14th Symposium of the International Fossil Coral and Reef Society Poland 2023

CONFERENCE BOOK

14th Symposium of the International Fossil Coral and Reef Society (IFCRS) Poland, 10–16 September 2023

CONFERENCE BOOK

Editors

Jarosław Stolarski and Anne M. Gothmann

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FOREWORD

Forty-four years – the length of time since the International Fossil and Coral Reef Symposium was last hosted in Poland (1979) – is an epoch. Extraordinary changes have taken place in coral science and in the world since then. The year 1979 in communist Poland was a year of shortages of basic goods, endless queues outside grocery stores, and rising inflation. It was also a year of hopeful events. In that year, the Workers' Defense Committee (KOR) was formed, and the visit of Pope John Paul II, with a clearly anti-communist agenda, gave hope for changes to the political system. In fact, in the next year (1980), the Solidarity movement, which promoted social change and advocated for worker's rights, transformed society even more, triggering revolutionary movements throughout the rest of Eastern Europe.

This social atmosphere created a unique setting for the 3rd International Symposium on Fossil Corals and Coral Reefs in Warsaw, which was composed of 66 participants from 22 countries. The many researchers in attendance set the narrative tone for studies of corals and fossil reefs over the coming years. The vast majority of the presentations focused on Paleozoic corals (their taxonomy, paleobiology, and morphogenesis). A few presentations discussed scleractinian corals (their taxonomy, the relationship between environment and the skeleton morphology, skeletal microstructures,and their diagenesis). In retrospect, it can be said that 1979 was a different reality: although the coral reefs of that time, such as The Great Barrier Reef, experienced serious bleaching events (e.g., in 1980), those events were not nearly as frequent or widespread as they are today. Interpretations of the phylogeny of scleractinian corals were proposed solely on the basis of morphological skeletal features – the molecular data did not exist at that time. It was also a world without the overwhelming influence of journal impact factors, without predatory and costly open access journals. A world of paper reprints, black and white images and typewriters.

Today in 2023, we see that Poland has radically changed politically and economically. More than 30 years after the round table agreements between the communist government and the opposition, we meet in a Poland belonging to the European Union and NATO. A Poland whose borders within the Schengen area can be crossed without any control. All these changes in 1979 were hard to imagine. Equally difficult to imagine are the changes that have taken place in research on modern and fossil corals and reefs over the last ~40 years. Molecular studies have revolutionized the interpretation of phylogeny: the system proposed by John Wells in the Treatise on Invertebrate Paleontology has become almost completely obsolete. Studies on gene expression and biomineralization experiments have allowed us to understand, at unprecedented precision, the influence of the environmental and physiological factors governing skeletal formation for modern corals. Thanks to new analytical tools, we are also able to visualize the structure of fossil coral skeletons at the nanometer scale and apply many previously inaccessible paleoenvironmental and paleophysiological proxies. At the same time, however, the catastrophic decline of modern coral reefs linked to climate change is progressing at an unprecedented pace. Calls for their protection are becoming more and more urgent. Modern coral reefs are quickly transforming into extinct ones. That is why the lessons of the geological past, former reef extinctions and their subsequent revival episodes, are an important baseline for scientists studying modern corals to understand. Now, we more clearly recognize the importance of mesophotic and deep-water environments as potential coral refugia (which has inspired the motto of this conference, "Going deeper").

Over the last 40 years, it seems that the field of science has also lost much of its innocence. Dangerously fast, scientometric indicators have become more widely used to indicate a publication's value instead of its real explanatory potential. It also seems that it is becoming more difficult to obtain funds for scientifically important work that is not worthy of mass media coverage. However, it is also true that the popular appeal of a topic is a function of the enthusiasm of the scientists who participate in the field of research and their ability to clearly convey the implications of their work to non-experts. Our presence at this symposium – the presence of many young and established scientists alike – is a clear sign that we believe in our scientific mission. Here, our theme of "Going deeper" also means going deep into society with a transparent message of how important and how sensitive coral reefs have been and remain in response to climate change.

Jarosław Stolarski
Symposium Chair

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The Conference has been financially supported by the programme "Excellence Science" of Ministry of Education and Science Republic of Poland

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SYMPOSIUM PROGRAM

09.09.2023 Saturday

5–8 PM	Registration and Welcome Party at Museum of Evolution of the Institute of Paleobiology, Polish Academy of Sciences (https://muzeumewolucji.pl) [Palace of Culture and Science]

10.09.2023 Sunday

10:00 AM	Meeting in Warsaw: Parking lot in the front of Museum of Evolution
1:00 PM	Owadów-Brzezinki: Exceptionally preserved Late Jurassic ecosystem
	Lunch with “rural housewives”
3:30 PM	Departure from Owadów-Brzezinki
4:30 PM	Arrival to Julianka: Coral colonization of the cyanobacteria-sponge bioherms, Late Jurassic
±6 PM	Arrival to European Centre for Geological Education, Chęciny (ECEG)
7 PM	Dinner

11.09.2023 Monday

7:30–9:00 AM	Breakfast
10:00 AM	**Opening Ceremony**
11:00–11:30 AM	Coffee break
11:30 AM	**Keynotes**

- **Tali Mass.** Mechanisms that enable corals to persist and thrive in extreme environments: what can we learn from modern corals.
- **Anne M. Gothmann.** Corals in changing seas: A geochemical journey through geological epochs.

1:30–2:30 PM	Lunch
2:30 PM	**Regular talks** [chaired by **Wolfgang Kiessling**: talks 15 min; discussions 5 min]

Corals and climate change

- **Nadia Santodomingo**, Zarinah Waheed, Ali Bin Seyd Hussein, Allia Rosedy, Chris Perry, Sindia Sosdian, Brain Rosen, and Kenneth G. Johnson. Long-term resilience of turbid ecosystems in the Coral Triangle.
- **Danijela Dimitrijević** and Wolfgang Kiessling. Reef refugia in the aftermath of hyperthermal events.
- **Jarosław Stolarski**, Paolo Montagna, Eric Douville, Maciej Mazur, and Francesca R. Bosellini. Evolutionary potential of scleractinian corals to buffer ocean acidification: Cenozoic fossil record perspective.

3:45 PM	Departure to “Wietrznia” nature reserve
4:15–6:45 PM	A brief history of Holy Cross Mountains” at “Wietrznia” nature reserve
7:30–9:00 PM	Dinner

12.09.2023 Tuesday

7:30–9:00 AM	Breakfast
9:30 AM	**Regular talks** [chaired by **Francesca R. Bosellini**: talks 15 min; discussions 5 min]

Coral biomineralization and skeletal proxies

- **Thomas C. Brachert**, Thomas Felis, Phyllis Mono, and Markus Reuter. Tropical reef corals underwent chronic heat stress but no bleaching events during the Late Miocene: Evidence from stable isotope data and calcification records.
- **Luisa C. Meiritz,** Christian Deusner, Jan Fietzke, Nadia Santodomingo, Thomas Felis, and Eleni Anagnostou. Reconstructing ultra-high-resolution climate variability and symbiont bleaching in tropical corals: Introducing a multi-proxy approach.

- **Mono Phyllis**, Thomas C. Brachert, Regina Mertz-Kraus, Michael Henehan, Vadim L. Stefanskyi, and Bogusław Kołodziej. First record of calcification performance of subtropical reef corals from the Eocene.
- **Andres Rüggeberg**, Robin Fentimen, Eline Feenstra, Antonietta Rosso, Thiery Adatte, Torsten Vennemann, Irka Hajdas, Norbert Frank, David van Rooij, and Anneleen Foubert. Cold-water coral mound build-up at the East Melilla Coral Province (SE Alboran Sea, western Mediterranean).
- **Jarosław Stolarski**, Deyanira Cisneros-Lazaro, Laura M. Otter, and Anders Meibom. Biological control over $CaCO_3$ polymorphism and the evolution of biomineralization: Insights from the bi-mineralic skeleton of *Paraconotrochus antarcticus* scleractinian coral.

11:20–11:45 AM Coffee break

11:45 AM **Regular talks** [chaired by **Brian Roy Rosen**: talks 15 min; discussions 5 min]

Challenges of coral phylogeny and taxonomy

- **Bernard Lathuiliére**, Danwei Huang, and the Corallosphere group. Tentative cladograms for Triassic and Jurassic coral families.
- **Zuzana Geistová** and Bogusław Kołodziej. Prolific development of amphiastreids and other pachythecal corals (Hexanthiniaria?, Scleractinia?) in reefs on the Štramberk Carbonate Platform (Tithonian–Berriasian).
- **Jingfang Bo**, Jianxin Yao, Jiafei Xiao, and Weiqing Liu. Anisian coral fauna from Guizhou, Southwestern China.
- **Isabel Rodriguez-Castro**, Ian D. Somerville, and Sergio Rodriguez. Origin and evolution of the genera *Lonsdaleia* and *Actinocyathus*: Insights for Mississippian palaeogeography from the Western Palaeotethys.

1:00–2:00 PM Lunch

2:00 PM **Regular talks** [chaired by **Nadia Santodomingo**: talks 15 min; discussions 5 min]

Coral paleobiology, functional morphology and photosymbiosis

- **Francesca R. Bosellini** and Jarosław Stolarski. The rolling stones: An extreme evolutionary adaptation of colonial scleractinian corals to colonize soft bottoms.
- **Błażej Berkowski**, Mikołaj K. Zapalski, and Phil Alderslade. Holdfasts and growing tips of heterocoral colonies: A case study of two Famennian genera *Oligophylloides* and *Mariaephyllia*.
- **Jan Król**, Błażej Berkowski, Julien Denayer, and Mikołaj K. Zapalski. Photosymbiosis in heliolitid corals.
- **Aleksander Majchrzyk**, Michał Jakubowicz, Pim Bongaerts, and Mikołaj K. Zapalski. Convergent patterns in light-induced phenotypic plasticity in Devonian and modern corals.
- **Le Yao**, Wei Lin, Markus Aretz, David J. Bottjer, and Xiangdong Wang. Colonial coral resilience by decreasing size: Reaction to increased detrital influx during onset of the late Palaeozoic Ice Age.
- **Mikołaj Zapalski**, Błażej Berkowski, Stanisław Skompski, John W. Pickett, and Gavin C. Young. An Early Devonian Mesophotic Coral Ecosystem from the East Gondwana.

4:15–4:45 PM Coffee break

4:45 PM **Regular talks** [chaired by **Lewis A. Jones**: talks 15 min; discussions 5 min]

Fossil coral reefs: research methods

- **Matthieu Saillol**, Markus Aretz, and Élise Nardin. A new quantitative approach for palaeoenvironmental and palaeoecological studies of biostromes: The case study of an Emsian biostrome in the French Basque Country.
- **Angelina Ivkić**, Felix Puff, Andreas Kroh, Abbas Mansour, Mohamed Osman, Mohamed Hassan, Ahmed Abo El Hagag, and Martin Zuschin. A comparison of three sampling techniques in Egyptian Pleistocene coral reefs.
- Francisco Sanchez Beristain, **Miguel A. Galeana-Morán**, Francisco Sour-Tovar, and Pedro Garcia--Barrera. Reviewing Fagerstrom's reef-guilds with Geometric Morphometrics: A case study of Permian reef from Mexico.

