter 2017, especially in the deeper parts of the water column. The assemblages displayed distinct seasonality as already documented for the Aegean Sea domain (Dimiza et al., 2015; Karatsolis et al., 2017) with winter periods characterized by the dominance of *Emiliania huxleyi* and *Syracosphaera molischii*. In contrast, the warm period exhibited higher species richness and diversity (maximum of 25 taxa observed at the surface layers) and low dominance indices when compared to the colder season. Summer assemblages featured high absolute abundances of *Rhabdosphaera clavigera*, *Syracosphaera halldalii*, *Umbellosphaera tenuis*, *Algirosphaera robusta*, and various holococcolithophores that were dominated mainly by *Syracosphaera arethusae* HOL, *Calyptrosphaera heimdaliae*, and *Helladosphaera cornifera*, which are found primarily in the upper photic zone. In addition, morphometric analyses conducted on well-developed *E. huxleyi* coccoliths showed the characteristic dominance of heavily calcified coccoliths during the cold season in the Aegean Sea (Triantaphyllou et al., 2018) with a slight decrease in the average coccolith length and coccolith width observed between the winter 2017 and winter 2019 sampling periods. This difference is more pronounced in the average tube width and relative tube width, probably suggesting increased calcification rates occurring in the Aegean Sea water column after the exceptional cold event of December 2016.

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Insights into the last glacial–interglacial shift: Microfossils and geochemical evidence from the Argentine continental margin

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The Argentine Continental Margin (ACM), located in the southwestern Atlantic Ocean, is one of the widest continental shelves in the world and is the only place in the Southern Ocean were water masses of south polar and equatorial origin interact. Its micropaleontological and geochemical record is key to understanding the oceanographic and climatic changes that occurred in the recent past. In this contribution, we present preliminary results on the calcareous nannofossils, foraminifera, and geochemical (total organic carbon [TOC], X-ray fluorescence [XRF], and stable isotopes) records from one gravity core retrieved in the ACM at the Piedra Buena Terrace (AU_GEO02_GC30: 57.967˚S, 44.5202˚W; 2756 m water depth). This core is 678.8 cm long and based on calcareous nannofossil assemblages, which are dominated by *Emiliania huxleyi*, is restricted to Subzone NN21b (Rivas, 2023). Absolute dating (^{14}C), measured on bulk sediment and planktonic foraminifera, indicates a Late Pleistocene to Holocene age. The core can be divided into six alternating barren and fertile intervals based on calcareous microfossils (nannofossils and foraminifera) that correlate with variations in TOC, $\delta^{13}C_{org}$, Mo, S, Al_2O_3, SiO_2, CaO, Sr, P, Ba, and C:N values. These intervals are interpreted to represent advances and retreats of the Polar Front during Marine Isotope Stages (MIS) 1 to 6. According to productivity (P, Ba) and redox (Mo, S) sensitive elements and TOC values, primary productivity was slightly enhanced during cold stages, showing a switch to a diatom-dominated phytoplankton community. The core AU_GEO02_GC30 represents one of the most complete records for the last glacial–interglacial transition in the ACM and offers an opportunity to study its impact on oceanography and the response of the phytoplankton community.

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Temperature-dependent calcareous nannofossil export productivity during early Paleogene hyperthermals

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Oceanic carbonate burial is the main carbon sink on a geological timescale. Deep-sea records of early Paleogene hyperthermals, which are abrupt greenhouse warming events associated with rhythmic massive releases of carbon into the ocean–atmosphere system, show drastic changes in calcite burial. Such lithologic perturbations have largely been attributed to chemically induced modulation of deep seafloor calcite preservation.

Here, we use microfossil (nannofossil abundances and planktonic foraminiferal fragmentation) and geochemical evidence (extraterrestrial ^{3}He) to reconstruct calcareous nannofossil fluxes across ~10 hyperthermals (~57.5–53.5 million years ago) for a North Pacific deep-sea site located above the lysocline. We also calculated the nannofossil fluxes during the Paleocene–Eocene Thermal Maximum (PETM) at South Atlantic and Southern Ocean sites, using previously published ^{3}He data, to obtain a global picture of the biotic response of planktonic calcifiers in the open ocean. Overall, we found a partial decoupling between seafloor saturation and calcareous nannofossil export production. Repeated 40–99% decreases in nannofossil burial across hyperthermals were primarily driven by warming-induced lowering of nannoplankton-derived calcite export productivity, and secondarily by changing bottom water chemistry. Our results emphasize that shallow-water (<1000 m) ecosystems and metabolic processes are overlooked as chief mechanisms for regulating carbon cycle feedbacks on a geological timescale.

Middle to Late Miocene calcareous nannofossil biostratigraphy and paleoecology at Broken Ridge, eastern Indian Ocean (ODP Site 752)

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The Middle to Late Miocene represents an important time interval in the Indian Ocean due to the reorganization of land masses and the occurrence of important climatic events, such as the establishment of a near-modern monsoonal wind system, the Middle Miocene Climatic Transition, and the subsequent northward shift of the westerlies during the Late Miocene. However, the effect of these forcing mechanisms on intermediate and surface ocean dynamics in the southern subtropical Indian Ocean remains poorly understood. Ocean Drilling Program (ODP) Site 752, located on the western flank of Broken Ridge (30˚53.475'S, 93˚34.652'E), represents a key location for understanding how oceanic currents may have been affected by the above-mentioned mechanisms in the eastern sector of the Indian Ocean during the studied Miocene interval.

During ODP Leg 121, an initial biostratigraphic framework for Site 752 was established. However, the limited biostratigraphic data, due to poor preservation of sediment material for the Middle to Upper Miocene, resulted in a low-resolution shipboard age-depth model. We present here a newly updated high-resolution biostratigraphic age-depth model based on fully quantitative nannofossil assemblage analyses and planktonic foraminiferal bioevents for the time interval between ~15 and ~8 Ma for Hole 752A. The biostratigraphic age-depth model was compared with a recently published astrochronologically tuned age-depth model (Lyu et al., 2023) for further validation. A high consistency between models was observed for the whole record, except for the interval between ~13 and 12 Ma, where the age difference is high. We link these discrepancies to the potential variance in age of the recorded bioevents for this interval between basins, as well as the error associated with the mathematical approach of the tuned age model.

Based on our quantitative nannofossil data, we further evaluated overall changes in the nannofossil assemblages at ODP Site 752. Unpaired pair group method with arithmetic mean (UPGMA) clustering analyses resulted in five major clusters. Cluster 1 is characterized by a high abundance of *Reticulofenestra minuta* (average = 49.25%) and low abundances of medium (>3 µm) and large (>5 µm) reticulofenestrids. Cluster 2 is defined by a high abundance of *Calcidiscus leptoporus* and a higher abundance of *Umbilicosphaera jafari* when compared with the other clusters (average values of 18.34% and 1.42%, respectively). Cluster 3 is characterized by a high abundance of medium-sized (3–5 µm) reticulofenestrids, whereas Cluster 4 is characterized by a high abundance of *Coccolithus pelagicus* and *Discoaster* spp. (average of 22.56% and 7.38%, respectively). Cluster 5 is defined by a high abundance of *Reticulofenestra producta* (24.61%) and large reticulofenestrids (>5 µm) such as *Reticulofenestra pseudoumbilicus*.

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Improving Arctic Quaternary geochronology and paleoceanographic reconstructions using calcareous nannofossils

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The challenges of dating Quaternary Arctic Ocean sediments continue to obscure paleoceanographic insights into the history of sea ice and the configuration and dynamics of past ice sheets. A key historical problem is that different geochronological tools provide widely different age estimates for the same sedimentary sequences. Calcareous nannofossils still provide the most robust biostratigraphic age markers for Quaternary Arctic Ocean sediments. However, Arctic sediments are dominated by fine-grained terrigenous material, and they commonly contain rare and poorly preserved coccolith specimens that can be difficult to identify under the light microscope (LM). By developing and applying a paired LM and scanning electron microscope (SEM) technique for observing the same nannofossil specimens (Razmjooei & O'Regan, 2024, preprint), we recently illustrated how poorly preserved nannofossils, which cannot easily be identified at the species level, were previously classified as *Gephyrocapsa huxleyi* using LM observations alone. Moreover, the visual resemblance between *G. huxleyi* and another Quaternary marker species, *Pseudoemiliania lacunosa*, had led to occasional misdiagnoses (Razmjooei et al., 2023). Proposed revisions to the placement of *G. huxleyi* and *P. lacunosa* in the stratigraphic framework of central Arctic sediment cores can resolve some of the disparity between different dating techniques and indicate a different chronostratigraphic framework than has been used for nearly two decades of paleoceanographic research. Two key questions that remain include: (1) when did *G. huxleyi* first enter the Arctic Ocean, and (2) where did it first appear in the lithostratigraphic framework of central Arctic sediments? Despite its relatively recent emergence (290 ka, Raffi et al., 2006), *G. huxleyi* exhibits significant morphological diversity. Recent research suggests that there were three episodes of evolutionary diversification within this species: before Marine Isotope Stage (MIS) 5, during MIS 5, and during MIS 1 (Bendif et al., 2023). Our LM-SEM imaging technique reveals two distinct morphotypes in central Arctic sediments. The first is exclusive to Holocene sediments, whereas the second appears in both Holocene and older intervals within the Arctic. The occurrence of these different morphotypes in Arctic Ocean sediments may provide additional important biostratigraphic age control. Testing this requires SEM-based analysis of the crystalline structures that form coccoliths in both central Arctic sediments with uncertain age control and better dated records from the Arctic–Atlantic gateway.

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Study of the paleoclimatic transition from Greenhouse to Icehouse conditions by means of calcareous nannofossils in the Southern, Atlantic, Pacific, and Indian Oceans

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The Eocene–Oligocene transition (EOT) occurred at approximately 34 Ma, lasted approximately 790 kyr, and includes the Eocene/Oligocene boundary (EOB). It marks the transition from a world without permanent ice sheets (Greenhouse conditions) to one with an Antarctic Ice Sheet (Icehouse conditions) (Hutchinson et al., 2021). The EOT was also a time of major extinctions and ecological reorganization in several biotic groups (Saraswati, 2021) that was probably due to several factors. This critical time interval is highlighted by multiple proxies and their correlations (Villa et al., 2014). The response of calcareous phytoplankton to global changes across the EOB is less well understood than other critical intervals such as the Paleocene/Eocene boundary (Dunkley Jones et al., 2008).

We undertook a high-resolution (5–10 cm), quantitative to qualitative analysis to improve the biostratigraphy of this interval and carried out a detailed paleoecological interpretation. In this study, 10 sites at low, medium, and high latitudes were considered with emphasis on understanding paleolatitude and paleobathymetry. Specifically, the objectives of this research work are to (1) reconstruct paleoclimatic and paleoceanographic conditions, (2) improve the framework of the changes that have occurred at different latitudes, (3) improve the knowledge of the effects recorded by calcareous nannofossils, and (4) improve paleoclimatic and paleoceanographic documentation by highlighting species distribution models.

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Evolution of coccolithophore communities in the Atlantic Iberian margin during the Common Era

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The Iberian margin, a climate-sensitive region that is susceptible to global warming effects and alterations in water supply, experiences seasonal wind-driven upwelling and belongs to the productive Canary Current Upwelling System. These systems hold significant importance for climate regulation and fishing but may face varying regional impacts due to climate change as predicted by the Intergovernmental Panel on Climate Change (IPCC). Efforts have been made to comprehend the variability of climate and marine ecosystem response to environmental changes in the Iberian margin during Late Pleistocene, specifically using microfossil assemblages that are preserved within the sediments. However, uncertainties persist regarding the potential influence of ongoing warming on primary production along the Portuguese continental margin.

To shed light on this issue and enhance predictions of future responses to environmental change, we reconstructed the variability in primary production over the past millennium through a detailed analysis of nannofossil assemblages that are preserved across different settings on the Portuguese continental shelf. Another objective was to distinguish between increased primary production caused by upwelling or river-derived nutrients. To create the coccolithophore time series, we employed sediment cores from offshore the Douro and Tagus Rivers and off Faro in the Algarve (Portugal). Preliminary findings reveal relatively similar coccolith assemblages at the Douro and Tagus sites that are predominantly composed of *Emiliania huxleyi*, *Gephyrocapsa muellerae*, *Gephyrocapsa oceanica*, and small *Gephyrocapsa* spp. The Faro site, outside of the upwelling influence, displayed a warmer assemblage with a greater number of reworked coccoliths. Moreover, our data unveiled significant fluctuations in abundance and composition of coccolith assemblages that can be linked to environmental changes at the study sites over time. The reconstruction of the response of key phytoplankton assemblages that are documented herein is anticipated to enhance projections of the eastern boundary upwelling system's response to environmental variability for upcoming decades.

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

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The Southern Ocean plays a vital role in global thermohaline circulation and serves as a significant sink for anthropogenic CO_2. However, the physical and chemical properties of its surface waters are undergoing rapid and unrelenting transformation. The rate of warming in Southern Ocean waters surpasses that of the overall ocean, and increased CO_2 absorption leads to reduced pH levels and decreased carbonate ion concentration, a phenomenon known as ocean acidification. This significant change in marine water characteristics poses a serious threat to general marine ecosystems and particularly to calcifying marine organisms.

Coccolithophores are the most abundant group of marine calcifying phytoplankton, and they are substantial contributors to pelagic production of particulate organic and inorganic carbon. Satellite observations suggest that extensive coccolithophore blooms develop in the Subantarctic circumpolar zone during the austral summer. Therefore, alterations in coccolithophore composition and calcification may have crucial implications for Southern Ocean marine ecosystems and ocean chemistry, ultimately affecting climate change. In this study, we compared the morphometric features of the coccoliths produced by *Calcidiscus leptoporus* across different time scales. Specifically, we analyzed coccolith occurrences that spanned the Holocene Epoch during an annual cycle by making sediment trap collections of underlying sediments and obtaining a sediment core. Our findings indicate that the variability of some morphological parameters of *C. leptoporus* coccoliths has a significant correlation with changes in carbonate chemistry. Extrapolation of our observations suggests that a future reduction in cell and coccolith size will have a negative impact on the efficiency of the biological pump in the Southern Ocean through a reduction of carbonate ballasting.

Pleistocene–Holocene calcareous nannofossils and foraminifera from the Argentine Continental Margin, southwest Atlantic Ocean

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As part of the "Pampa Azul Initiative", a national program aimed at promoting ocean science research in Argentina, several sediment cores were obtained during the YTEC-GTGM 5 cruise in 2022 aboard the R/V *Austral.* Calcareous nannofossils and foraminiferal assemblages were analyzed in 14 samples recovered from two gravity cores taken on the slope of the Argentine Continental Margin. Both cores contain abundant foraminifera and calcareous nannofossils but also show evident signs of reworking. In the gravity core AU_GEO05_GCA (478 cm; water depth 1865 m), calcareous nannofossil assemblages are characterized by the dominance and high abundance of *Emiliania huxleyi*, followed by *Gephyrocapsa muellerae*, *Gephyrocapsa oceanica*, and *Gephyrocapsa* spp. small. Foraminiferal assemblages are composed of planktonic species that include *Globoconella inflata* (d´Orbigny, 1839), *Globigerina bulloides* (d´Orbigny, 1826), *Globorotalia truncatulinoides* (d´Orbigny, 1839), and *Globorotalia hirsuta* (d´Orbigny, 1839). They are accompanied by, in a much lower abundance, benthic foraminiferal species that include *Cibicidoides* spp. (Thalmann, 1939), *Lobatula wuellerstorfi* (Schwager, 1866), and *Pullenia bulloides* (d'Orbigny, 1846). Towards the base of the core, a decrease in nannofossil and benthic foraminiferal abundances was recorded, together with an increase in reworked calcareous nannofossils (*Reticulofenestra* spp.), radiolarians, and silicoflagellates. According to the dominance of *Emiliania huxleyi* in all samples, we interpreted a Late Pleistocene–Holocene age (Subzone NN21b).

Gravity core AU_GEO05_GCB (631 cm; water depth 2375 m) was divided into two sections based on the microfossil assemblages. The lower section (570–275 cm) contains a nannofossil assemblage dominated by *G. muellerae* and *G. oceanica*. The most abundant foraminiferal taxa are *G. inflata* and *G. bulloides*. In the overlying section (187–8 cm), the nannofossil assemblage is composed of *E. huxleyi* with *Gephyrocapsa* spp. as accompanying taxa. With regard to foraminifera, *G. inflata* and *G. bulloides* have the highest abundances, but an increase in *Neogloboquadrina pachyderma* (Ehrenberg, 1861) and *Neogloboquadrina incompta* (Cifelli, 1961) was observed. Although reworked specimens were recognized in all samples, at 275 cm, the highest abundance of *Reticulofenestra* sp. specimens was recovered. Calcareous nannofossil assemblages allowed us to assign a Middle Pleistocene age (Zone NN20) to the lower section, and a Late Pleistocene–Holocene age (Subzone NN21b) to the upper section. Although the cores were collected from near each other at similar depths and having similar thicknesses, it is interesting to highlight the differences in the ages of their lower sections.

Calcareous nannofossils from the Paleocene–Eocene Thermal Maximum, IODP Site U1557, South Atlantic Ocean

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Calcareous nannoplankton are the most abundant calcifying organisms in the modern ocean. They are widespread and evolve rapidly, making them ideal for assessing biotic changes during periods of transient climate change. The Paleocene–Eocene Thermal Maximum (PETM, ~56 Ma) was an abrupt and dramatic global warming event that resulted from huge amounts of isotopically light carbon being released into the atmosphere, and which had profound effects on the biosphere. The PETM is also considered to be a partial analog to modern rates of greenhouse gas emissions. Here, we utilize material from a newly recovered PETM section from International Ocean Discovery Program (IODP) Site U1557, the first such record from the western South Atlantic. Initially identified by a distinct layer of reddish-brown clay with a significant increase in magnetic susceptibility, species of *Rhomboaster* that are restricted to the PETM interval have also been identified.

Across the PETM interval at Site U1557, sedimentation rates are extremely high (11.53 cm/kyr; normal pelagic sedimentation rates are generally <1 cm/ky), and total organic carbon values are also unusually high, indicating high overall surface water productivity at that time. Nannofossil analyses show a relatively well-preserved and diverse assemblage with the presence of the PETM-specific taxa *Rhomboaster calcitrapa* and *Rhomboaster cuspis*, although forms of the *Discoaster araneus* group are noticeably absent. Instead, we record slightly deformed specimens of the *Discoaster multiradiatus* group across this interval. This new record from the western South Atlantic will be compared with other South Atlantic records from Walvis Ridge, Maud Rise, and Agulhas Plateau to improve our understanding of surface water conditions and the relationship between plankton and climate during a period of extreme environmental stress where few records exist.

Evaluating Oligocene calcareous nannoplankton diversity and community dynamics

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The Oligocene (33.9–23.03 Ma) remains a relatively understudied interval, yet it is bookmarked by two large glaciations signifying the development of a continental-sized ice sheet on Antarctica (Eocene/Oligocene boundary at 33.9 Ma) and the expansion of the ice sheet (Oligocene/Miocene boundary at 23.03 Ma). The lack of high-resolution, long-term records has hampered efforts to document the structure of biotic change through the Oligocene, a time of significant ocean and climate reorganization as the Earth system switched from the warm climates of the Paleogene to the cooler world of the Oligocene and initiation of glacial–interglacial cycles.

Here we present long-term, high-resolution community records of nannoplankton assemblages from the early Oligocene to Early Miocene (31.89–21.77 Ma) obtained from Integrated Ocean Drilling Program (IODP) Sites U1406 and U1411 in the northwest Atlantic Ocean. We document the evolutionary history and community dynamics of calcareous nannoplankton throughout this time to investigate the drivers behind the decline in diversity following the Eocene peak and to analyze population restructuring associated with the emergence of key extant coccolithophore groups that constitute the foundation of modern phytoplankton communities. Generating these long-term records is crucial for understanding the background-level dynamics, and they are essential for accurately gauging the scale and impact of transient climatic events (i.e., Eocene/Oligocene and Oligocene/Miocene boundaries).

Application of nannofossils (the missing piece of the puzzle) from offshore Newfoundland: Upgrading the regional stratigraphy via an integrated multidisciplinary approach

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The Atlantic margin of Canada has a long, >50-year history of oil and gas exploration that is comparable with the North Sea. The province of Newfoundland and Labrador, whose continental shelf covers more area than the North Sea, has had 529 wells drilled, five that have produced oilfields in the offshore Jeanne d'Arc Basin (Hibernia, Terra Nova, White Rose, North Amethyst, and Hebron). There also have been major discoveries further offshore in the deep-water Flemish Pass Basin that have not yet been developed (e.g., Bay du Nord). In Newfoundland, oil and gas production became a mainstay economic activity during the 1980s, effectively replacing cod fishing after the collapse of the Grand Banks fishery industry. This investment in drilling led to intensive biostratigraphic work, which focused on palynology and foraminifera. There was limited or no use of nannofossils, the study of which was in its relative infancy during the 1980s. In the prolific Jeanne d'Arc Basin, where attention was focused on strata dated to the Early Cretaceous and Late Jurassic, local lithostratigraphic schemes were age calibrated using palynology, which remained the go-to discipline until recently. Key wells were often reanalyzed several times for palynology and foraminifera to resolve anomalies, sometimes by the same contractor. Unfortunately, this resulted in many contradictory interpretations and a large volume of biostratigraphic "baggage" with some age interpretations possibly based on lithostratigraphy alone.

Around 2010, exploration extended into deeper waters, and there was increased emphasis on nannopaleontology. Nannofossils were utilized successfully at wellsites for real-time monitoring of deep-water exploration wells in the Laurentian Basin (Middle Jurassic to Middle Miocene) and Orphan Basin (Late Jurassic to Oligocene). Comparison of these new nannofossil data with historical biostratigraphic data (then publicly available) indicated that there was a substantial need for improving resolution and certainty in wells where nannofossils either had not been used or only a handful of samples were analyzed for nannofossils. This realization spawned a series of non-exclusive studies focusing on the frontier exploration basins where there was a need to maximize information gleaned from limited well penetrations. These studies covered the Orphan Basin (10 wells), Flemish Pass (16 wells), Carson Basin (9 wells), and Southern Flemish Pass into Jeanne d'Arc Basin (16 wells). Other key wells to the south of Newfoundland were examined for research and development. The main goal of these studies was to integrate palynology, micropaleontology, and nannopaleontology data to improve biostratigraphic resolution and its accuracy. New analyses were biased towards nannofossils, the missing piece of the puzzle. This integrated approach helped resolve many ambiguities and restore confidence in biostratigraphy, and it has been applied successfully during recent exploration campaigns.

Here I present a brief overview of available nannofossil data that show the variations in recovery/diversity through time and across the offshore basins, from the onset of normal marine conditions in the Early Jurassic (Pliensbachian) to the Miocene. Historically, the main exploration prospects were Late Jurassic or Early Cretaceous in age, but economic interest has widened to include the Paleogene. All presented information consists of non-proprietary data that were generated during PetroStrat's non-exclusive studies or in-house research.

Particulate inorganic carbon in the Pacific sector of the Southern Ocean: Satellite measurements versus coccolithophore estimates

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We have compared particulate inorganic carbon (PIC) derived from satellite data to *in situ* coccolithophore-based estimates in two latitudinal transects of the Pacific sector of the Southern Ocean (separated in time and space) in non-bloom conditions. *In situ* and satellite-derived PIC show good agreement in the Subantarctic and Polar Front zones in both transects, but they differ to the south of the Polar Front. We attribute this mismatch to the high abundance of small opal particles in the Antarctic zone. *Gephyrocapsa huxleyi* (also known as *Emiliania huxleyi*) is the dominant species in the study area and almost the only species found in the southern part of both transects south of the Subantarctic Front. Using morphometric analyses, we found that different morphotypes of this species, i.e., type A (morphogroup A) and types B, B/C-C, and O (morphogroup B), show only minor latitudinal differences in size, mass, and degree of calcification. It is mainly the dominant morphogroup B that contributes to the coccolithophore PIC content in surface waters. Satellite products are an invaluable tool to estimate global PIC, but these should be combined with field samples whenever possible to validate remote sensing-derived PIC.