- **Bogusław Kołodziej**, Zuzana Geistová, Justyna Kowal-Kasprzyk, and Petr Skupien. Three types of reefs in the Štramberk Limestone developed at the Jurassic/Cretaceous transition (Carpathians, Czech Republic).

7:00–9:00 PM Bonfire dinner

13.09.2023 Wednesday

7:30–9:00 AM Breakfast

9:00 AM **Regular talks** [chaired by **Markus Aretz**: talks 15 min; discussions 5 min]

Reefs in space and time

- **Natsuko Adachi**, Naoto Minami, Yoichi Ezaki, Jianbo Liu, Mahito Watabe, Gundsambuu Altanshagai, Batkhuang Enkhbaatar, Dorj Dorjnamjaa. The thrombolite-dominated archaeocyath reefs of the Cambrian Series 2 from the Zuune Arts area of western Mongolia: Construction and palaeoenvironments.
- **Julien Denayer** and Francis Tourneur. The Devonian Coral Fauna of the Bruche valley (Northern Vosges Massif, France).
- **Cian McAuley**, Alex Brasier, Kevin Page, Joyce Neilson, John Still, Neil Ogle, and Neil Davies. Deep and dirty coral bearing bioherms from the Late Devonian of South Devon: Exploring the limits of Palaeozoic carbonate buildups.
- **Liang Kun**. Middle Devonian (Givetian) coral-stromatoporoid patch reefs from the Lazhulung Formation, Xizang (Tibet) and their implications.
- **Edouard Poty.** Micro-mudmounds at the end of the late Frasnian, the last gasp of Frasnian bioconstructions before their end.
- **Thomas Stemann** and Simon F. Mitchell. A mesophotic coral fauna from the Middle Rupelian of Central Jamaica.
- **Addis Endeshaw**, Nadia Santodomingo, Haileyesus Negga, and Anneleen Foubert. Paleoecological characterization of Middle and Late Pleistocene reefs of the Danakil Depression (Northern Afar, Ethiopia).
- **Miguel A. Galeana-Morán**, Francisco Sour-Tovar, and Francisco Sanchez Beristain. A brief review of the study of "coralline sponges" from Mexico.

12:00–12:30 PM Coffee break

12:30 PM **Regular talks** [chaired by **Julien Denayer**: talks 15 min; discussions 5 min]

Coral paleobiodiversity patterns

- **Wolfgang Kiessling**, Daniela Dimitrjević, Kerstin Frühbeisser, Nussaïbah B. Raja, and Francesca R. Bosellini. Matches and mismatches between reef proliferation and reef builder diversity on geological time scales.
- **Lewis A. Jones,** Angelina Ivkić, Andreas Kroh, Abbas Mansour, Mohamed Osman, Mohamed Hassan, Martin Zuschin. Inverse latitudinal diversity gradients in Last Interglacial coral reef communities.
- **Arnaud Ruchat**, Bernard Lathuiliére, Stephan Wohlwend, Gaudenz Deplasez, Herfried Madritsch, Gregor P. Eberli, Susanne Feist-Burkhardt, Elias Samankassou. Bajocian coral reefs: Likely a global reef growth event.
- **Travis Stone**, Rowan Martindale, Stéphane Bodin, Bernard Lathuiliére, Raphael Vasseur, Tanner Fonville, François-Nicolas Krencker, and Lahcen Kabiri. Extinction-induced changes to Moroccan reef ecology in the Early Jurassic.

1:50–2:50 PM Lunch

2:50–4:00 PM **Poster session** & coffee

Coral paleobiodiversity patterns

- **Daniela Dimitrjević**, Timothy L. Staples, Nussaïbah B. Raja, John M. Pandolfi, and Wolfgang Kiessling. Novel reef communities emerging after mass extinction events.

Coral biomineralization and skeletal proxies

- **Anne M. Gothmann**, Joash Daniel, Yi Wynn Chan, John Cliff, Lubos Polerecky, Julie Grenger, Josie Mottram, and Maria Prokopenko. Nanoscale imaging of organic matrix and aragonite formation in a skeleton of a cold-water coral *Balanophyllia elegans*.
- Valentina di Fazio, Giuseppe Falini, Raffaele Gattelli, Christian Ghiroldi, **Stefano Goffredo**, Arianna Mancuso, Chiara Marchini, Paolo Montagna, Fiorella Prada, and Marco Taviani. Skeletal properties of the coral *Desmophyllum dianthus* are related to the aragonite saturation state along a depth gradient in the Mediterranean Sea.

Coral paleobiology, functional morphology and photosymbiosis

- Klaudiusz Salamon and **Bogusław Kołodziej**. Skeleton microbiome of fossil scleractinian corals deciphered from microborings.
- **Jan J. Król**, Błażej Berkowski, and Mikołaj Zapalski. Approximation of skeletal density in tabulate corals.

Fossil coral reefs: research methods

- **Martin Zuschin**, Angelina Ivkić, Edwige Pons-Branchu, Paolo Montagna, Marco Taviani, Abbas Mansour, Mohamed Osman, Mohamed Hassan, Ahmed Abo El Hagag, and Andreas Kroh. New U-Th age data for Middle and Late Pleistocene coral terraces at five localities of the northern Red Sea of Egypt and their palaeoecological composition.
- **Tanja Unger**, Matthieu Saillol, Markus Aretz, Stephen Lokier, Mathias Mueller, and Adrian Immerhauser. The Klutert Biostrome: A model for reefs in sediment-stressed environments?
- **Le Yao**, Stephen Kershaw, Shuzhong Shen, and Xianngdong Wang. New reef classification model with insights into Phanerozoic evolution of reef ecosystems.
- **Xia Wang**, **Hanting Zhong**, Jianhua Chen, Zongqi Lin, Cai Wang, Yuhan Zeng, Lingzan Meng, Mingcai Hou, Yalin Li, and Chengshan Wang. Outcrop3D: A digital pathway to the deep-time reefs.

Reefs in space and time

- **Miranda Hartley**, Mattias Green, Hannah Byrne, and Iael Perez. Cnidaria: A proxy for Cambrian tides?
- Tanya Singh, **Zuzana Geistová**, and Bogusław Kołodziej. Cretaceous corals from SE India: a return to Ferdinand Stoliczka's (1873) research area.
- **Victor Ohar**. Corals from the middle Visean black shales of the Donets Basin.
- **Brian Roy Rosen** and **Jill Darrell**. Glimpse of a Brigantian (Mississippian) tropical sea floor on the Derbyshire carbonate platform, England.

4:15 PM	Chęciny castle and town tour
7:15–9:00 PM	Dinner

14.09.2023 Thursday

7:30–8:30 AM	Breakfast
8:30 AM–2:30 PM	Devonian mesophotic environments of the Holy Cross Mountains
2:30–5:00 PM	Lunch (& Pierogi presentation) at Ethnographic Park in Tokarnia (near ECEG)
since 6:00 PM	General Assembly
8:00–9:00 PM	Dinner

15.09.2023 Friday

7:00–8:30 AM	Breakfast
9:500 AM	Departure from European Centre for Geological Education, Chęciny
12:30 PM	Arrival to Kraków (Parking Wawel, near Wawel Castle)
4:00 PM	Departure from Kraków (Parking Wawel, near Wawel Castle)
4:30 PM	Arrival to Wieliczka Salt Mine
5:00 PM	Wieliczka Salt Mine guided tour
7:00–9:00 PM	Conference Dinner at Wieliczka Salt Mine
±9 PM	Departure from Wieliczka Salt Mine to Kraków (arrival ±10 PM)

EXCURSION GUIDE

A BRIEF HISTORY OF THE HOLY CROSS MOUNTAINS

Anna ŻYLIŃSKA

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(based on Żylińska 2008, 2017; Matyja 2015; Radwański 2015; Skompski 2015; modified and updated)

The prominent hilly area one encounters when driving from Warsaw down south to Kraków are the Holy Cross (Świętokrzyskie) Mountains (HCM). Here, the sedimentary rocks from almost all parts of the Palaeozoic, Mesozoic and Cenozoic succession occur in close vicinity to each other, making the area a perfect locality to host field courses for students of geology as well as international conferences devoted to stratigraphy, sedimentology, palaeontology, and structural geology, to mention just a few of the main topics of these important gatherings.

The uniqueness of the HCM comes from their location at the junction between the Meta-Carpathian arc and the Mid-Polish Anticlinorium, between the Central European Variscides in the west and the East European Craton (EEC) in the east. They represent one of the very few areas in Europe where Palaeozoic rocks are exposed at the surface in the direct vicinity of the Teisseyre-Tornquist Line, and their pre-Variscan basement belongs to one of the main geotectonic domains in Europe – the Trans-European Suture Zone (TESZ; e.g., Berthelsen 1992; Dadlez et al. 2005; Nawrocki et al. 2007).

In the geological sense, the HCM are part of the Mid-Polish Anticlinorium, a major NW-SE oriented anticlinal structure comprising the sedimentary succession of the Mid-Polish Trough that was inverted prior to the Cenozoic (Fig. 1). The complex geology of the HCM can be attributed to their multi-stage evolution, of which the Cretaceous tectonic inversion and uplift was one of the last major structural reorganizations (e.g., Kutek and Głazek 1972; Krzywiec et al. 2018; Łuszczak et al. 2020; Remin et al. 2022, and references therein). This reorganization resulted in partial removal of a thick overburden of Mesozoic strata and exhumation of the Palaeozoic rocks; this exposure is now referred to as the Palaeozoic core or, more correctly, the Palaeozoic inlier, which crops out in a c. 70 km long and 50 km wide belt. The inlier is surrounded by Permian and Mesozoic formations from the north, west, and south-west, and is referred to as the Permian–Mesozoic margin. Further exhumation of Palaeozoic strata was related to the uplift of the peri-Carpathian forebulge in the Miocene times (Leszczyński and Nemec 2015). The youngest marine strata of the area occur to the south and south-east, and are linked with Miocene shallow-marine deposits that filled the Carpathian Foredeep Basin (e.g., Radwański 1969; Wysocka et al. 2016; Fig. 2).