Unusual calcareous nannofossil assemblages from the Cenomanian–Turonian (93.9Ma) of North America: Implications for nannofloral response to Oceanic Anoxic Event 2

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Oceanic Anoxic Event 2 (OAE2), a period of global marine anoxia and black shale deposition, took place across the Cenomanian/Turonian boundary (CTB; 93.9 Ma). Biomarkers, along with many microfossil groups, indicate that there was elevated paleoproductivity during OAE2. However, previous studies of calcareous nannofossils show a shift to oligotrophic assemblages, especially in Europe and North America. It is important to understand this apparent disconnect between nannofossil and other productivity proxies as it may provide insights into how modern nannoplankton will respond to anthropogenically induced oceanographic changes such as elevated nutrient levels and loss of oxygen.

Here we describe the results of recent investigations of calcareous nannofossils from the CTB across the USA and Canada. We used novel integrated statistical techniques that combine geochemical proxies with nannofossil assemblages to reinterpret the paleoecology. We also observed several taxa that are generally rare in, or absent from, other Upper Cretaceous sections. Overall, the assemblages have high species richness, sometimes exceeding 60 species in a sample, which is likely due to enhanced preservation from a high clay content. The statistical analysis and subsequent revision in paleoecologic interpretations indicate that primary productivity may have been elevated in nannoplankton across the CTB, in contrast to other studies. However, there is a notable spatial heterogeneity in the nannofloral assemblages that likely is related to local paleoenvironmental factors. It is possible that previous interpretations of nannofloral oligotrophy may reflect these small-scale heterogeneities.

We also suggest that such shallow shelf settings were centers of evolutionary innovation in the Late Cretaceous and acted as refugia from harsh marine environments, as they did after the mass extinction at the end of the Cretaceous. We describe some rare and newly discovered taxa that have higher occurrences in these shallow shelf environments. We note a rapid expansion of the nannoliths in Canada in the earliest Turonian and comment on the possible evolution of the widespread Turonian nannolith genus *Marthasterites*. Overall, our results show the importance of focused studies of Cretaceous marginal marine environments as a way to gain a better understanding of the evolutionary history of calcareous nannoplankton and their response to global climate change.

Calcareous nannofossils, Oceanic Anoxic Event 2, and the Cenomanian/Turonian boundary in cores from eastern Louisiana, USA

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Sediments of the Tuscaloosa Formation extend across the northern Gulf of Mexico basin and east of the Sabine uplift in Texas and Louisiana. The sediments consist of three informal units: the lower Tuscaloosa, the Tuscaloosa marine shale, and the upper Tuscaloosa. They are equivalent in age to the Woodbine Sandstone and Eagle Ford Shale in west Texas. Collectively, these sediments are associated with the onset of sea-level rise during the early to late Cenomanian, with maximum transgression during the late Cenomanian and into the early Turonian, and with a regression in the middle Turonian.

Although extensive biostratigraphic analyses have been published on west and east Texas Cenomanian–Turonian sections, very few biostratigraphic data exist from similarly aged sediments from eastern Louisiana. Here we examine the calcareous nannofossil assemblages from spot cores in the Biloxi Marshlands P-2 and O-1 wells and compare them to assemblages from the updip Eads Poitevent core. The oldest spot cores are from Biloxi Marshlands P-2 and are early Cenomanian (Zones UC1 and UC2, lower Tuscaloosa) to late Cenomanian (Zone UC3, Tuscaloosa marine shale) in age. The presence of *Eiffellithus turriseiffelii* and *Corollithion kennedyi* in the basal sample places the bottom of the core in Zone UC1. The first occurrence of *Broinsonia gammation* (Zone UC2) is at 21,263.2 ft (6481.0 m), and the first occurrence of *Lithraphidites acutus* (base of Zone UC3) is at 21,253.2 ft (6477.9 m). *Corollithion kennedyi* is present through the highest cored sample (20,110.0 ft), suggesting an age no younger than late Cenomanian. The cored interval in the Biloxi Marshlands O-1 well is from the upper Tuscaloosa, is late Cenomanian to early Turonian in age, and it is assigned to Zones UC4–UC7. The last occurrence of *Helenia chiastia* at 19,411.8 ft (5916.7 m) marks the Cenomanian/Turonian boundary.

Examination of total organic carbon (TOC) and carbon isotope ratios of bulk organic carbon ($\delta^{13}C_{org}$) from the Biloxi Marshlands O-1 well suggests that Oceanic Anoxic Event 2 (OAE2) is present from 19,413–19,407 ft (5917.0–5915.2 m). The base of the event was not cored, as evidenced by the fact that carbon isotopes are at their heaviest in the base of the core. The TOC is at 4–5% throughout the OAE2 interval. Carbon isotope ratios shift more negatively from -23‰ to -25‰ above the Cenomanian/Turonian boundary. However, an unconformity is identified using biostratigraphy at the UC6a/UC7 zonal boundary, which indicates that the top of OAE2 is truncated. Preliminary comparison with the updip Eads Poitevent core suggests that in eastern Louisiana, the carbon isotope excursion for OAE2 may not be isochronous, and further work is needed to confirm this finding.

Preliminary biostratigraphy of the lower Cenomanian Buda Limestone from the U.S. Geological Survey GC-3 and GC-5 cores, Texas, USA

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The lower Cenomanian Buda Limestone is a widely occurring formation found across the Texas Gulf Coast Basin and extending across the state and into southeastern New Mexico and northern Mexico. In central Texas, it overlies the Albian Del Rio Formation at its base and is unconformably overlain by the Eagle Ford Group at the top. Thickness of the Buda Limestone in central Texas typically ranges from 32.8–82.0 ft (10–25 m), except where it is absent along the apex of the San Marcos Arch (SMA) in the Austin area. The Buda Limestone was deposited in a shelf setting in the northern Gulf of Mexico during transgressive flooding of the platform in a period when the gulf's connection with the Western Interior Seaway was disrupted.

As part of ongoing research on Gulf Coast (GC) Basin Cenomanian–Turonian sections drilled by the U.S. Geological Survey, calcareous nannofossil biostratigraphic analysis of the resultant GC-3 and GC-5 cores, extending from the SMA to the eastern flank of the Maverick Basin, was performed. Calcareous nannofossil abundances are highly variable throughout the sections. Samples taken from white, chalky limestone typically had lower species abundance than those taken from the gray, silty stringers that are interspersed throughout the Buda Limestone. The base of the Buda Limestone in the GC-3 core at 331.5 ft (101.0 m) is considered to be earliest Cenomanian (Zone UC0) in age, based on (1) the last occurrence of *Crucicribrum anglicum* in the underlying Del Rio Formation, (2) the common occurrence of *Eiffelithus turriseiffelli*, and (3) the absence of any younger marker species. The last occurrence of *Gartnerago gammation*, which is commonly thought to occur in the early Cenomanian before the base of *Gartnerago segmentatum*, is at 321.3 ft (97.9 m) in GC-3 and may mark the top of Zone UC1. *Corollithion kennedyi* is absent throughout the Buda Limestone and only has its first appearance in the overlying Eagle Ford Group, suggesting that the depositional environment of the Buda Formation was not favorable for this species and thus making biostratigraphic analysis challenging. *Nannoconus* spp., a group thought to have preferred marginal to neritic carbonate platforms, and *Lithraphidites alatus* are frequent to common throughout the lower part of the Buda Limestone. The first occurrence of *Lithraphidites acutus* at 127.0 ft (38.7 m) in GC-3 is in the lower Eagle Ford Group and marks the base of Zone UC3.

Minor amounts of glauconite and pyrite are present in the basal Buda Limestone, and calcitic ooids are common, all of which increase in abundance up-section. Exceptionally low total organic carbon (TOC) values (<1%) are recorded throughout. The presence of ooids, extremely low TOC, and common nannoconids, along with the lack of marker species often associated with organic-rich shales, all corroborate that Buda Limestone deposition occurred in the early Cenomanian on a flooded carbonate platform with little sedimentary influence from the proximal shoreline.

Early to Middle Miocene nannofossils from the Valhall–Hod area, Norwegian North Sea

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The siliceous–diatomite succession of the lower to middle Miocene is currently a focus in the Norwegian sector of the North Sea in the Valhall–Hod area, owing to its potential as a hydrocarbon reservoir. Cored sections from the Valhall and Hod fields together provide a unique, continuous record of the Aquitanian to Langhian succession of the Lark Formation (upper part of the Hordaland Group). The succession is equivalent to the recently established Dany and Nora Formations in the Danish sector of the North Sea, which comprise gray to brown muds with diatom-rich intervals. A high-resolution, multidisciplinary biostratigraphic study, including foraminifera, dinoflagellate cysts, diatoms, silicoflagellates, and calcareous nannofossils, has recently been carried out on the lower to middle Miocene succession in six wells from the Valhall and Hod fields. The biostratigraphic framework resulting from the study of the two new cored wells, 2/11-12S (Hod field) and 2/8-G10A (Valhall field), was tested successfully on ditch cuttings samples from four neighboring, non-cored wells: 2/8-N4, 2/8-V6, 2/8-8, and 2/11-1.

Biostratigraphic subdivision of the North Sea Miocene succession, using dinoflagellate cysts and microfossils (foraminifera, Bolboforma, and pyritized diatoms), has proven to be reliable in clays and marls, and recently siliceous diatoms have been successfully applied to the siliceous intervals for biostratigraphic breakdown. Nannofossil biostratigraphy is not conventionally used in the Miocene of the North Sea due to the success and effectiveness of other fossil groups and comparatively long nannofossil zone ranges. However, a limited number of nannofossil samples, which were collected from calcareous intervals in the six wells, contained nannofossil assemblages with varying abundance, diversity, and preservation. The Valhall and Hod fields lower to middle Miocene sections span nannofossil Zones NN3–6. The nannofossil biostratigraphy supports that of the other microfossil disciplines in this study, supplementing the refined and robust biostratigraphic framework.

Useful nannofossil events, in stratigraphic order, that correlate across the Valhall–Hod area include the first occurrences (FOs) of *Cyclicargolithus floridanus*, *Helicosphaera carteri*, *Helicosphaera ampliaperta*, and *Discoaster emblematicus* and the last occurrences (LOs) of *Discoaster caulifloris*, *D. emblematicus*, *Discoaster exilis*, *Helicosphaera bipuncta*, and *C. floridanus*. Nannofossil assemblages also include *Helicosphaera bipuncta*, *Helicosphaera waltrans*, *Helicosphaera walbersdorfensis*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus apoxis*, and *Sphenolithus puniceus*. Early to middle Miocene sea surface temperature fluctuations are indicted by variations in the relative abundance patterns of *Discoaster* spp. and *Sphenolithus* spp. (warm affinity) and *Reticulofenestra* spp. (cool affinity), complementing the microfossil and dinoflagellate cyst data.

Biostratigraphy and the energy transition

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The ongoing energy transition means that the subsurface has never been more in demand than it is today. In addition to selective exploration for and exploitation of traditional resources, subsurface understanding is required to store CO_2 and hydrogen, to locate critical minerals, for geothermal energy, and for engineering projects including wind turbine location. Geoscientists are therefore required to predict and characterize the subsurface. This in turn requires an ability to correlate rock units and determine their depositional setting to build the most plausible subsurface models possible. Chronostratigraphically significant correlation and paleoenvironmental interpretation are the long-established strengths of biostratigraphy, especially when integrated with techniques such as sedimentology, sequence stratigraphy, isotope stratigraphy, and geophysics. Such applied biostratigraphy may be carried out as part of desktop studies or during operations, such as the drilling of a well.