The Palaeozoic succession of the HCM is relatively complete (e.g., Szulczewski 1996). Breaks in the stratigraphic record are marked both by hiatuses and angular unconformities, but the number, magnitude and lateral extent of the stratigraphic gaps is not identical over the entire area. Differences in facies development, stratigraphy, and tectonic evolution have resulted in the traditional subdivision of the HCM Palaeozoic inlier into two regions: the Kielce Region in the south and the Łysogóry Region in the north, separated by the WNW-ESE trending Holy Cross Fault (or Dislocation). This fault has been variously interpreted: either as a border between the Małopolska Block (with the Kielce Region in its northernmost part) and the East European Craton (EEC; with Łysogóry in its south-western margin), or as the boundary between the Małopolska and Łysogóry terranes (see e.g., Konon 2007 for an overview). Therefore, the regions are understood either as tectono-stratigraphic (e.g., Czarnocki 1919; Stupnicka 1992) or palaeogeographic units (e.g., Belka et al. 2002; Nawrocki and Poprawa 2006, and references therein) of proximal or exotic provenance. A crustal structure identical with that of the EEC was distinguished in the Małopolska Block by deep seismic sounding experiments, which indicates that both units are connected with the EEC (palaeocontinent of Baltica; Malinowski et al. 2005), with the Małopolska terrane being probably a proximal terrane dextrally relocated along the TESZ margin of Baltica (Nawrocki et al. 2007). Palaeomagnetic data for Ordovician (Schätz et al. 2006) and Silurian rocks (Nawrocki 2000) indicate that at least

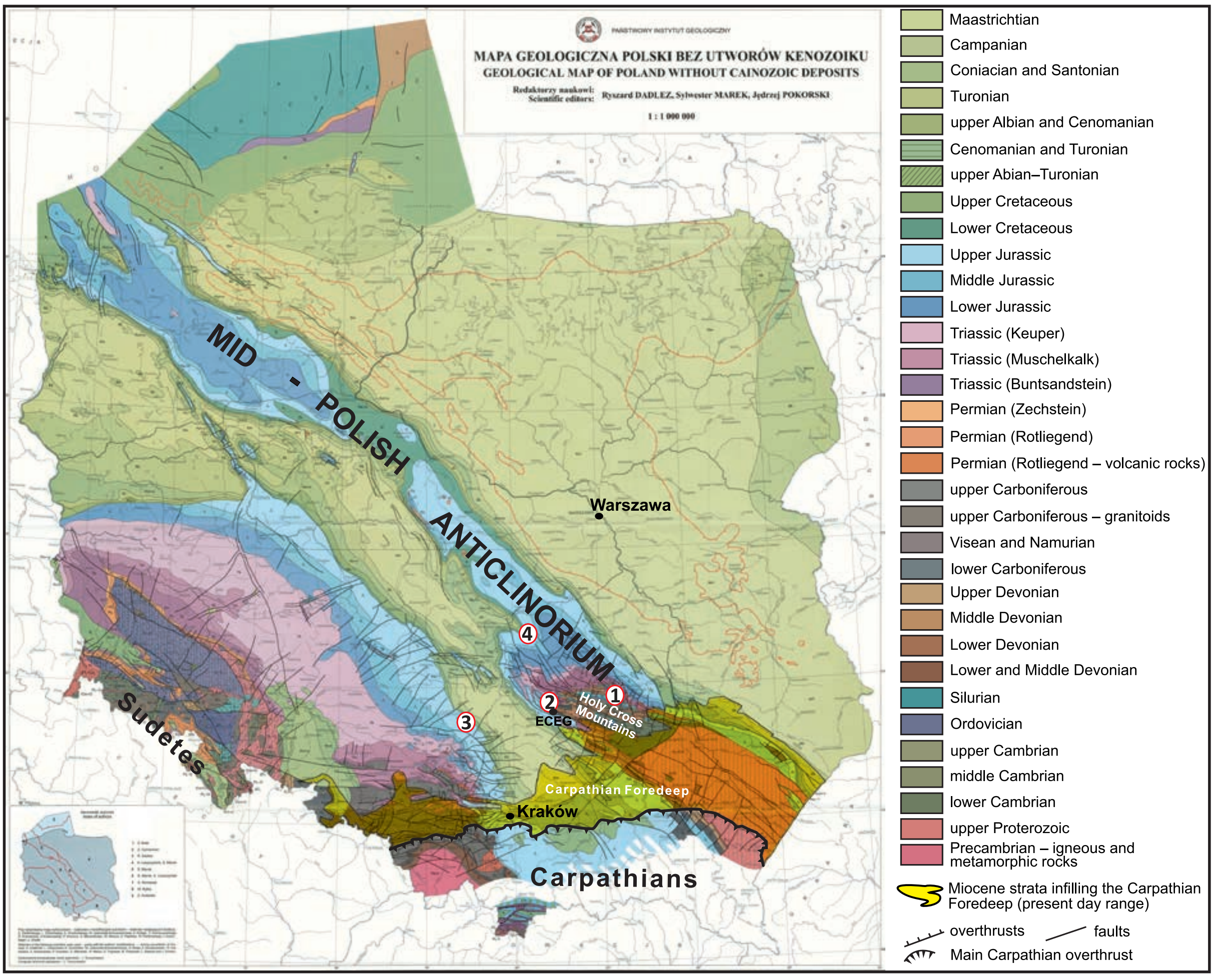

Fig. 1. Geological map of Poland without Cainozoic deposits, after Dadlez et al. (1998), modified to show the present-day range of Miocene strata infilling the Carpathian Foredeep. Red circles indicate the localities visited during the 14th Symposium of the International Fossil Coral and Reef Society: 1 – Skały Quarry (Devonian); 2 – Ostrówka Quarry (Devonian); 3 – Julianka (Jurassic); 4 – Owadów-Brzezinki (Jurassic).

from Ordovician times the Kielce Region was near its present position with respect to Baltica. The Kielce Region is characterized by a more complex structural evolution, relatively shallower facies and smaller thickness of the Palaeozoic succession in comparison to the Łysogóry Region.

The lowermost unconformity tentatively attributed to mid-Cambrian folding (e.g., Gągała 2005) has so far been recognized only in the Kielce Region (Szczepanik et al. 2004), and therefore its lateral extent and the magnitude of the hiatus remain unclear. The unconformity apparently corresponds to a presumed hiatus in the Furongian (upper Cambrian) of the Łysogóry Region, but this issue is still a matter of active study.

The next unconformity is also known only from the Kielce Region. It is attributed to the Sandomierz folding and located at the Cambrian/Ordovician boundary (Samsonowicz 1934). Upper Tremadocian strata rest in the southernmost part of the area directly on sandstones representing Cambrian Series 2 or 3. The stratigraphic gap narrows gradually to the north towards the Holy Cross Fault, where in its direct vicinity the upper Tremadocian conglomerates unconformably overlie Furongian mudstones (Szczepanik et al. 2004).

A Late Caledonian unconformity occurs directly above Ordovician and Silurian deposits that compose a high-order depositional cycle terminated by deposition of very thick greywacke – this unconformity, again, is present only in the southern region. On the contrary, in the northern region, sedimentation continues across the Silurian/Devonian boundary, reflecting the filling up of a Caledonian foreland basin (Narkiewicz 2002; Kozłowski 2008), which is the only trace of a

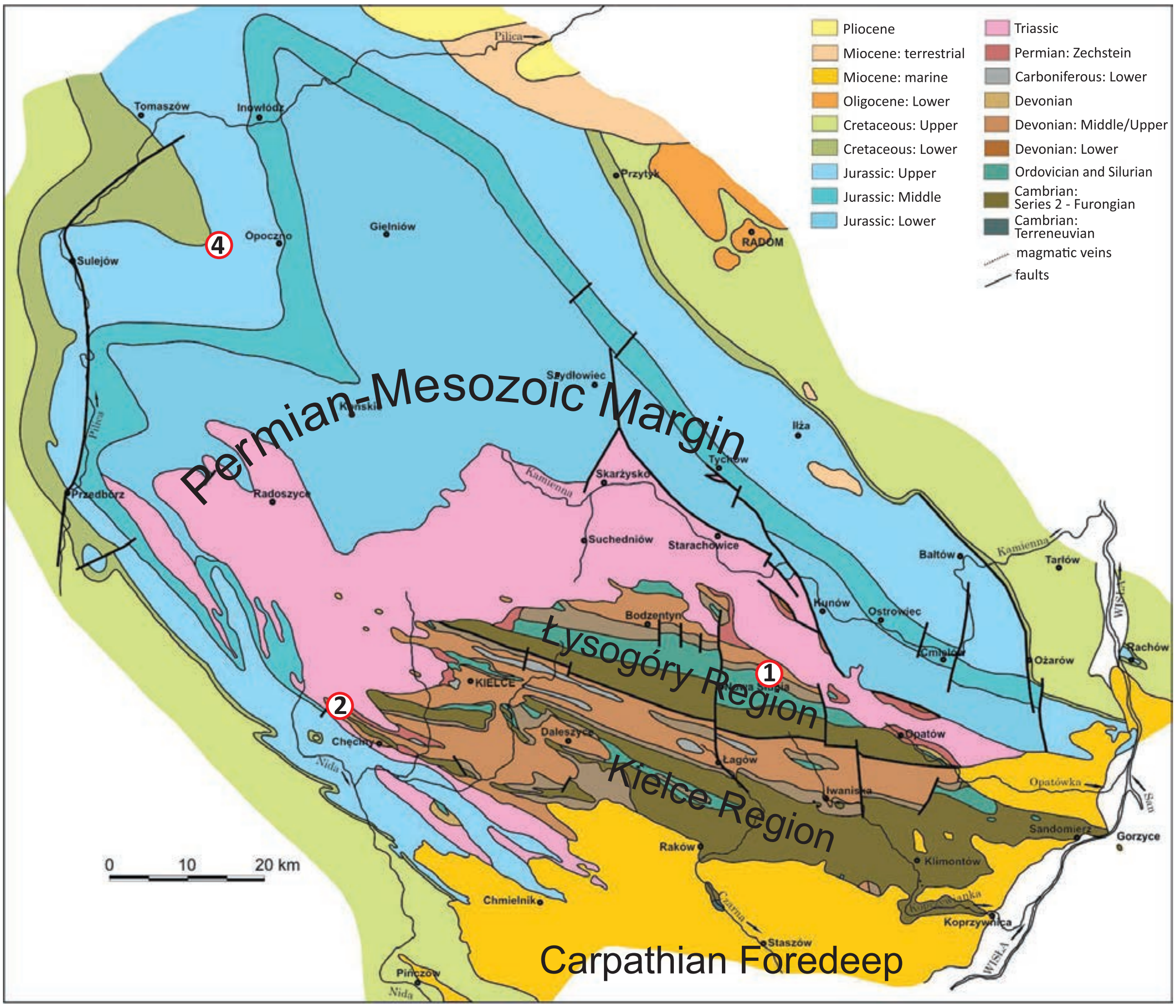

Fig. 2. Geological map of the Holy Cross Mountains (after Samsonowicz 1966 – appendix to the "Guide to Physical Geology labs", edited by W. Jaroszewski, Wydawnictwa Geologiczne, simplified and updated). Red circles indicate the localities visited during the 14th Symposium of the International Fossil Coral and Reef Society: 1 – Skały Quarry (Devonian); 2 – Ostrówka Quarry (Devonian); 3 – locality 3 is beyod the area shown by the map; 4 – Owadów-Brzezinki (Jurassic).