Successful applied biostratigraphy is rooted in the detailed understanding of the fossils involved, including the agreed identity of taxa (through taxonomic studies) and an understanding of stratigraphic ranges that ideally are calibrated to the standard chronostratigraphic scale. Bioevents (e.g., the inception and extinction of taxa) can be recognized, placed in order, and biozonation schemes developed, defined by these events and characterized by assemblages of taxa. To some, this may seem old-fashioned science, but it remains essential. Misuse of taxonomic names and poor age calibration can lead to uncertain stratigraphic or paleoenvironmental ranges, diluting the power of the fossils involved. Calibration of Turonian nannofossil bioevents and biozonation schemes is a case in point, and despite decades of research, agreement on the identity of the fossils and their ranges remains to be achieved. It may be that digital techniques such as machine learning will prove useful in the quest for improvement in biostratigraphic understanding by accelerating identification and interpretation procedures, but their success depends on a major effort of standardization in understanding identity and range. In short, the time of the "stratigraphic atlas" of a particular fossil group has not yet passed!

It is essential that the value of applied biostratigraphy in the energy transition is understood, and not just by biostratigraphers, but by the geoscience community in general. Successful case studies and best practices need to be shared. Moreover, a new generation of applied biostratigraphers is required to answer the subsurface challenges of the energy transition. Provision of energy with minimal environmental impact is the greatest challenge humanity faces in the 21st century if health, prosperity, and societal stability are to be maintained. This requires a major upgrade in the understanding of the subsurface that is supported by all aspects of geoscience, not least of which is biostratigraphy.

Early Pliocene calcareous nannofossils contribute to the paleoceanographic reconstruction of the Cretan Basin (southern Aegean Sea, NE Mediterranean)

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A detailed investigation of calcareous nannofossil accumulation rates and hydroclimatic proxies in the Deep Sea Drilling Project (DSDP) Site 378 sediment record located in the Cretan Basin aims to improve our knowledge of the response of the NE Mediterranean during the warm Early Pliocene (Skampa et al., 2024). The studied sequence has been dated between ~5.2 and 3.9 Ma (i-cycles 490–374). The age of the first Zanclean marine sediments that overlie the Messinian deposits demonstrates that the Cretan Basin was partially desiccated for at least ~400 kyr, reflecting the fact that it was a shallow epicontinental area in the Late Miocene. This multiproxy study, including elemental concentrations and stable isotope measurements, revealed intervals of warm surface waters and low-oxygen conditions on the seafloor that were associated with the orbitally driven occurrence of rhythmic sapropelic layers in the Early Pliocene. Between ~5.2 and 4.6 Ma, the sapropelic layers were characterized by an elevated abundance of *Reticulofenestra* spp. and *Florisphaera profunda*, indicating increased productivity throughout the photic zone. The dominance of the former in the accumulation rates reflects adequate nutrient availability in the surface layers, which is most likely associated with increased riverine runoff into the eastern Mediterranean. In addition, the moderate abundances of *F. profunda*, compared to in the Levantine Basin (Athanasiou et al., 2017), may suggest that the formation of Levantine Intermediate Water (LIW) was not strong enough to reach the Cretan Basin at the beginning of the Pliocene. In the subsequent time interval of ~4.6–3.9 Ma, the increase in the middle photic zone of the productivity index *Helicosphaera* spp. and the salinity thriving taxon *Umbilicosphaera jafari* in the sapropelic and intercalated marly layers, respectively, imply freshening and enhanced middle photic zone productivity that was associated with an intensification of the saline and nutrient enriched LIW

presence at intermediate water depths. The increase in LIW intrusion, combined with the complete restoration of north–south Aegean marine gateways, led to the establishment of a hydrographic system similar to the modern Aegean Sea.

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Responses of calcareous nannoplankton to mid-Pliocene dynamics between climate and the carbon cycle in the North Atlantic

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Calcareous nannoplankton, a vital component of marine ecosystems, serve as key players in the oceanic carbon cycle. Thus, exploration of their population dynamics, biomass variations, and calcite content will provide insights into past interactions between climate and the carbon cycle. Using sediment samples from mid-latitude North Atlantic Integrated Ocean Drilling Program (IODP) Site U1313, we assess the calcareous nannofossil assemblage and calcification response to major climate steps during a period of global warming under close-to-modern orbital and continental configurations (mid-Piacenzian Warm P eriod, ~3.3 to 2.9 Ma). Here, we present initial results from a total of 200 samples spanning Marine Isotopic Stage (MIS) M2 to KM5c, a period encompassing an anomalously cold glacial stage within the warm background climate of the Pliocene prior to the full-scale bipolar glaciation of the Pleistocene. This research seeks to improve our understanding of how calcifying phytoplankton responded to mid-Pliocene "glacial–interglacial" conditions and whether their productivity, calcite content, and/or morphology are linked to documented climate and pCO_2 changes at or above modern values.

We used quantitative coccolith slide preparation techniques and AI microscopy (SYstème de Reconnaissance Automatique de COccolithes [SYRACO]) at CEREGE (Aix-en-Provence, France) to quantify changes in absolute and relative abundances of nannofossil species, as well as coccolith morphology (size and mass). With these data, we calculated group-specific coccolith mass accumulation rates, as well as changes in morphological diversity index (MDI). In combination with existing records spanning this interval, including many from Site U1313, this new calcareous nannofossil dataset will help us to understand coccolithophore productivity, calcification, and carbonate export responses to climate and carbon cycle changes during the Pliocene, with implications for understanding the near future responses of marine calcifiers.

Nannofossil image searches using Scampi

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It has been demonstrated that latent-space clustering of microfossil image embeddings can be leveraged to identify meaningful groupings of microfossils (Martinsen et al., 2024). By extending this approach with a content-based image retrieval (CBIR) method, we have demonstrated a system called Scampi, which acts as a powerful search engine tailored expressly for the needs of biostratigraphers (Wade et al., 2024). In our method, computer vision techniques can automatically extract crops of all the individual microfossils from whole slide images on scanned slide preparations. An arbitrary "query" image can then be compared to every single crop among the millions obtained from any given well, promptly returning the most relevant matches for expert approval. This process may be repeated for multiple "queries" of a known taxonomy, rapidly building up large numbers of expert-verified species identifications, significantly expediting the classification workflow. These observations can then be plotted by depth to produce the range charts familiar to biostratigraphers. Additionally, our approach encourages uniform analyses across multiple wells, facilitating seamless well correlations that are integral for comprehensive geological assessments at field and regional scale. Crucially, efficiency does not come at the expense of reliability because the system is designed with a strong emphasis on auditability and explainability, thereby maintaining high levels of confidence in species counts.

The analytical muscle of Scampi, powered by its sophisticated image processing algorithms, unlocks the potential for innovative workflows that were formerly not feasible. Equinor has recognized the transformative capability of our approach and is integrating Scampi as a minimum viable product for palynology. We are now exploring the applicability in the nannofossil domain with promising initial results (Figure 1). Scampi's heightened efficiency in analyses paves the way for a new era of speed and precision in microfossil identification and counting.

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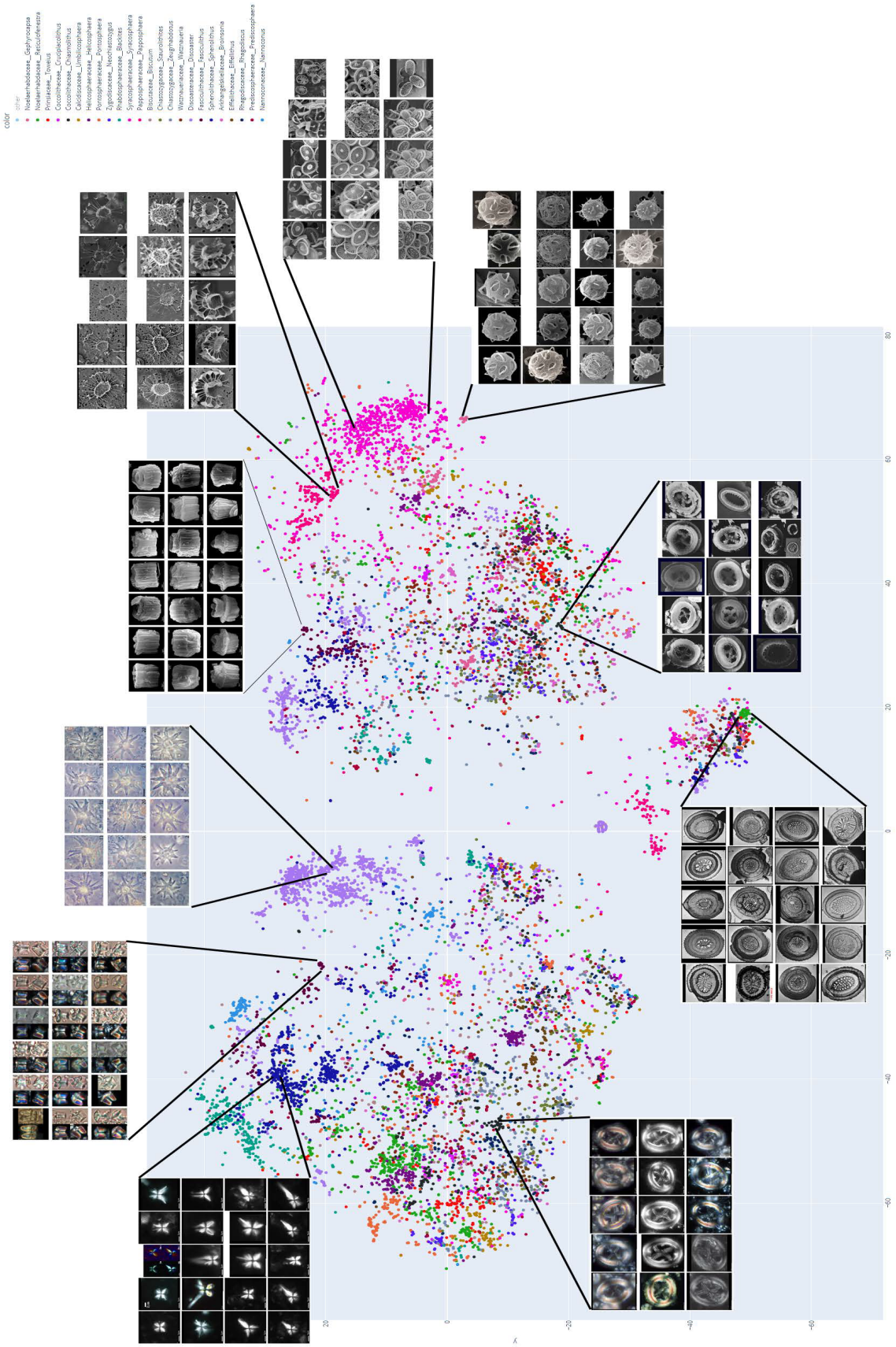

Figure 1. t-SNE embedding of feature vectors generated from nannofossil images (Young et al., 2024), with illustrative examples displayed.

Early Eocene hyperthermals in northern Bulgaria (SE Europe): New nannofossil and stable isotope data

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We present new calcareous nannofossil and benthic carbon and oxygen stable isotope records for a marl-rich, shallow-water succession of the Paleocene–Eocene transition that is exposed at three neighboring sections in central northern Bulgaria (Pleven District). The presence of nannofossil Zones NP9, NP10, and NP11 is confirmed with high-resolution nannofossil biostratigraphy. The carbon dissolution interval is marked by the abrupt drop of $CaCO_3$ content and deposition of a clay interval at the onset of the Paleocene–Eocene Thermal Maximum (PETM). Stable isotope analyses of $\delta^{13}C$ and $\delta^{18}O$ were performed on benthic foraminiferal tests. The stepped carbon isotope excursion (CIE) profile consists of three discrete intervals of decreasing carbon isotope values. An unusual two-fold CIE in the PETM interval is documented with a total negative shift of 2.89‰. Moreover, three paired negative excursions are identified: two in the uppermost Thanetian (upper Zone NP9 within the PETM interval) and one within the lower Eocene (Zone NP11). The presence of a carbon dissolution interval in the uppermost part of the Paleocene is unequivocally supported by the sedimentological study.

The most prominent negative carbon isotope excursion (4.90‰ negative shift) is observed within Zone NP11. It is related to the Eocene Thermal Maximum 3 (ETM 3) event (or “X” event), dated at 52.84 Ma ago. This hyperthermal event preceded the Early Eocene Climatic Optimum (EECO), the interval with the hottest climate in Earth's Cenozoic history. The paleotemperature data for the seawater, derived from $\delta^{18}O$ values in benthic foraminiferal shells, ranged between 23.18˚C and 35.73˚C during the PETM and reached a maximum of 38.43˚C during the ETM 3 event. In addition, during the ETM 3 event the deposition of the mineral aragonite, characteristic of coastal settings with high evaporation and high seawater temperature, was recorded.

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Calcareous nannofossil response to the early Oligocene Rhodope volcanic eruptions in some central and eastern Paratethyan basins: A comparison

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The aim of the present study is to evaluate the impact of two large early Oligocene Rhodope volcanic eruptions on the marine calcareous nannoflora across several central and eastern Paratethyan basins, including the Thrace Basin (Limnos Island, Greece). The tuff layers from the Hungarian Paleogene Basin (Central Paratethys), Massignano, Umbria-Marche Basin, Italy (western Mediterranean), eastern Carpathian Basin, Romania (Eastern Paratethys), western Black Sea Basin, Bulgaria (Eastern Paratethys), and Thrace Basin, Turkey and Limnos Island, Greece (Eastern Paratethys) have been dated at 33.3 Ma ± 0.1 Myr and 32.7 Ma ± 0.1 Myr, perfectly matching the ages of two early Oligocene supereruptions from the Borovitsa volcano in eastern Rhodope, Bulgaria. The calcareous nannoplankton response to the eruptions was investigated using published data from these basins and our newly obtained quantitative data from Limnos Island (southernmost Thrace Basin). Our results from Limnos significantly differ from the published data from Central and Eastern Paratethys localities, where volcanic eruptions and gradual cooling prompted a decline in species diversity and quantitative abundance and an increase in cold-water nannofossil taxa (e.g., in the Hungarian Paleogene Basin and the pre-Carpathian Basin in Romania). In Limnos, nannofossil species diversity is high (64 taxa recorded), as well as quantitative abundance in the assemblages. However, after each volcanic eruption, there was a resulting increase in the number of species considered eutrophic, such as *Cyclicargolithus floridanus*, *Reticulofenestra bisecta*, and *Zygrhablithus bijugatus*. This reflects an increase in primary productivity and reduced, but moderate, temperature of the seawater.

In conclusion, the documented response of the calcareous nannoplankton to early Oligocene Rhodope volcanic eruptions shows considerable differences across central and eastern Paratethys basins. In the small and more isolated basins (Hungarian, eastern Carpathian, and western Black Sea), the species diversity and quantitative abundance decrease, whereas the number of cold-water taxa increases. In the deep-water environment of Limnos (Thrace Basin), nannofossil species diversity and quantitative abundance remain high, whereas assemblages are dominated by species preferring a temperate sea water temperature. We speculate that the connection between the Paratethyan isolated basins and the Mediterranean Sea remained open during this time through the southernmost part of the Thrace Basin (Limnos Island).

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Calcareous nannofossil changes in reddish-brown sediments in the abyssal South China Sea during the Oligocene–Miocene

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Oceanic red beds are unique pelagic sediments in the global ocean, providing excellent archives for understanding chemical weathering and relevant climate change in their source areas. During International Ocean Discovery Program (IODP) Expedition 367/368/368X, a series of boreholes were drilled in the northern South China Sea (SCS). At the abyssal Site U1499 (3758 m below sea level), successive core sections were recovered from 792 to 929 m below seafloor. The most remarkable features in these cores are the consecutive occurrences of reddish-brown sediments. Although calcareous microfossils were relatively sparse in some intervals due to poor preservation or low recovery, some key species, which were well preserved and present in most of the samples, were useful for age determinations. Fifteen calcareous nannofossil datums were recognized through the studied interval, revealing a generally continuous succession dated from the early Oligocene to the Late Miocene. By combining calcareous nannofossil and foraminiferal biostratigraphic data, the development and evolution of the oceanic red beds in the northern SCS could be reconstructed. The changes in nannofossil abundance and assemblage composition were mainly influenced by global sea level changes, environmental factors, and regional tectonic events. These results imply that formation of the oceanic red beds probably resulted from the extent of deepwater ventilation in the abyssal SCS. During the Middle Miocene, a short hiatus between 13.6 and 12.0 Ma correlated with an intensive sedimentation rate increase, which was the main reason that oceanic red bed deposition ended.

Multivariate evaluation rubric for assessing the reliability of Cretaceous nannofossil index taxa and bioevents

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Calcareous nannofossils (nannoplankton) are essential in biostratigraphy because of their widespread distribution, dynamic evolution, distinct morphological characteristics, and sensitivity to environmental and climatic changes. As a key tool in biostratigraphy, they offer crucial information about geologic strata by documenting the age of deposition and providing insights on past environments and ecosystems. While the reliability of an index nannofossil taxon or bioevent is a critical factor for accurate biostratigraphic interpretations, current approaches to assess reliability are primarily qualitative, highlighting the need for a more standardized framework.

Here we discuss a multivariate quantitative evaluation rubric to address the complexities associated with assessing the reliability of calcareous nannofossil bioevents. Using existing data and information sourced from published literature and our own records from the Cretaceous chalk of southern England, this rubric combines a range of criteria including (1) taxonomic clarity and consistency, (2) morphological specificity and distinction, (3) geographical and temporal distribution, (4) rarity and frequency, (5) preservation quality, (6) reliability and usefulness based on published literature, and (7) references and source validity. The development of these guidelines is based upon a thorough synthesis of biostratigraphic work done by the calcareous nannofossil community over the years, aiming to provide a standardized framework designed to strengthen consistency and accuracy in nannofossil-based biostratigraphic interpretations. Furthermore, the use of this rubric extends beyond qualitative assessments by integrating multivariate analyses using a quantitative ranking of various criteria that may be applicable to specific time scales or regions. These reliability test guidelines thus allow for the determination of robust nannofossil index species and bioevents, mitigating potential interpretative ambiguities and discrepancies inherent within a stratigraphic record. This underscores its significance for advancing biostratigraphic work within the calcareous nannofossil research community and beyond, ultimately benefiting both academic research and industrial applications.

Investigating the size variability and coccolith mass of *Emiliania huxleyi* in the Aegean Sea (NE Mediterranean): 20 years of evidence on modern assemblages compared to the last two thousand years

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The Aegean Sea, particularly its northern sector, is a key area for understanding climate fluctuations due to its importance as a source of deep-water formation in and subsequent ventilation for the entire eastern Mediterranean. A high anthropogenic CO_2 content, which can be detected at intermediate and deep layers of the North Aegean Sea, is considered to reflect the effective transportation of the absorbed atmospheric CO_2 from the surface to deeper waters due to dense water formation (Krassakopoulou et al., 2017).

Variability in the size and mass of *Emiliania huxleyi* from the Aegean Sea (measurements of ~5000 coccoliths) has been studied in water and sediment trap samples collected during the last 20 years. Biometric analyses confirm a consistent pattern of increase in size and calcification degree during winter/springtime with low sea surface temperatures (SST) and moderate productivity, as compared to summertime high temperatures and low productivity, which is consistent with previous observations of Triantaphyllou et al. (2010). Interestingly, the interannual coccolith length (CL) estimate for the entire Aegean area, both on a seasonal and spatial basis, displays an overall decrease during the 20 years of the studied time interval, whereas relative tube width (RTW) values show a generally increasing tendency that is directly associated with a similar pattern in the North Aegean. The estimated coccolith mass (Young et al., 2014) has an overall constant pattern averaging 2.2 pg, although a difference between average values is observed between cold (November–April: 3.2 pg) and warm (May–October: 2.1 pg) intervals. A decreasing tendency in the *E. huxleyi* coccolith mass (-0.6 pg), particularly during the cold season, is recorded in the North Aegean. During the warm months, only the North Aegean *E. huxleyi* coccoliths are featured by RTW and mass increases, although both parameters display consistently lower values with respect to the cold period (average mass: 3.5 pg in the cold vs. 1.5 pg in the warm months).

Within a high resolution North Aegean Sea sediment record that spans the past 1500 years (Gogou et al., 2016), the *E. huxleyi* RTW indicates an overall increase since the beginning of the 19th century, which is similar to the modern bio-calcification signal. Interestingly, the *E. huxleyi* coccolith mass in the Common Era is decreasing when compared to the cooler intervals of the Little Ice Age and the Late Antique Little Ice Age, which is in line with the expected acidification impacts due to increase in SST and anthropogenic CO_2 content in the Aegean water column.

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Morphometric analyses of *Eprolithus floralis* from Oceanic Anoxic Event 2 in the Eastbourne section

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Oceanic Anoxic Event 2 (OAE2) (Cenomanian/Turonian boundary interval, CTBI; ~94 Ma) is regarded as one of the most extreme paleoenvironmental stressors that is characterized by global warming, accelerated hydrological cycle, enhanced production and burial of organic matter, very high concentrations of volcanically produced CO_2, and altered chemistry and structure of the oceans. During OAE2, calcareous nannoplankton were forced to face anomalous oceanographic and climatic conditions that induced both extinctions and originations, as well as changes in abundance and calcification patterns. Previous studies documented fluctuations in the size of a few taxa and specifically "dwarfism" of *Biscutum constans* at the core of the OAE2 perturbation.

The Eastbourne section is one of the reference records of OAE2 because of its completeness and high-resolution chronostratigraphic framework. This section has one of the thickest CTBI records in the Anglo-Paris Basin and consists of epicontinental pelagic deposits of the English Chalk. A large, high-resolution, multiproxy dataset reveals an interval of cooling, a phenomenon known as the Plenus Cold Event, during OAE2. We performed abundance and morphometric analyses of *Eprolithus floralis* on 44 samples from the Eastbourne section to assess its adaptation to varying paleotemperatures and ocean chemistry, particularly at the onset of OAE2, across the Plenus Cold Event, and during the recovery phase after OAE2.

The results show an increase in relative abundance of *E. floralis* from the base section, reaching highest values within the OAE2 stratigraphic interval, and decreasing after it. Morphometric analyses revealed larger total diameter and dominance of specimens with rays with a spiky outline before and after OAE2, whereas within OAE2, specimens with smaller total diameter and rays with a rounded outline are dominant (~70%). The diaphragm average diameter shows relatively lower values before and after OAE2, whereas larger dimensions are registered during OAE2, except for the chemostratigraphic peak B, which is characterized by *E. floralis* specimens with the smallest diaphragm diameter of the section. The total diameter displays an ~7% and 10% reduction within OAE2 relative to the intervals preceding and following the perturbation, respectively. Conversely, the diaphragm increases by ~1.3% during OAE2, although a minimum occurs during the chemostratigraphic peak B coeval with the total diameter minimum.

Our findings indicate that although *E. floralis* is usually interpreted as a cold-water species, its abundance and morphometric fluctuations are unrelated to temperature fluctuations across OAE2. It is worth noting that the size fluctuations of *E. floralis* can be correlated with those documented for *B. constans* and, in particular, a synchronous minimum size is detected for both taxa in correspondence to the chemostratigraphic peak B, which is considered the interval of greatest environmental disturbance. This similarity suggests that the main environmental stressors affecting *B. constans* size during the early phase of OAE2 also influenced *E. floralis* morphometry.