Caledonian arc-continent orogen (Kozłowski et al. 2014), probably representing the equivalent of the Avalonia-Baltica suture (Narkiewicz 2002).

The next depositional sequence reflecting a pronounced deepening-upward cycle comprises Devonian up to Visean deposits (Szulczewski 1995) and is bounded by major angular unconformities, of which the topmost is the Variscan unconformity documented in the entire HCM and neighbouring areas. Variscan folding that took place here in post-Visean times resulted in distinct N-S to NNE-SSW shortening (e.g., Lamarche et al. 1999, 2002) and buckle folding (Konon 2006). During the late folding events or in the post-folding stage, the folds were cut by faults with a dominating strike-slip component (Konon 2007); as a result, block domains bounded by faults were formed (Konon 2006, 2007).

The overlying Permian–Mesozoic depositional cycle has a completely different geological history. The Variscan mountains gradually levelled during the Permian when the valleys between them were filled with continental clastics of local provenance, followed by shallow-marine limestones and mudstones attributed to the Zechstein transgression. The overlying Mesozoic succession generally developed in stable, epicratonic, platform conditions of the eastern part of the Central European Basin (Kutek and Głazek 1972). The evolution of sedimentation in each of the Mesozoic systems generally reflects a transgressive-regressive pattern, with the deepest settings recognized approximately in the middle part of each system. The very high subsidence rates observed within the large, NW-SEorientedbasin running along the EEC margin, i.e. the Mid-Polish Trough, resulted in the fact that by the end of the Cretaceous, the Palaeozoic substratum of the HCM was covered by over 1 km of the Triassic, about 2 km of the Jurassic and up to 3.5 km of the Cretaceous (e.g., Kutek and Głazek 1972; Łuszczak et al. 2020). At the end of the Cretaceous, the Mid-Polish Trough was inverted into the Mid-Polish Anticlinorium; gradual removal of Mesozoic strata then proceeded during the Palaeogene. At that time, the morphology of the HCM was very much as it is now, with eroded material transported towards the south to the Tethys Ocean. In turn, the gradually rising Carpathian Mountains in the beginning of the Neogene resulted in the formation of the Carpathian Foredeep basin (Fig. 1). The last marine stage in the geological history of the HCM area, attributed to the warm and shallow sea of the Para-Tethys, took place at that time. The sea encroached an area with a diverse geological history, forming bays separated by rocky ridges in places where resistant carbonate rocks occurred in the substrate, or covered large parts of the now exposed Palaeozoic basement composed of less resistant strata. With the uplift of the peri-Carpathian forebulge (Leszczyński and Nemec 2015), the earlier Miocene rocks were reworked and redeposited towards the basin interior. The Pliocene was a time of intense erosion and denudation, whereas the Pleistocene is recorded in the area in the form of deposits attributed to all advances and retreats of the Scandinavian ice-sheet (see Lindner 2015). At that time, part of the Palaeozoic inlier remained free of ice cover; in the final stage of the Ice-Age, stone runs developed on the slopes of the highest culminations (Łysogóry) in periglacial conditions.

FACIES DEVELOPMENT IN THE HCM

Cambrian – The Cambrian rocks in the HCM are developed as a thick (up to 3000 m) siliciclastic unit. The succession developed in high-latitude, cool shelf seas surrounding the Baltica palaeocontinent and is dominated by shallow marine, often intensely bioturbated sandstones prevailing in the west, and mudstones and shales of deeper settings in the eastern part of the area. Despite a patchy distribution of trilobites in the succession, they are the base for the biostratigraphic scheme for the area which is often supplemented by analysis of acritarch assemblages (e.g., Żylińska 2002, 2013; Żylińska et al. 2006; Żylińska and Szczepanik 2009; Szczepanik and Żylińska 2016, 2021; Nowicki and Żylińska 2019, 2021; and references therein). So far, the Precambrian/Cambrian boundary has not been recognized, and the relation to the basement remains unknown.

Ordovician – The Ordovician of the HCM is relatively thin (total thickness not exceeding 400 m) and in the Kielce Region rests unconformably with a thin basal conglomerate on Cambrian Series 2 to Furongian rocks. The subsequent Ordovician succession generally reflects a transgression, with typically shallow-marine facies and small thickness of strata. A characteristic feature of the sedimentation pattern in the Middle and Late Ordovician is the emergence of a central elevation with shallow-marine, condensed limestones (Dzik et al. 1994; Trela 1998, 2005), surrounded by deeper intra-shelf basins with a thick succession of graptolitic shales, mostly representing dysoxic environments. The limestones developed on the outer part of a drowned isolated carbonate platform in temperate water settings with a low accumulation rate (e.g., Trela 1998). Changes in oceanic circulation resulted in intense colonization of the surrounding dysoxic basin by soft-bodied burrowers (Trela 2007).

Silurian – Both regions of the HCM display a similar evolution of sedimentation during most of the Silurian, with black graptolitic shales characterizing the Llandovery, Wenlock and the basal Ludlow. This part of the succession contains also siliceous shales and lydites, as well as limestone intercalations and nodules, and is up to 300 m thick. In mid-Ludlow times, deposition of extremely thick (up to 500 m) greywacke commenced in both areas. Provenance analysis points to a similar source of the greywacke material in both regions related to an arc-continent orogen (Kozłowski et al. 2014), but occurrence of more mature sediments and lack of Caledonian deformation in the Łysogóry Region in comparison to that of the Kielce Region indicate a more distal position of the former area in relation to the arc-continent collision zone. The greywackes of the Kielce Region are unconformably overlain by Lower Devonian clastics, which is related to the late Caledonian orogeny, whereas shallowing upward sedimentation linked with filling up of a foreland basin continues across the Silurian/Devonian boundary in the Łysogóry Region (Narkiewicz 2002; Kozłowski 2008).

Devonian – The Devonian sedimentary succession of the HCM reflects the rhythm of eustatic sea-level oscillations. At that time, the area was located within the tropics on the southern shelf of Laurussia (or the Old Red Continent), a major landmass that evolved from the collision between Baltica, Laurentia and Avalonia at the Silurian/Devonian boundary. The Devonian is developed in two distinct palaeogeographic units – the northern, deeper Łysogóry unit and the southern, shallower Kielce unit, with the Kostomłoty Transitional Zone in between (e.g., Racki 1992).

The Lower Devonian is characterized by extensive siliciclastic deposition. In the north of the area it rests conformably on the Silurian and is about 550 m thick. Its fauna, sedimentary structures and trace fossils indicate evolution from continental to shallow-marine clastics deposited in nearshore, storm- and wave-dominated settings (Szulczewski 1995) that can be interpreted as early subordinate oscillations of the Devonian transgression (Szulczewski and Belka 2000). In the south, the Lower Devonian is much thinner and unconformable to the Silurian.

Transgressive/regressive events that took place close to the Early/Middle Devonian boundary resulted in the cessation of clastic sedimentation and in the development of a carbonate platform (up to 800 m total thickness) already during the Eifelian. The development of this platform dominated the palaeogeography and depositional pattern of the entire area during the Middle and Late Devonian. The evolution of the carbonate platform displays three phases: non-reefal peritidal deposition, followed by bank and reef phases (Racki 1992; Szulczewski 1996). The first facies common for both regions of the HCM is a thick series of generally monotonous Eifelian dolomites, which in selected localities display exceptional structures and fossils. One of them is Skały Quarry near Nowa Słupia (Figs. 1 and 2; **STOP 1**), which exposes beautifully preserved sedimentary cycles typical of shallow-marine tide-dominated settings, with unique horizons yielding large brachiopods of the genus *Bornhardtina* (Skompski and Szulczewski 1994).

The lateral shrinkage of the carbonate platform resulted in the formation of a sedimentation pattern similar to that from the Late Ordovician times, with a central elevation, dominated by reef limestone deposition and two intra-shelf basins, largely filled with over 1000-m thick marly-shale deposits (Szulczewski 1971, 1995). A striking feature in the northern basin is the presence of Middle Devonian shallow-marine fine-grained clastics, where an assemblage of trace fossils attributed to the life activity of anemones has been recognized (Orłowski and Radwański 1986). The prolonged and stepwise drowning of the carbonate platform was stimulated by eustatic sea-level rises (Racki 1992) and syn-depositional block-faulting (Szulczewski 1978). Tectonic extension acted as a primary control during the main drowning phases (Szulczewski et al. 1996a), governing the subsidence rate of particular blocks and volcanic activity. Elevated blocks were subject to low sediment net rate and display stratigraphic condensation and reworking, as evidenced by remarkably fossiliferous crinoidal-cephalopod limestones (as for example in the Fammenian of Ostrówka Quarry; **STOP 2**) and/or extremely rich conodont assemblages (Racki and Szulczewski 1996; Szulczewski et al. 1996b). Superimposed on local events are global phenomena at the Frasnian/Fammenian boundary, when a major biotic crisis resulted in the extinction of c. 50% of genera and a significant impoverishment in many faunal groups (see Szrek and Ginter 2007, but also Szrek and Salwa 2020).

Tabulate and rugose corals dominate the Devonian coral fossil record in the entire area beginning from the Eifelian (e.g., Stasińska 1958, 1974; Różkowska 1956; Fedorowski 1965, 1967; Nowiński 1992; Zapalski 2005, 2012). Some of the tabulate communities were later reinterpreted as representing mesophotic coral ecosystems (Zapalski et al. 2017).

Carboniferous – Deposits representing this system are restricted to the Mississippian and are present only in the Kielce Region. Sedimentation in the early phase was controlled by the swell-to-basin topography inherited after the Late Devonian, with non-deposition in the central swell at the Devonian/Carboniferous boundary, and very thin and discontinuous lowermost part of the succession (Szulczewski 1996). The deposits are represented by alternating limestones and shales within the swells and black siliceous shales within the basins; the latter sediments onlapped the slopes of the swell and successively buried its top in late Tournaisian times. Black shale sedimentation characterizing this anoxic environment prevailed in the Visean in the entire basin, and was locally interrupted by the deposition of carbonate sub-marine fans with benthic fauna from different ecological niches (including rugose and tabulate corals; Fedorowski 1970, 1971; Nowiński 1976; Figs. 1 and 2; **STOP 2**), derived from a hypothetical carbonate platform located to the south of the area (Belka et al. 1996). The Carboniferous succession terminates with the sedimentation of fine siliciclastics. Uppermost Mississippian and Pennsylvanian strata are absent in the HCM.

Permian – The Permian rests with a pronounced unconformity on Palaeozoic rocks that were folded and faulted in Variscan times. The Permian succession begins with coarse basal breccia and conglomerates; the age of these deposits cannot be stated precisely, although part of them are lateral equivalences of the shallow-marine sediments of the Zechstein sea that flooded the uplifted Palaeozoic massif by the end of the Permian.

The Palaeozoic/Mesozoic boundary interval in the HCM is characterized by the presence of red clastic rocks, of which part are assigned to the Rotliegend facies and part – to the Buntsandstein. The two facies have been traditionally distinguished by a simple criterion of the presence of solely local (Rotliegend) or allochthonic (Buntsandstein) sources of the clastic material; however, the real stratigraphic assignment of the strata still remains unclear.