Evolutionary change in crystallographic orientation and morphology of Cenozoic coccoliths: Insights from *Toweius*, *Reticulofenestra*, and *Umbilicosphaera*

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The interlocking crystal units that form heterococcoliths have two different crystal orientations: near-vertical c-axis (V-unit) and near-horizontal c-axis (R-unit) (Young et al., 1992). The taxonomy of coccolithophores and V/R composition is consistent, suggesting that the crystallographic orientation in coccoliths has a common phylogenetic origin. Comparison of crystallographic orientation among closely related species and between families and genera should show how crystallography contributed to differences in morphology during the evolutionary process. We measured crystallographic orientations of the genera *Umbilicosphaera* (Miocene–Pleistocene), *Reticulofenestra* (Miocene), and *Toweius* (Eocene). The top of the coccolith surface was analyzed using scanning electron microscopy (SEM) and electron back-scattered diffraction (EBSD). If the shield surface was too steep for the electron beam to hit it, as was the case for *Toweius* spp., a cross section of the coccolith was prepared with focused ion beam (FIB) sectioning and analyzed using transmission electron microscopy (TEM). The crystallographic orientation of the distal shield of *Reticulofenestra* was not found to be significantly different from that of the closely related extant genera *Emiliania* and *Gephyrocapsa*, with the c-axis inclined 20˚–30˚ toward the central opening. *Toweius* has two distinct crystal units showing different c-axis directions. The crystallographic orientation of the elements forming the proximal shield and inner cycle of the distal shield was closer to the R-units of *Reticulofenestra*, whereas the c-axis of the outer cycle element of the distal shield seems to be the V-unit. This suggests that evolution from *Toweius* to *Reticulofenestra* was accompanied by loss or miniaturization of the V-unit. The *Umbilicosphaera* lineage shows species-specific differences (e.g., element morphology, presence of bridge, etc.) due to subtle changes in crystallographic orientation and element growth direction (~10˚ in c-axis) (Utsunomiya & Kogure, 2024), but crystallographic orientations of their V- and R-units are clearly different from those of *Toweius* and *Reticulofenestra*. Therefore, crystallographic orientation is considered to have changed with the evolution of the coccolithophores.

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Paleocene–Eocene calcareous nannofossil biostratigraphy of the Surprise Hill core from Virginia, USA

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We present the lithology and calcareous nannofossil biostratigraphy of the Surprise Hill core, which was drilled in the Salisbury Embayment in Northumberland County, Virginia, USA. The sedimentary record begins in the early Danian and includes a robust Paleocene–Eocene Thermal Maximum (PETM) section up through the Early Eocene Climatic Optimum (EECO). We identified calcareous nannofossil datums that include the first occurrence (FO) of *Heliolithus cantabriae* (59.60 Ma) in the Brightseat Formation, the FO of *Discoaster multiradiatus* (56.01 Ma) in the upper Aquia Formation, the FOs of *Discoaster salisburgensis* var. *anartios* and *Rhomboaster* spp. (54.99 Ma) in the lower Marlboro Clay, and the FOs of *Tribrachiatus orthostylus* (53.67 Ma) and *Discoaster lodoensis* (52.64 Ma), the last occurrence (LO) of *T. orthostylus* (50.66 Ma), the FO of *Discoaster sublodoensis* with five rays (48.96 Ma), and the LO of *D. lodoensis* (48.37 Ma) in the Nanjemoy Formation. An unconformity is present at 208.8 m that marks the contact between the Danian Brightseat Formation below and the Selandian through Thanetian Aquia Formation above.

The abundance of *Chiasmolithus bidens* decreased precipitously just before the PETM, and this was also documented in the South Dover Bridge (SDB) core in Maryland and in the tropical Atlantic from Ocean Drilling Program (ODP) Hole 1259B. Additionally, *Hornibrookina arca*, whose abundance is usually <5%, increased to ~40% in the Aquia Formation just prior to the PETM. A similar increase was also documented in three other cores in Maryland. The carbon isotope excursion (CIE) of the PETM was identified from analyses of benthic foraminifera and is accompanied by a change in the nannofossil assemblage, with *C. bidens* and *H. arca* being almost absent. A dissolution zone (85 cm thick) was recognized in the basal Marlboro Clay, which is consistent with global patterns of dissolution at the PETM onset. During the PETM, the genus *Toweius* shows little change in relative abundance, but there is a clear change in species composition within the genus, and *Toweius serotinus* replaces *T. tovae* and *T. eminens* as the dominant species. In the recovery phase of the PETM, *T. tovae* and *T. eminens* are replaced by *T. callosus* and *T. occultatus*, which is similar to what was found in the SDB core. The abundance of the genus *Reticulofenestra* increases gradually through the interval, and the *Toweius–Reticulofenestra* turnover occurs just after the FO of *Discoaster lodoensis*, which marks the base of Zone NP12. The calcareous nannofossil assemblage data from the Surprise Hill core provide a better understanding of the biotic response to paleoenvironmental changes on the continental shelf from the late Paleocene to early Eocene.

Cretaceous and Cenozoic calcareous nannofossil biostratigraphy of the northwestern inland basins of Colombia

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Calcareous nannofossils, one of the most valuable micropaleontological groups for dating and correlating Mesozoic and Cenozoic oceanic deposits, have been little documented in onshore deposits of South America. We present here a summary of ten years of micropaleontological research on calcareous nannofossils in the northwestern inland basins of Colombia that establishes a biostratigraphic framework for Colombian onshore deposits. Our study is based on the analysis of 2444 samples from 88 onshore deposits across the Caribbean, Pacific, and inter-Andean valley basins. The analysis reveals that calcareous nannofossils were identified in 57% of the analyzed samples, exhibiting moderate to poor preservation and common to rare abundance. We identified fourteen micropaleontological assemblages, which include nannofossil markers used in the standard biozonations for tropical and subtropical regions. This enables us to place Colombian deposits within these well-dated biozonations, resulting in a chronostratigraphic framework spanning from the Aptian (Early Cretaceous) to the Calabrian–Chibanian (Pleistocene). These results are compared to previous ages reported in the literature, demonstrating a good correspondence with foraminifera, palynomorphs, and ammonites. This comparative analysis serves to corroborate the reliability of our independent framework for dating and correlating Colombian deposits. Future work should focus on Pacific inland basins and Mesozoic onshore deposits to add additional refinement to this chronostratigraphic framework, which is expected to contribute to the understanding of the geologic evolution of oceanic seaways operating in the Mesozoic and Cenozoic between the eastern Pacific Ocean and the proto-Caribbean Sea.

Challenges of optical properties of calcareous nannofossils

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Morphological features refer to changes in the external appearance and structural units of calcareous nannofossils. These features are evident in their optical properties, which are crucial for identifying and classifying calcareous nannofossils using a petrographic microscope under cross-polarized illumination. This identification process primarily depends on the interaction of light with the atomic structure of the calcareous nannofossils. Fundamental optical properties used in the identification and differentiation process include interference colors, retardation colors, extinction types (Figure 1), and elongation direction.

Examining the bending directions (e.g., laevogyre or dextrogyre) of extinction lines in cross-polarized light and interference color distribution (with the use of a gypsum plate) in cross-polarized light can significantly help to differentiate distal and proximal profiles of calcareous nannofossils. Applying optical properties to identify and classify calcareous nannofossils presents several challenges due to their complex morphology and anisotropic nature. Calcareous nannofossils are composed of calcite, an anisotropic uniaxial (-) crystal. Optical properties depend on orientation, so it must be specified which profile the optical properties belong to (i.e., plan, distal, proximal, or side view). This study uses a mobile mounting technique to reveal the optical properties at different orientations that can be used to identify taxa.

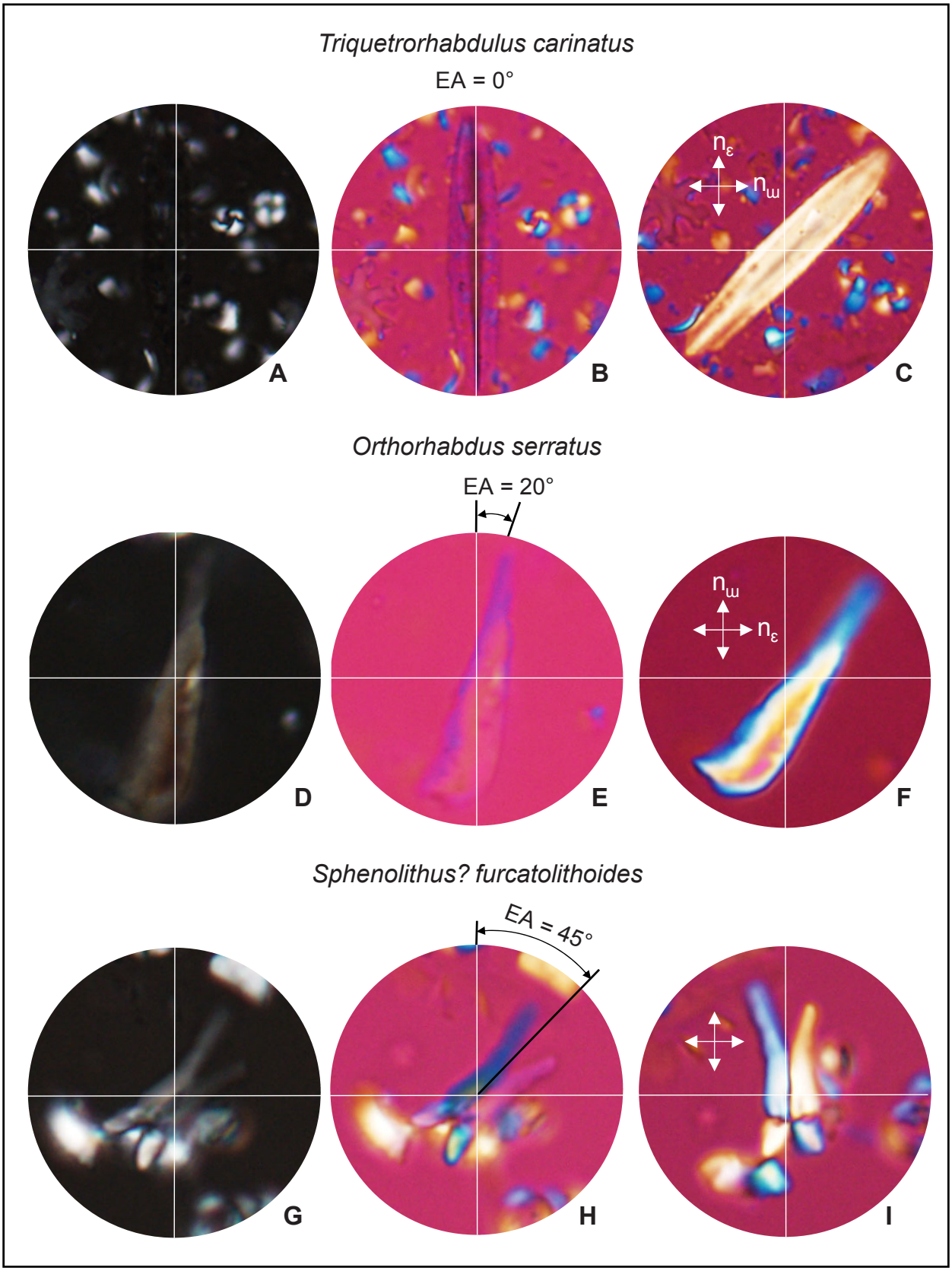

Figure 1. Illustration of extinction angle (EA) types for calcareous nannofossils. A–C: Parallel or straight extinction (0˚). D–F: Inclined or oblique extinction (20˚). G–I: Symmetrical extinction (45˚).

Mediterranean marine sediment core database: Unlocking paleoclimate signals for the last 20,000 years

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The Mediterranean Sea is a key area for the study of the dynamics of past climates thanks to its unique geography and hydrology. Its relatively small size and rapid response to climate change make it an ideal laboratory for deciphering the impact of marginal basins on global climate (Chiggiato et al., 2023). Within this context, climatic indicators (proxies) serve as indispensable tools for characterizing intervals for which instrument records are not available. Furthermore, they can be used to construct future scenarios.

Here, we present a comprehensive database derived from more than 1500 marine sediment cores collected in the Mediterranean Sea that span the last 20,000 years, or from the Last Glacial Maximum (LGM) to the present day. This database provides general information about oceanographic cruises and detailed descriptions of the recovered sediment cores. For each core, proxies of the primary environmental variables are provided from the literature.

The main aim of this effort was to identify the most studied variables and proxies used for the reconstruction of past climatic conditions over the last 20 kyr, as well as to identify any knowledge gaps in terms of proxies and space and time coverage. We have compiled climatic data from over 400 scientific articles and selected 36 cores from the Mediterranean Sea, including both extensively studied cores and those with potential significance for future research efforts. One notable aspect of this work is to offer a comprehensive graphic basin-scale synthesis of the main environmental variables available in the Mediterranean Sea over the last 20 kyr and to categorize the available proxies into abiotic (76%) and biotic (24%) proxies. Among the biotic proxies, foraminifera are the most studied, followed by calcareous nannofossils. Available paleoclimatic data on calcareous nannofossils have a fairly even distribution across the Mediterranean Sea and are primarily derived from quantitative assemblage studies, reworked coccoliths, and changes in the abundance of specific taxa (e.g., *Emiliania huxleyi* and *Florisphaera profunda*).

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Unlocking the mystery of *Clausicoccus subdistichus* across the Eocene–Oligocene transition

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During the Eocene–Oligocene transition (EOT), Earth's climate shifted from a warm, unglaciated state to a cold, glaciated state as large ice sheets developed on Antarctica. At the same time, a sudden increase in the calcareous nannofossil *Clausicoccus subdistichus* is documented in many land sections and deep-sea drilling sites. In addition to the demonstrated value of biostratigraphic events associated with this taxon, questions and uncertainties remain regarding the sensitivity and significance of this taxon in relation to Antarctic glaciation.

Here, we present morphometric and abundance data of the *C. subdistichus* group (i.e., *C. subdistichus* and *C. fenestratus*) from the Indian (Ocean Drilling Program [ODP] Site 756), Pacific (International Ocean Discovery Program [IODP] Site U1509; ODP Site 1209), and Atlantic (Integrated Ocean Drilling Program Site U1411) Oceans. Our data reveal a synchronous increase in abundance (acme event) and size of the *C. subdistichus* group at these sites across the EOT. We interpret this increase as a response to enhanced productivity conditions that were the result of an increase in the northward water transport of nutrients from the Southern Ocean to low and middle latitudes caused by the ice buildup on Antarctica. This hypothesis is further supported by independent proxies, such as opal and benthic foraminiferal accumulation rates, reported from the Southern Ocean and low–middle latitudes, respectively (Diester-Haass & Zahn, 1996: Coxall & Wilson, 2011).

The increase in size of the *C. subdistichus* group is associated with a positive global $\delta^{13}C$ anomaly, which correlates with an oversaturation of $[CO_3^{2-}]$ in seawater that previously was attributed to global shifts in carbonate production and burial (Merico et al., 2008). A partial contradiction arises from the non-standard, high abundance and large cell size observed for *C. subdistichus* across the EOT, which contradicts the typical behavior observed in other nannoplankton taxa (e.g., *Reticulofenestra*) under conditions of high productivity (i.e., high abundance, small size). This discrepancy may be related to the peculiar carbonate geochemistry of the ocean at the onset of Antarctic glaciation.

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Early and Middle Jurassic Tethyan calcareous nannofossil zonation: Taxonomic updates and biostratigraphic improvements

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Biostratigraphic investigations of Tethyan sections, which span the Toarcian–lower Bajocian interval and have been published in the last two decades, were collected and compared with standard schemes. This assessment found that there were some discrepancies in the succession of events based on biozonations, which has resulted in our revision of the age of some biohorizons. Moreover, some new/additional nannofossil events are proposed as subzonal markers. A morphometric analysis of the genus *Watznaueria*, whose specific distribution is crucial for Jurassic biostratigraphy, was also conducted to identify diagnostic features that make possible unambiguous identification of the marker species *W. colacicchii*, *W. contracta*, and *W. britannica*. Moreover, a new species, *W. gaetanii*, was established based on a different bridge ultrastructure.

This work attests to the utility of establishing new biohorizons for Tethyan stratigraphic successions because they offer the ability for a more precise age dating of Lower to Middle Jurassic key sections. This more detailed chronostratigraphic framework is extremely useful, both for the oil and gas industry and for academic research. Moreover, this study provides new evidence of a comprehensive intrageneric evolutionary lineage that started in the Toarcian and accelerated during the Aalenian under stable paleoceanographic conditions in an oligotrophic regime.

Confocal laser imaging of calcareous nannofossils

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Calcareous nannofossils are typically studied using various transmitted light microscope techniques, including cross-polarized light and phase contrast, as well as scanning electron microscopy (SEM). Light microscopy takes advantage of the anisotropy of calcite, which allows coccoliths to produce birefringence under cross-polarized light. Sample preparation for the light microscope is simple and quick. Scanning electron microscopes provide much higher resolution, allowing imaging of the detailed structure of calcareous nannofossils, but this method requires coating the sample with an ultrathin layer of a non-reactive metal (such as gold or gold-palladium) prior to analysis. Additionally, SEM analysis is done under vacuum, which requires extra time during analysis. Here, we show results from a new imaging technique, confocal laser scanning, using a Keyence VK-X3000 digital microscope. Sample preparation for this method is similar to that for the light microscope, with the exception that no coverslip is placed over the sample, allowing the laser direct access to the material. The microscope is equipped with a 100× objective to allow high-resolution imaging of specimens. The digital microscope software allows users to take multiple images through a specimen to create a 3D image, which can then be analyzed using a variety of measurements. The laser scanning technique creates high-resolution images that show detailed coccolith structure, analogous to SEM images. We compare images taken with the confocal laser scanning technique with those using standard light microscopy and SEM. We conclude that the confocal laser scanning technique is a fast and easy-to-use microscopy technique for examining coccolith structure.

Calcification response of *Emiliania huxleyi* to temperature and pH variations under calcitic and aragonitic sea conditions

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Climate change and ocean chemical composition variation have occurred over extended geological periods. During these times, coccolithophores, a crucial group of pelagic calcifiers, have historically either adapted to these fluctuations or suffered biocalcification crises. Notably, the seawater magnesium/calcium, oscillating between aragonitic seas (>2) and calcitic seas (<2), significantly impacts coccolithophore biocalcification. Additionally, variations in ocean temperature and pH, as climate change stressors, are critical factors influencing this process. Although the combined impacts of ocean acidification and warming have been shown to have an interactive effect on coccolithophores, the response of the climate change stressors under different seawater Mg/Ca remains understudied. Here we performed a comprehensive analysis of the coeffects of temperature and pH under aragonitic/calcitic seas (defined by different Mg/Ca) on the biocalcification of coccolithophores, providing insights into their mechanisms of response to changing marine environments in both past and present oceans.

We cultured *Emiliania huxleyi* (RCC963) with artificial seawater under a range of Mg/Ca (0.2, 1, 5), temperatures (15˚C, 21.5˚C, 28˚C), and pH (7.4, 7.8, 8.2) to evaluate the physiological traits and calcification sensitivity by measuring the growth rate (μ), calcification rate, and coccolith morphology. Our findings indicate that in a calcitic sea, *E. huxleyi* is more vulnerable in its growth rate to changes of temperature and pH as compared to an aragonitic sea. Coccolith morphology also supports different responses to the Mg/Ca variations, with more malformed and incomplete coccoliths observed under decreasing temperature and pH in an aragonitic sea. Additionally, in an aragonitic sea, increased temperature negatively impacts the calcification rate under low pH conditions, whereas in a calcitic sea with higher Mg/Ca analogous to the Cretaceous Period, coccolithophore calcification was less affected by climate change stressors. These findings suggest that acidification and warming impacts vary with oceanic Mg and Ca levels. Replication of these experiments across a broader range of Mg/Ca and different species will provide valuable insights into the impacts of historical climate changes on ocean biocalcification crises and enhance understanding of coccolithophore evolutionary responses to shifts in ocean chemistry over geological timescales.

Late Paleocene eastern Tethys paleoenvironmental reconstruction using calcareous nannofossils in the Patala Formation, Salt Range, Pakistan

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The Paleocene/Eocene (P/E) boundary, which correlates with the thermal maximum event, is one of the most important transitions in the Cenozoic. In some studies, the P/E boundary is marked by an unconformity in the Kohat-Potwar Basin, whereas others put it within the Patala Formation. In this study, calcareous nannofossil assemblages from the Patala Formation in the Trans-Indus Range allowed identification of the P/E boundary and reconstruction of the paleoenvironmental thermal conditions. The Patala Formation is placed in Zone NP9 based on the first occurrence of *Discoaster multiradiatus* and the consistent occurrence of *Calciosolenia aperta* and *Fasciculithus richardii*. The co-occurrence of Paleocene, Eocene, and Cretaceous species in the Patala Formation is due to unconformities both at the formation's upper and lower boundaries in the Trans-Indus Range. The P/E boundary corresponds to the unconformity between the Patala Formation and the overlying Nammal Formation, which is likely the result of the India–Asia collision at 56–55 Ma. Malformed assemblages of the *Discoaster araneus* group and *Rhomboaster* spp., which characterize the Paleocene–Eocene Thermal Maximum (PETM) event, were identified in the Patala Formation, whereas the pre-PETM phase could be identified by decreasing diversity and abundance of the genus *Fasciculithus*. The neritic PETM event found in the Tethys Sea is characterized by low salinity and increasing productivity due to terrestrial input. The Patala Formation also contains an increase in low-salinity species and higher productivity. Moreover, the synchronous increased productivity could be the result of higher temperatures due to the onset of the thermal maximum event. Abundant calcareous nannofossils indicate a stable sea level in the Trans-Indus Range, which might be deeper than inner neritic environments.

Cretaceous–Paleogene calcareous nannofossils and their biostratigraphic and paleoceanographic implications in southern Tibet

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Tibet, known as the Earth's third pole, was once part of the eastern Tethys Ocean and now serves as a key region for paleoceanographic and paleoclimate research due to its arguably most complete, continuous Cretaceous through Paleogene marine strata in China. Previous studies have shown that this region contains reasonably well-preserved and diverse calcareous nannofossil assemblages, with over 100 nannofossil species identified from the Upper Cretaceous, more than 60 from the Lower Cretaceous, and over 60 from the Paleogene. These findings not only demonstrate the diversity and preservation of Tibetan nannofossils but also form the foundation for Cretaceous–Paleogene paleoceanographic research. However, there are significant challenges, such as harsh geography, intense tectonic activity, diagenesis, and terrestrial dilution, which collectively hinder nannofossil studies. Consequently, there have been few calcareous nannofossil biostratigraphic studies in Tibet, highlighting the need for innovative approaches, international collaborations, and unwavering perseverance in research.

Recent studies in Tibet over the past decade have advanced the application of calcareous nannofossils in identifying significant geological events and paleoceanographic changes. These studies were conducted primarily in southern Tibet, which was formerly part of the India Plate, and they emphasize the importance of accurate biostratigraphic frameworks for understanding the paleoceanographic evolution of the region. To date, nannofossils have been instrumental in dating the Oceanic Anoxic Event (OAE) 1b, OAE 1d, and OAE2, the Cretaceous/Paleogene (K/Pg) boundary, and the India–Eurasia plate collision. They also indicate that the final closure of the eastern Tethys Ocean in the early Eocene was due to tectonic uplift, which may have caused Cretaceous fossils to be extensively redeposited into Paleogene sediments. Paleoceanographic conditions can be inferred from nannofossil assemblages using species with specific ecological preferences to indicate variations in ocean surface temperature and nutrient conditions, which can be formulated as temperature and nutrient indices, respectively. These indices provide valuable insights into past oceanographic conditions and contribute to our understanding of climate change over geologic timescales.