Triassic – The part of stable Europe with the HCM area moved from the dry, subtropical climate zone (c. 25ºN latitude) in the beginning of the Triassic to a more humid zone located almost 1,700 km to the north (c. 40ºN latitude) by the end of this period (Nawrocki 2008). The lower and upper part of the Triassic succession is related with continental settings of the Buntsandstein and Keuper facies, respectively, which are typical for the Central European Basin. Marine settings appeared approximately during the mid-Triassic with deposition of the Röt and Muschelkalk facies. Carbonate sedimentation with characteristic terebratulid coquinas and beds with ceratites appeared during three transgressive events from the Tethys Ocean (Szulc 2000). The disappearance of a normal marine setting was related with the beginning of Keuper facies deposition, which took place in the HCM area earlier than in Germany (Trammer 1975).

Jurassic – A striking difference of the Lower Jurassic in the HCM area compared to the Central European Basin is the presence of continental and marginal-marine settings, dominated by fluvial and deltaic environments; owing to lack of precise biostratigraphic tools, this part of the Jurassic was correlated with the chronostratigraphic framework by means of sequence stratigraphy (Pieńkowski 2004). The Middle Jurassic is developed as marine clastics (e.g., Giżejewska 1975), with a distinct deepening and transition from clastic to carbonate sedimentation at the Middle and Late Jurassic boundary (Matyja and Wierzbowski 2006). The Upper Jurassic commences with bedded and biohermal limestones and marls containing siliceous sponges preserved as calcareous 'mummies' (Matyja and Pisera 1991). The maximal extent of the sponge megafacies was in the Oxfordian. Regressive events appeared later, reflected in the development of a shallow carbonate platform, at first in the north-eastern part of the area (Gutowski 1998) and later also in the south-western part (Matyja 1977). Coral reefs colonized elevations on the sea that constituted former sponge buildups or appeared on the marly sea bottom as pioneer assemblages beginning the ecological succession of rich shallow-marine assemblages (Matyja and Wierzbowski 1996; Gutowski 2004a; **STOP 3**). The coral assemblages are dominated by forms preferring deeper and calmer settings (Roniewicz 1966; Roniewicz and Roniewicz 1971). Higher up, the shallow carbonate platform includes coral-nerineid-diceratid limestones, platy limestones and oolite-platy limestones (e.g., Kutek et al. 1992), with the gradually shallower facies appearing earlier in the north-eastern part of the area, and later in the south-western part of the area (Matyja et al. 1989; Gutowski 2004b). Following a sea level rise recognized throughout Europe, the shallow-water platform was drowned as reflected in the appearance of coquina beds and marls with more abundant ammonites including invasive migrants (Matyja and Wierzbowski 2000). Typically, the top of the Jurassic is erosive and with a stratigraphic gap overlain by mid-Cretaceous strata (Albian or Cenomanian (e.g., Gutowski 1998). The topmost part of the Jurassic is recorded in the NW margin of the HCM and further beyond (e.g., Kutek and Zeiss 1994; Wierzbowski et al. 2016; **STOP 4**).

Cretaceous – The Cretaceous in the vicinity of the HCM is composed of two mostly marine sedimentary-diastrophic stages. The lower part is represented by clays and mudstones continuing from the Jurassic and has been recognized on the surface in the Tomaszów Syncline (Kutek et al. 1989). Probably from the Hauterivian, the entire area was subject to long-term erosion or at least non-deposition related with the Neo-Cimmerian tectonic phase. The succession of the second marine phase begins with Albian or Cenomanian clastic transgressive deposits, sometimes with a slight angular unconformity and always with a huge stratigraphic gap with regard to the Jurassic substrate. Sedimentation changed from clastic- to carbonate-dominated by the end of the early Turonian (Marcinowski and Radwański 1983). From that time till the end of the Paleocene the chalk facies, with opokas and flints, marls and gaizes, appeared in a large part of Poland (Walaszczyk 1992). These deposits can best be viewed in exposures along the Vistula River northwards from the HCM area. Some sites with Maastrichtian strata yielded colonial scleractinians attributed to *Madrepora* sp. (Stolarski and Vertino 2006).

Palaeogene – This was a time when after the Laramide phase the uplifted Palaeozoic massif of the HCM was subject to intense erosion of its Mesozoic cover. Lower Palaeocene marine strata have been recorded only to the north of the HCM along the Vistula River; later a regression took place.

Neogene – The presence of Miocene deposits in the HCM area is related with the evolution of the Carpathian Foredeep Basin. A widespread transgression from the Tethys Ocean on a diversified basement composed of rocks characterized by different susceptibility to erosion resulted in a wide array of littoral and sublittoral facies formed in tropical to subtropical conditions, including siliciclastics, marls, red-algal limestones, and bioclastic limestones. A unique facies is the Korytnica Clays, replete with a great abundance of shelly biota (see overview in Radwański and Górka 2015), including hermatypic and ahermatypic Scleractinia (Stolarski 1991; Roniewicz and Stolarski 1991). Partial evaporation of the basin resulted in a remarkably thick sequence of gypsum (over 40 m) developed along the southern slopes of the HCM. The last marine deposit is related to the reworking and redeposition of the earlier formed Miocene red-algal limestones towards the basin.

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EXCEPTIONALLY PRESERVED LATE JURASSIC ECOSYSTEM OF OWADÓW-BRZEZINKI, CENTRAL POLAND

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The Owadów-Brzezinki quarry is an active open-pit marl and limestone mine located in central Poland in the Łódzkie Voivodeship (Opoczno County) in the northwestern margin of the Holy Cross Mts (Fig. 1). The rocks exposed in the quarry belong to the uppermost stage of the Upper

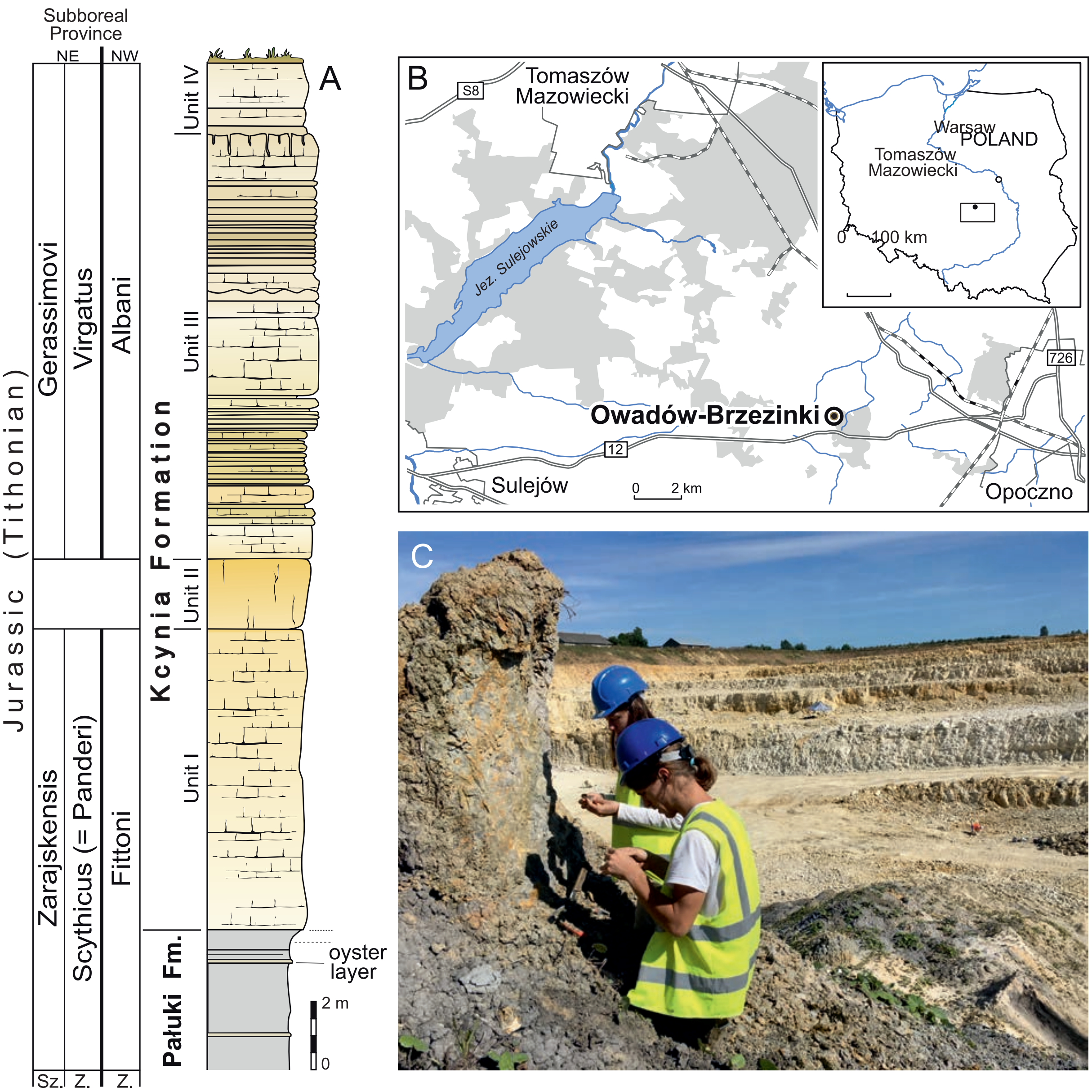

Fig. 1. Location of the site and lithological succession in the study area. **A**. Lithological succession and biostratigraphy of the Owadów-Brzezinki Quarry. The topmost part of the Pałuki Fm and overlying limestones of the Kcynia Fm (Units I–IV). **B**. Road map with the location of the Owadów-Brzezinki site and its proximity to Tomaszów Mazowiecki in Central Poland. **C**. General view of the Owadów-Brzezinki section (paleontological field work). Abbreviations: Fm, Formation; Sz., Subzone; Z., Zone.

Jurassic – the Tithonian – and are independently correlated with the local East European Substage – the Middle Volgian. This palaeontological site is one of the most important recent palaeontological discoveries from Poland (Kin et al. 2012, 2013; Błażejowski et al. 2016, 2023). Excavation work has been carried out systematically since 2013. It has beenconducted at the Institute of Paleobiology PAS in Warsaw as part of research projects supported by the Polish National Science Centre and has involved undergraduate students, doctoral students and scientists from all over the world (Fig. 1C). Remarkable well-preserved fossils of marine and terrestrial organisms of Late Jurassic age, many of them new to science, provide a good opportunity to study the taphonomy of the ecosystem, evolution and migration of taxa, and paleoenvironmental changes (cf. Błażejowski et al. 2016, 2019; Wierzbowski et al. 2016).

AN OVERVIEW OF THE MOST IMPORTANT PALAEONTOLOGICAL FINDS

The palaeontological site of Owadów-Brzezinki is referred to as a new "taphonomic window" into the Late Jurassic and provides insight into the evolution of life on Earth. It is especially notable that new species endemic to this site are constantly being discovered, such as the lobster-like decapod crustaceans (Feldmann et al. 2015; Błażejowski et al. 2016; Fig. 2) and xiphosuran arthropods (Kin and Błażejowski 2014; Błażejowski 2015; Błażejowski et al. 2019, 2020; Fig. 3). These deposits constitute one of the largest accumulations of Jurassic horseshoe crabs discovered so far. The most prominent taxa of vertebrates discovered so far are represented by the ichthyosaur *Cryopterygius kielanae* (Tyborowski 2016; *Undorosaurus* according to Zverkov and Jacobs 2021), the pancryptodiran turtle, *Owadowia borsukbialynickae* (Szczygielski et al. 2018) and isolated plesiosaur teeth (Weryński and Błażejowski 2023). Other vertebrate taxa are represented by Actinopterygii and Elasmobranchii (Kin et al. 2013; Błażejowski et al. 2015) and marine crocodylomorphs (Błażejowski et al. 2016), with additional shore fauna represented by insects, terrestrial crocodylomorphs, and possibly pterosaurs (Kin et al. 2013). The Owadów-Brzezinki section is located within both the Brzostówka marls of the topmost part of the Pałuki Formation (Fm) and the overlying limestones of the Kcynia Fm (Błażejowski et al. 2016; Fig. 1). The uppermost part of the Pałuki Fm and the overlying limestones of the Kcynia Fm include the Sławno Limestone Member (Mb), "*Corbulomima* limestones", and a horizon of "serpulid" beds exposed in the section (Kutek 1994). The sedimentary pattern observed in the Owadów-Brzezinki section indicates a gradual marine regression revealed

Fig. 2. Lobster-like decapod crustaceans *Mecochirus* sp. nov. (ZPAL Cr.11/O-B/22/1). Pałuki Formation, Upper Jurassic (Tithonian).

Fig. 3. Horseshoe crab exoskeleton – *Crenatolimulus darwini* (Kin and Błażejowski, 2014).

by a transition from offshore to coastal and lagoonal settings. Its uppermost part was deposited during a short-term marine transgression and shows the reappearance of coastal environments (Błażejowski et al. 2016; Wierzbowski et al. 2016).

The uppermost part of the Brzostówka Marl Mb of the Pałuki Fm from the Owadów-Brzezinki quarry (ca. 4 m thick) consists of black, blue-greyish and yellow-bluish marls with the intercalation of thin oyster-bearing and marly limestone beds (cf. Błażejowski et al. 2016; Wierzbowski et al. 2016). The marls yielded abundant marine microfossils, bivalves, ammonites, decapod crustaceans and fish (Błażejowski et al. 2016). The overlying limestones of the Kcynia Fm have been subdivided into four lithological units (Fig. 1).

According to the stratigraphical studies of Kutek (1994) and Matyja and Wierzbowski (2016) based on the ammonite fauna, the lower part of the Owadów-Brzezinki deposits is dated to the regularis horizon (the uppermost part of the Brzostówka Marl Mb of the Pałuki Fm) and zarajskensis horizon (Unit I of the Sławno Limestone Mb of the lowermost part of the Kcynia Fm) of the Zarajskensis Subzone of the Scythicus (Panderi) Zone of the Middle Volgian, as well as to the Fittoni Zone from the "Bolonian" zonation of England. The upper part of the Owadów-Brzezinki section (Unit III and Unit IV belonging to the "*Corbulomima* limestones" and "serpulid" beds, respectively) has, in turn, been assigned to both the Gerassimovi Subzone of the Virgatus Zone of the Middle Volgian and the Albani Zone of the "Portlandian". Owadów-Brzezinki has recently attracted much attention not only due to the exquisite quality and quantity of preserved fossils, but also due to its palaeogeographic significance – this site is proposed to encompass an important area, located on the border of the Boreal/Subboreal and Tethyan realms, where the mixing of temperate and tropical faunal biota occurred (Błażejowski et al. 2023; Fig. 4).

THE OWADÓW-BRZEZINKI GEOEDUCTION AREA

The discussed area is of importance not only for paleontology as a science and popularization of this field in Poland, but also for the development of the region and its people. For several years

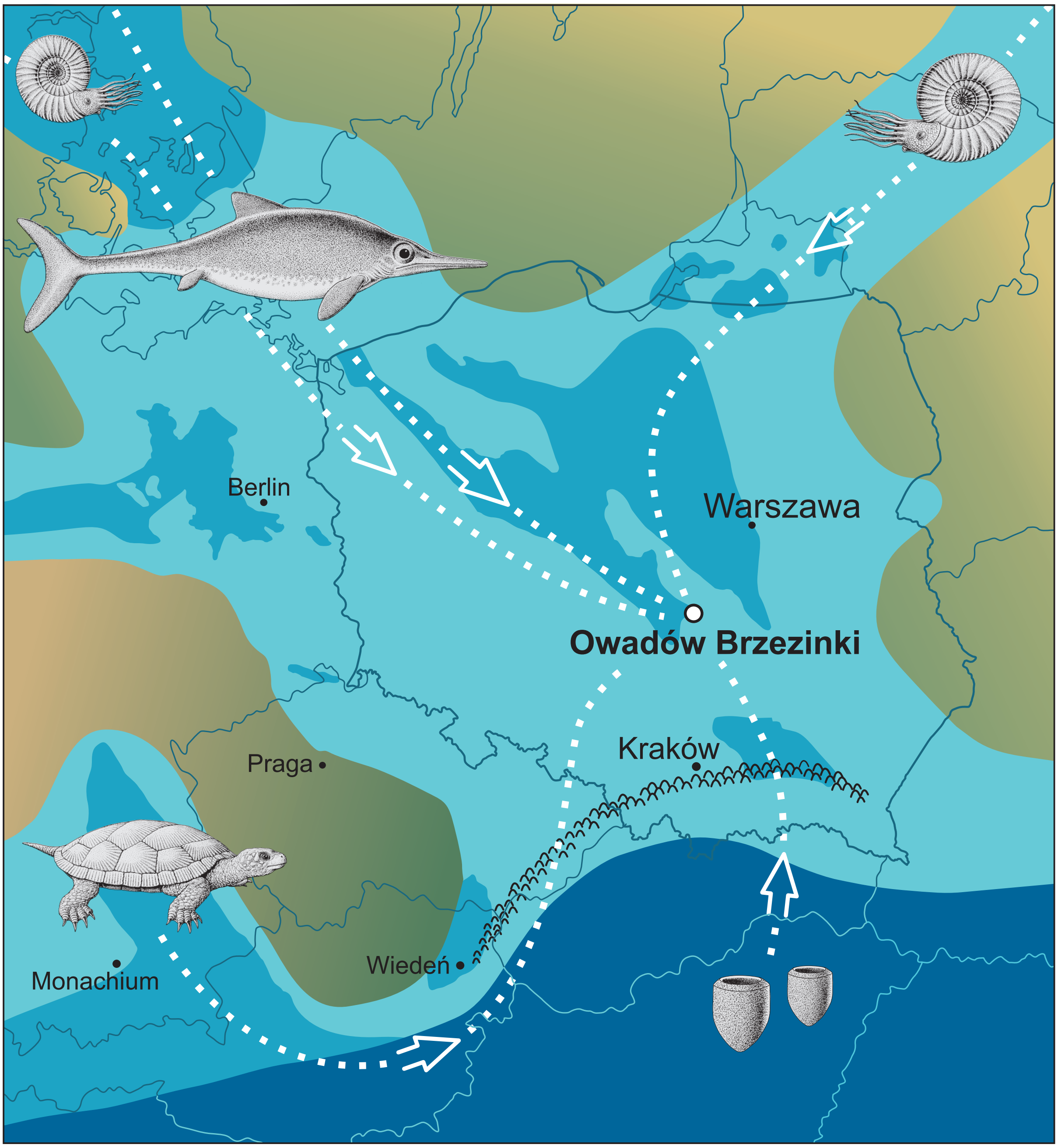

Fig. 4. Paleogeographical map of Europe at the end of Jurassic (acc. B. Błażejowski, B. Matyja, and A. Wierzbowski).

now, workshops and lectures have been held in the Sławno Commune aimed at promoting knowledge of geology and especially palaeontology among the population of the region by initiating an atmosphere of understanding and respect for the natural environment. These activities are directed mainly to school children and youth, as well as to people interested in research and protection of the geological heritage of our country. It also serves as an attraction for national and international geological and paleontological conferences. Of great interest to researchers and the public alike is the palaeontological pavilion in the thematic geoeduction area (called also "Owadów-Brzezinki Geopark"), under supervision of the Sławno Commune, where fossils of Jurassic animals were discovered and where their reconstructions are currently displayed (Fig. 5). The most spectacular specimens include natural-sized ammonites, fish and marine reptiles: ichthyosaurs and turtles, and crocodylomorphs, as well as flying pterosaurs. The scientific team examining the fossils from this site supervised the creation of the exhibition at the museum and the plaques at the geo-educa-

Fig. 5. **A**. The entrance gate to the Owadów-Brzezinki Geosite (geopark) in Sławno community. **B**. The palaeontological pavilion presents life-size reconstructions of animals which inhabited the local seas and islands during the Late Jurassic.

tional path running along the observation deck at the edge of the quarry. The telescopes placed on the terrace allow for observing the limestone excavation works carried out by the owner of the quarry (Nordkalk Company), as well as the research and exploration camps of scientists. In the central part of the observation deck there is a 12-meter-long statue of an ichthyosaur, which is a symbol of local paleontological discoveries.

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CORAL COLONIZATION OF THE CYANOBACTERIA-SPONGE BIOHERMS, LATE JURASSIC, JULIANKA QUARRY, POLAND

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LOCALITY

The abandoned "Janina" quarry at Julianka village lies 20 kilometers east of Częstochowa, in the Przyrów district, at the north-eastern skirt of the Częstochowa Upland ("Częstochowa Jura"). The quarry is located in a very picturesque area with rocky hills of massive limestones, which are remnants of the Late Jurassic (mostly Late Oxfordian) cyanobacteria-siliceous sponge biohermal complexes. The geological and morphological development present here is similar to that of other highland areas in Central Europe, referred to as the "Jura" areas (after the Jura Mts.), like the Franconian Jura and the Swabian Jura in southern Germany. All of these Jura areas stretch along the former northern margin of the old Tethys Ocean, and all of them show the presence of similar deposits of sponge megafacies, generally indicative of a deep-neritic environment (Fig. 1). The quarry has been known to geologists for a long time, but its original description was made in reference to the transgressive Cretaceous deposits – of the uppermost Albian and Cenomanian (Różycki 1938).