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Impact of the biological carbon pump on atmospheric pCO_2 over the past 800,000 years

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Atmospheric CO_2 concentration (pCO_2) varied in a cyclic pattern over recent glacial–interglacial cycles, a phenomenon that is mainly related to carbon uptake and release in the ocean. One important hypothesis invokes the role of marine productivity, namely the biological carbon pump (BCP), where the production and downward export of phytoplanktonic and planktonic organic and inorganic carbon act as a sink and a source of CO_2 for the atmosphere, respectively. Evidence points toward the BCP having an important role in modulating pCO_2 over the last glacial cycle, but its evolution and impacts on the climate system beyond that period remain elusive.

For this study, micropaleontological, geochemical, and scanning electron microscope analyses of sediment core MD04-2718 (48˚53.31'S, 65˚57.42'E), which was retrieved in the Indian sector of the Subantarctic zone (SAZ), were combined with data from published papers. With this information, we were able to reconstruct millennial changes in the BCP strength over the last 800 kyr and integrate these changes within a coherent glacial–interglacial climate scenario that includes variations in pCO_2. In detail, we show that the carbonate ($CaCO_3$%) and organic (TOC%, $\delta^{13}C_{org}$, C/N) fractions of the studied core reflect coccolith, planktonic foraminifera, and organic matter export productivity, respectively, and that the TOC/$CaCO_3$ may be used as a powerful tool to reflect changes in the BCP. An increased BCP during glacial periods is related to increased phytoplanktonic organic carbon export production and is probably due to the fertilization effect of enhanced iron-rich dust supply. A decreased BCP during interglacial periods reflects enhanced coccolith and planktonic foraminifera export production, probably due to increased sea surface temperatures and the reinvigoration of Southern Ocean upwelling that brought nutrient-rich water to surface waters. Overall, our results show that a strengthened BCP during glacials might help sequester CO_2 into the deep ocean at the expense of the atmosphere, whereas a weakened BCP during interglacials might enhance ocean CO_2 leakage.

Understanding the specialized cellular mechanisms that support calcification in coccolithophores

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Coccolithophores are a group of calcifying phytoplankton that play a major role in the global carbon cycle by producing most of the biogenic calcification that occurs in modern oceans. Extant coccolithophores calcify to very different degrees, and heavily calcified species contribute to most of the carbonate flux to the deep ocean. The degree of calcification also has an important impact on coccolithophore physiology. In lightly calcified species, calcification represents only a minor fraction of total cellular carbon fluxes, whereas in heavily calcified species, calcification can occur at up to twice the rate of photosynthesis. We have been investigating the physiological processes that enable coccolithophores to perform intracellular calcification at such remarkable rates by focusing on the mechanisms of calcium and carbon uptake and subsequent regulation of intracellular pH. Direct measurements of the cellular microenvironment around coccolithophore cells have allowed us to determine how carbonate chemistry changes around the cell during calcification and have provided insight into the interactions between photosynthesis and calcification. Furthermore, we have identified a novel family of calcium channels that are likely to play an important role in supporting the high rates of calcium uptake required by coccolithophores. These calcium channels are found in all haptophytes, but have become greatly expanded in the calcifying lineages, which supports their potential role in coccolith formation. In combination, our results demonstrate major physiological differences between lightly calcified and heavily calcified coccolithophore species that likely contribute to their distinct biogeographical distributions. Understanding how coccolithophore physiology is constrained by these specialized mechanisms is important if we are to have a better understanding of their response to future environmental changes.

A high-resolution depth profile of coccolithophores from oligotrophic waters in the North Atlantic Gyre (part 2)

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We report abundances and vertical distribution of coccolithophore species from samples retrieved on 28 January 2015 by the RV *Meteor* during cruise M113/2 at station #39 located at 31.46˚N, 44.44˚W in the North Atlantic Gyre. This location is representative of oligotrophic regions of oceans with a deep chlorophyll *a* maximum at 120 m. Oligotrophic regions account for 70% of the photosynthetic volume of the oceans. We seek to understand not only the biogeographic distribution of coccolithophores but also their contribution in this region to the biogeochemical cycling of carbon. Our results so far include:

1. Whenever possible, at least 300 specimens at 24 depths, from 5 m to 400 m, were evaluated with a scanning electron microscope (SEM) to determine community composition. We counted and digitally imaged over 5000 coccolithophore specimens. Each was placed and catalogued in the interactive database Nannotax.
2. Living coccolithophores were detected in the water column down to 250 m and possibly to 300 m, as determined by abundance patterns.
3. We estimate that $>4.5 \times 10^7$ living coccolithophores were in the samples retrieved from the water column that we studied. The highest abundances, $>4.2 \times 10^4$, occurred at 50 m during the winter/spring mixing season.
4. We identified 158 species from mostly phytoplankton groups but also some zooplankton. Of these species, 123 were identified as coccolithophores, including possibly a few undescribed species. Total species diversity is very high compared to about 280 known oceanic coccolithophore species. About 30 species are represented by a single sample, suggesting we might find more species by searching the filters further.
5. The assemblage is typical of the North Atlantic Gyre (excluding the Sargasso Sea community), which can be characterized by depth zones (surface layer, mixed/deep chlorophyll maximum, and shadow community). Having clearly characterized assemblages allows comparison with other vertical transects.
6. The mixed layer is remarkably homogeneous during the winter/spring season, both in terms of composition and coccolithophore morphology. There is no obvious change in morphology with depth, even for *Emiliania huxleyi* or *Umbellosphaera* spp., contrary to findings in the western Sargasso Sea.
7. Low numbers of holococcolithophores and high levels of *E. huxleyi* possibly reflect a mildly oligotrophic environment due to mixing that occurred during sampling.
8. The Syracosphaeraceae are especially well represented, whereas the Pappospheraceae are the major missing group.
9. Despite making >5000 coccosphere images, we found no combination coccospheres.
10. Only about 10 specimens are assigned to undescribed taxa, thus >99.5% can be reliably identified.
11. This large set of images was collected without any selection, which means they could be used to acquire good quality data on variations in coccolith size, coccosphere size, and liths per sphere.

Paleocene to Eocene calcareous nannofossil zonation in the western Tarim Basin, Central Asia

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The western Tarim Basin, which is located between the Tianshan Mountains and the Kunlun Mountains of Central Asia, was covered by the shallow, epicontinental, northeastern part of the Tethys Sea from the Late Cretaceous to Eocene. According to previous studies, marine sediments containing calcareous nannofossils are found in the Paleogene Qimugen, Kalataer, Wulagen, and Bashibulake Formations. In this study, calcareous nannofossil assemblages from four sections (Bashibulake, Kuzigongsu, Simuhana, and Aertashi) were correlated to discuss the biostratigraphy in the western Tarim Basin. The Qimugen Formation is placed in nannofossil Zones NP7–10 (Thanetian to Ypresian) in the Tianshan Mountain area, in which the first occurrences of *Heliolithus riedelii*, *Discoaster multiradiatus*, and *Rhomboaster*/*Discoaster* (RD) assemblages (namely, *Discoaster araneus* group and *Rhomboaster* spp.) have been recorded. The Paleocene–Eocene Thermal Maximum (PETM) is well defined by the RD assemblages in the western Tarim Basin. The top of the Qimugen Formation is placed in Zones NP10–11 (Ypresian) as identified by the last common occurrence of *Discoaster multiradiatus* in the Tianshan Mountains region. In the Kunlun Mountains area, the Qimugen Formation is placed in Subzones NP9a and NP9b based on the first occurrence of *D. multiradiatus* and the *D. araneus* group in the Aretashi section. The Kalataer and Wulagen Formations are placed in Zones CNE12–13 (Lutetian) based on the occurrences of *Nannotetrina* spp., *Discoaster bifax*, *Reticulofenestra umbilicus*, *Cribrocentrum reticulatum*, and *Chiasmolithus solitus* in the Tianshan Mountains area. In the Kunlun Mountains area, by analyzing the extension of the co-occurrence of *R. umbilicus* and *C. solitus* in the Aertashi section, the calcareous nannofossil layer in the Wulagen Formation is placed in Zone NP16 (late Lutetian to Bartonian). The middle part of the Bashibulake Formation is placed in Zone CNE17 (Bartonian/Priabonian) based on the common occurrence of *Cribrocentrum erbae*.

Developing tools to compile and visualize nannofossil occurrence data

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The Neptune database is an invaluable compilation of planktonic microfossil occurrence data. Adding data from Neptune into Nannotax has provided effective visual summaries of the abundance and stratigraphic distribution of taxa. However, the data in Neptune are mostly >20 years old, are exclusively from ocean drilling cores, and coverage of the Mesozoic is rather sparse. Recently, we have been working on an extended Cretaceous nannofossil occurrence database. This is intended both for research, to allow investigation of the autecology of nannofossils and their response to environmental change, and for documentation of their stratigraphic occurrence on Nannotax.

We have developed the database so that all data uploading, editing, and displaying are done via webpages as part of the Nannotax system. The workflow is based on the upload of distribution tables (samples versus species) from a single drill site or outcrop. First, metadata (location, analyst, source publication, etc.) for the table are entered via a form, and then the table of data is uploaded as a tab-delimited file or spreadsheet. Next, a data-cleansing step ensures sample data are consistently labeled and that the recorded taxa are correctly linked to entries in Nannotax. The data upload script then populates the sample and occurrence tables. An optional step allows calculation of sample depths and entry of zonal assignments. The uploaded data are then displayed, and age-diagnostic data are summarized in an age-depth plot that allows a line of correlation to be drawn and ages assigned to the samples. Finally, paleolatitudes and paleolongitudes are added using g-plates (this step requires use of an external script but can be done in large batches).

Data visualization primarily uses systems previously developed for use with the Neptune database, and this allows plotting of range charts, distribution maps, and plots of occurrence frequency against time and paleolatitude. An extra system has been developed to allow examination of all occurrence data from a single time-latitude defined interval. Access to this database is currently restricted prior to publication, but it should be available by the end of 2024. An age-depth plotting tool is already directly accessible from Nannotax (tools menu), and the database development tools will be available for future projects.

Reconstructing Cretaceous climate: Insights from a new calcareous nannofossil occurrence database

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The Cretaceous Period is recognized as a prototypical greenhouse climate interval, which is regarded as a potential analog for predictions of future climate change. Historically, geochemical and paleontological proxies, such as $\delta^{18}O$ of carbonates, TEX_{86} paleothermometry, fossil assemblage abundances, and biogeography were used to reconstruct paleotemperature evolution during the Cretaceous. However, a comprehensive and integrated database of microfossil occurrences, which is essential for thorough Cretaceous paleoclimate reconstructions, remains elusive.

Calcareous nannofossils were the dominant group of phytoplankton living in the photic zone of the Cretaceous oceans, and their sensitivity to environmental factors makes them robust biotic proxies for sea surface temperature reconstructions. While the Neptune database has provided substantial insights into the occurrence and distribution of calcareous nannofossils, it predominantly features data that are over two decades old, with sparse coverage of the Cretaceous (~2600 samples) and a massive bias toward the Recent. To address these limitations and enhance the reliability of scientific research, we have compiled Cretaceous occurrence data from 111 sections that include onshore outcrops and deep-sea drilling sites, which have new age-depth models with revised and robust age information. Around 8000 samples and 200,000 nannofossil occurrences from the Berriasian to Maastrichtian were added to the existing Neptune database, tripling the data available. This initiative aims not only to investigate the paleoecological dynamics and environmental responses of nannofossils but also to ensure meticulous documentation of their stratigraphic occurrences, which will be detailed in a forthcoming version of Nannotax. Although access to this enriched dataset is currently restricted pending publication, it is anticipated it will be made publicly available by the end of 2024.

Utilizing this novel database, our research quantitatively evaluates the latitudinal distribution of common and paleoenvironmentally diagnostic nannofossil taxa at a high resolution through the Cretaceous. Our objectives include (1) assessing the paleotemperature preferences of Cretaceous calcareous nannoplankton to establish refined temperature indices and (2) constructing a detailed evolutionary trajectory of Cretaceous sea surface temperatures, thereby contributing a novel perspective to the discussion of Cretaceous paleoclimate evolution.

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