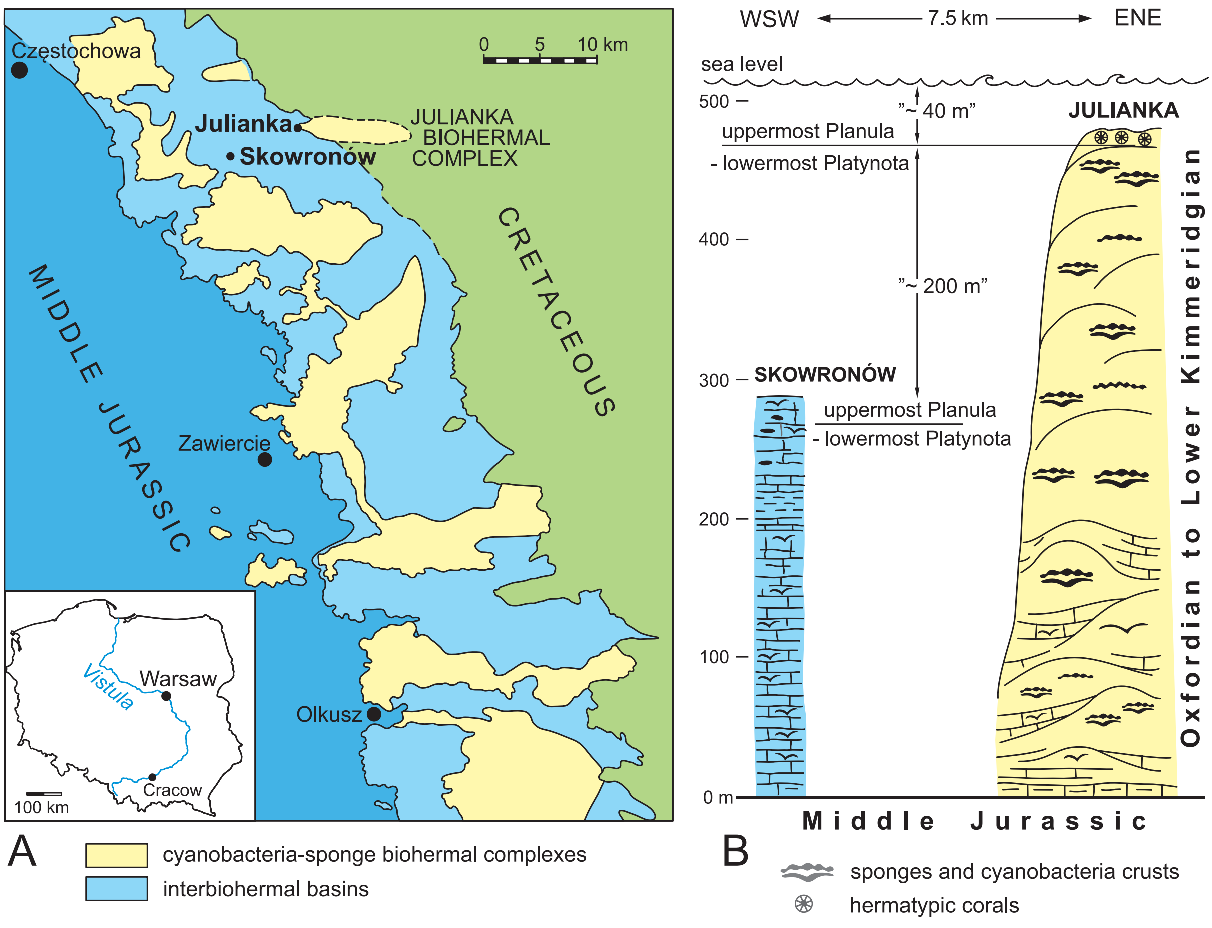

Fig. 1. Distribution of the Late Jurassic cyanobacteria-sponge biohermal complexes in the Cracow-Wieluń Upland (Polish Jura) (**A**), and sea-bottom relief at the Julianka Biohermal Complex in the Early Kimmeridgian (Planula/Platynota chron boundary) when the hermatypic corals settled the topmost parts of the complex (**B**) (after Matyja and Wierzbowski 1996).

GEOLOGICAL PROFILE AND INTERPRETATION

The Jurassic limestones of the quarry first came into prominence when it appeared that they contain "deep-water" coral assemblages directly following the development of older cyanobacteria-siliceous sponge biohermal complexes (Matyja and Wierzbowski 1996, 2006; see also Roniewicz and Roniewicz 1971).

The lowest deposits locally exposed at the bottom of the quarry are soft, friable "chalky" limestones with dark cherts. They yield abundant fauna: siliceous sponges (Lithistida and Hyalospongea), calcareous sponges, brachiopods, bryozoans, serpulids and others. These deposits belong to the upper part of the cyanobacteria-sponge massive limestone complex, as seen in the neighboring borehole Podlesie P-9, placed about 10 kilometers east of the Julianka quarry: the borehole penetrated sponge limestones at thicknesses of at least 300 meters below the coral limestones (Wierzbowski et al. 2016). These sponge massive limestones represent a huge biohermal complex (Julianka Biohermal Complex). Several biohermal complexes and separated interbiohermal basins developed in the whole area of the Częstochowa Upland, which resulted in markedly diversified relief of the sea bottom. These sediments accumulated for about 160–200 m during the Bifurcatus Chron of the Late Oxfordian, i.e. before the development of the coral limestones. Additionally, the character of the faunal assemblages and the sedimentological features of the biohermal complexes indicate that they probably developed in deep water, at least a few hundred of meters in depth.

The settlement of coral assemblages at the top of the biohermal complexes had to be preceded by a sudden sea-level fall. It is marked in the Julianka section by a sharp erosional boundary at the top of the older deposits with sponges. Locally, near that boundary, appear "transitional" deposits with diversified faunal assemblages composed of numerous brachiopods, various bivalves, calcareous sponges, lamellar corals (*Microsolena*), crinoids and other echinoderms, and ammonites. Such deposits were recognized at some parts of the Julianka succession, and at a neighboring quarry near Sygontka village. Their faunal assemblage is of autochthonous character, and it suggests a slow sedimentation rate along with an abundance of organic matter, normal salinity, and good water-circulation (Heliasz and Racki 1980). According to age estimates based on ammonites (Matyja and Wierzbowski 2006), this stratigraphic interval corresponds to the uppermost part of the Planula Zone–lowermost Platynota Zone, correlated with the middle part of the Lower Kimmeridgian, in accordance with the recently accepted Global Boundary Stratotype Sections and Points (GSSP) of the base of the stage. At the same time the fossiliferous "chalky" limestones with sponges started to spread over the micritic limestones of the adjoining interbiohermal basins, as seen in the outcrops at nearby Skowronów village. This indicates that during the foundation of the coral buildups at the top of the Julianka Biohermal Complex, the relief of the sea bottom still existed, with variations in bathymetry of about 200 meters.

The massive coral limestones occurring above are about 20 m in thickness and form isolated coral buildup seen in the north-western part of the quarry. The coral assemblage consists here of several platy (or lamellar) forms of the genera: *Microsolena* (dominating taxon), but also *Thamnasteria*, *Thecosmilia*, *Actinarea*, *Fungiastrea*, and *Pseudocoenia* (determined by Ewa Roniewicz). Microsolenids share a number of morphological similarities with present-day agariciid scleractinian coral *Leptoseris* (mesophotic *Leptoseris fragilis*): the thamnasterioid arrangement of calices, lack of corallite walls and importantly, well developed perforate septa with pennulae. In present-day *Leptoseris*, the pennulae fused together to form continuous lateral ridges (menianae), which support a complex gastro-vascular system (Schlichter 1991a). This gastrovascular system consists of ducts radiating from the polyp's pharynx and aid in heterotrophic suspension feeding modes. Such a striking similarity of micromorphological features of septa between microsolenids and *Leptoseris* suggests that microsolenids developed an analogous gastrovascular system and suspension feeding, an adaptation to poorly illuminated (?mesophotic) waters (Figs. 2, 3).

Other associate fauna includes calcareous sponges, brachiopods, and various echinoderms (especially crinoids). The sedimentary textures are coral boundstone to wackestone with peloids and bioclasts. Towards the east, the coral limestones are laterally replaced by bedded soft, po-

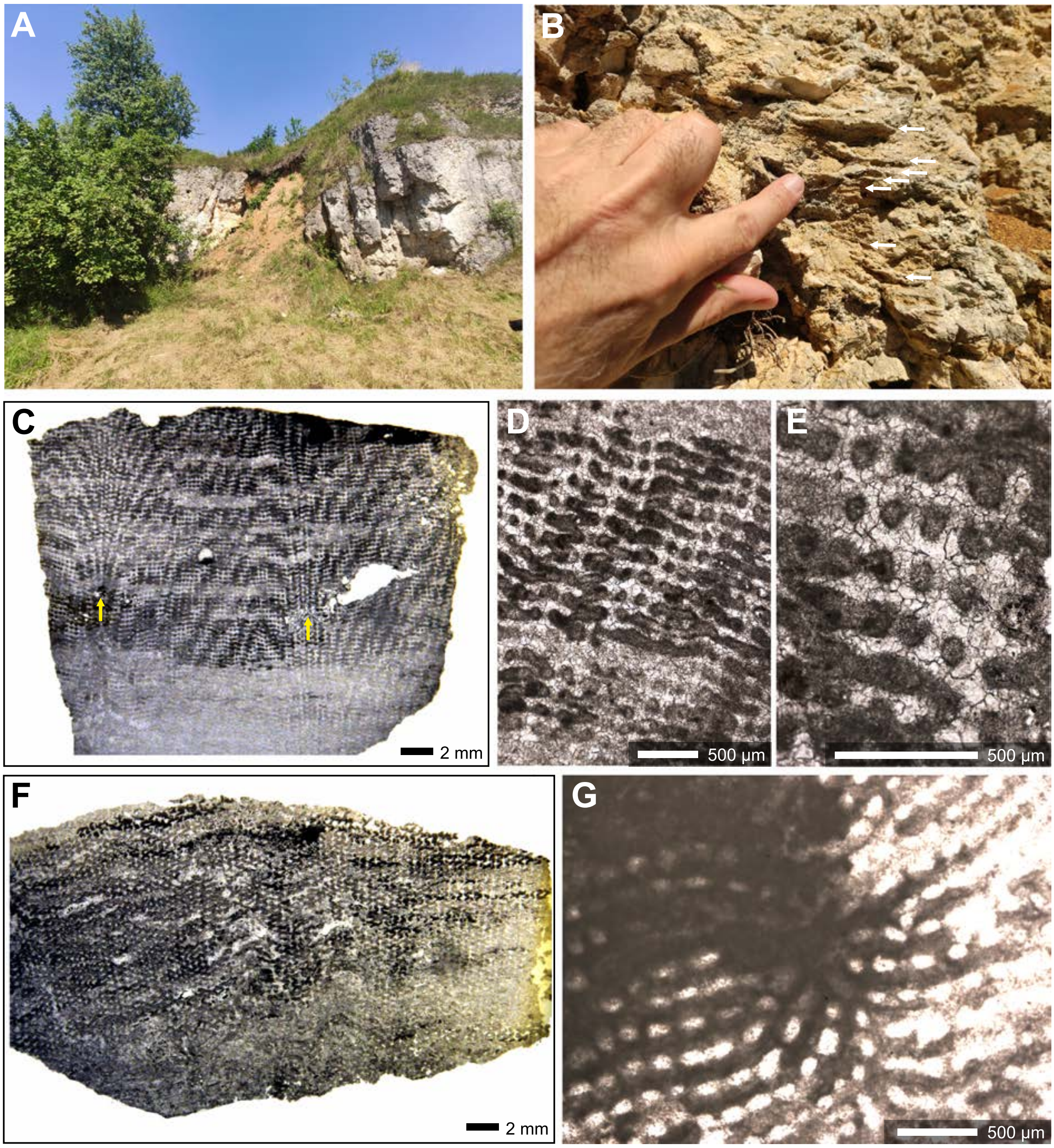

Fig. 2. Julianka limestone quarry and lamellar microsolenid scleractinian corals from this locality (Lower Kimmeridgian). **A**. General view of the northern part of the quarry (near the entrance) where limestones with rich coral fauna are exposed. **B**. Numerous lamellar colonies in growth position (white arrows). **C**–**G**. Longitudinal tangential (C–F) and transverse (G) sections of *Microsolena agariciformis* Etallon,1859 (different magnifications; ZPAL H.28/8). Yellow arrows (C) mark regions sectioned near the corallite centers. Recrystallized skeletons show regularly perforated septa (D, E) and pennulae (G) that form horizontal series (D, E).

rous limestones with cherts. The lithology includes packstones to wackestones and biomicrites to bioplemicrites. These are cut by a dense system of almost vertical neptunian dykes, some of them filled with micritic limestones. The oldest of them developed during Late Jurassic, possibly not differing markedly in age from surrounding rocks because of similar faunal content, some are markedly younger being of the Cretaceous age (Brachaniec et al. 2016).

Above the coral deposits, there exist glauconitic sands and sandstone with abundant marine fauna (Marcinowski 1970), deposited in the uppermost Albian and Cenomanian. There is a marked stratigraphical gap between the Jurassic limestones and the overlying Cretaceous deposits, cover-

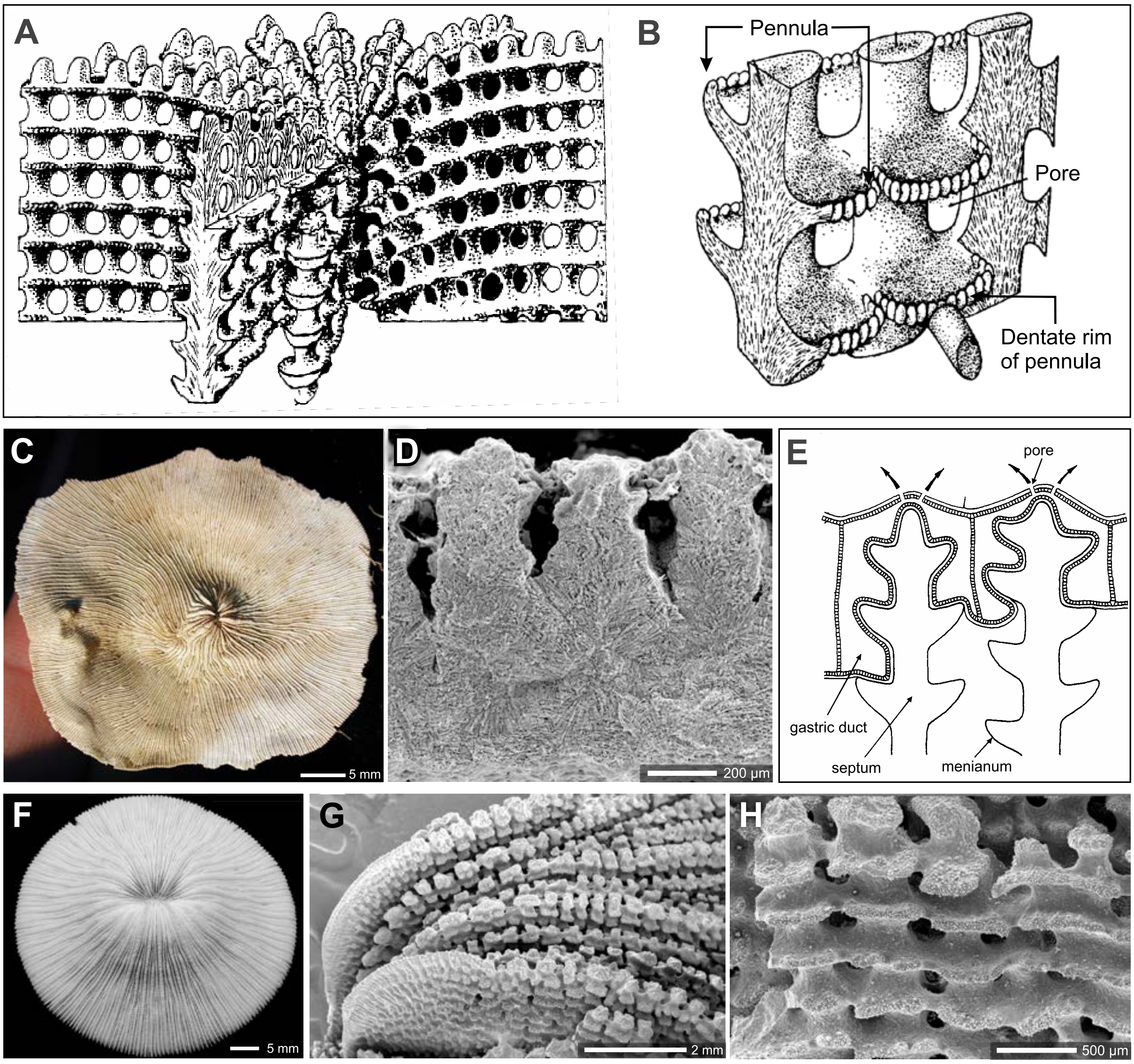

Fig. 3. Model of skeletal organization of *Microsolena* scleractinian coral with regularly perforated septa and horizontal series of pennulae (**A**, general view; **B**, detail) (after Morycowa and Roniewicz 1995). **C**, **D**. Distal view (C) and longitudinal broken section (D, SEM micrograph) of lamellar colony of modern zooxanthellate, agariciid scleractinian coral *Leptoseris fragilis* Milne Edwards and Haime, 1849, with menianae developed on lateral sides of septa (ZPAL H.25/48). **E**. Model of gastrovascular, suspension feeding flow-through system in *L. fragilis* (gastric ducts supported by menianae and pores in oral epithelium) (after Schlichter 1991b; Roniewicz 1996). **F**–**H**. *Cycloseris sinensis* Milne Edwards and Haime, 1851 (F, distal oblique view; USNM 92971) with perforated septa and well developed pennulae (G, H; ZPAL H.25/157).

ing a large part of the Upper Jurassic (large part of the Kimmeridgian and Tithonian) and nearly the whole Lower Cretaceous. The younger Jurassic overlain possibly by the earliest Cretaceous deposits as originally deposited here, have been uplifted, and removed owing to a major period of erosion during the late Early Cretaceous, due to the Neo-Cimmerian tectonic deformations. That time the exposed Jurassic limestones were also subjected to karstification and silicification: the quarry presents the pre-Late Albian–Cenomianian karst forms with remnant of the cave that developed prior to the silicification and submergence (Głazek et al. 1992).

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THE DEVONIAN AND CARBONIFEROUS OF THE HOLY CROSS MOUNTAINS

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During the Devonian, the Kielce Region represented a carbonate platform, shallowest in the central part, with deeper basins towards the north and south. Givetian to Frasnian rocks near Chęciny were deposited in the deeper, southernmost part of this carbonate basin.

Between the Kielce and Łysogóry Regions, a transitional basin – the Kostomłoty Transitional Zone (KTZ) – was characterized by mixed, marly-shale facies (Racki 1985, 1992). Givetian rocks of the KTZ yielded abundant tabulate corals (Nowiński 1992, Zapalski 2012), some of them were later interpreted as forming a mesophotic coral ecosystem (Zapalski et al. 2017).

The Devonian in the Łysogóry Region is mostly represented by mixed, carbonate-siliciclastic facies. A number of diversified coral communities thrived in this part of basin from the Emsian to the Givetian (e.g., Stasińska 1958, 1974; Zapalski 2005). Some of these communities have been interpreted as mesophotic coral ecosystems (MCEs, Zapalski et al. 2017), especially from the late Eifelian parts of the Skały Beds.

According to the generally accepted views (summarized for example by Skompski 2015), the development of the carbonate platform was rapidly terminated by events at the boundary between the two Late Devonian ages: the Frasnian and the Famennian. The nature of these events still remains unclear, but their influence on the evolution of organisms and sedimentary conditions within the shelf of Laurussia was far-reaching. A global biotic crisis led to the extinction of 50% of genera and impoverishment in the number of species in many animal groups, including the stromatoporoids responsible for the construction of large carbonate build-ups, determining the structure of carbonate platforms in the Ordovician, Silurian and Devonian around the world. The Upper Devonian succession of the Holy Cross Mountains was additionally influenced by minor tectonic block movements that uplifted and sank the sea floor. Parts of the sea floor with the most profound relief (usually organic build-ups) were often elevated above sea level, and their tops were subject to erosional shearing or even karstification. Subsidence of the sea floor induced the appearance of characteristic cephalopod and crinoid facies on these blocks, in which the increase of sediment thickness was compensated by submarine erosion. Low increases in total thickness resulted in highly condensed successions, in which the thickness of the sediment preserved per unit of time was several times lower than in successions in the surrounding, deep basins. The deepening trend continued through most of the early Carboniferous (Szulczewski et al. 1996).

STOP 1: Skały Quarry and heap, Bodzentyn Synclinorium, Łysogóry Region

Eifelian mesophotic coral ecosystems in mixed, carbonate-siliciclastic sedimentation of the Łysogóry Region

The thick, Middle Devonian sequence of mixed facies crops out in many places of the Bodzentyn Syncline, in the central part of the Łysogóry Region. It has been well known since the 19th century, mostly due to its highly fossiliferous nature, beginning with the works of Zeuschner (1869; see literature review in Halamski 2009). The lithostratigraphy of the entire section, spanning from the Grzegorzowice village in the south, through Skały and Włochy in the north was investigated in detail by Pajchlowa (1957), who divided the entire sequence into informal lithological sets. Lithology is diversified, mostly composed of clays, marls and limestones. The entire sequence crops out in an active Skała quarry and its surroundings. While the quarry is inaccessible due to intensive exploitation, we will be able to collect fossils on the nearby heap.

The carbonate sequence starts with Wojciechowice dolostones that are overlain by a thin layer of limestones of the Kowala Formation, on top of which Skały Formation is another unit (Racki et

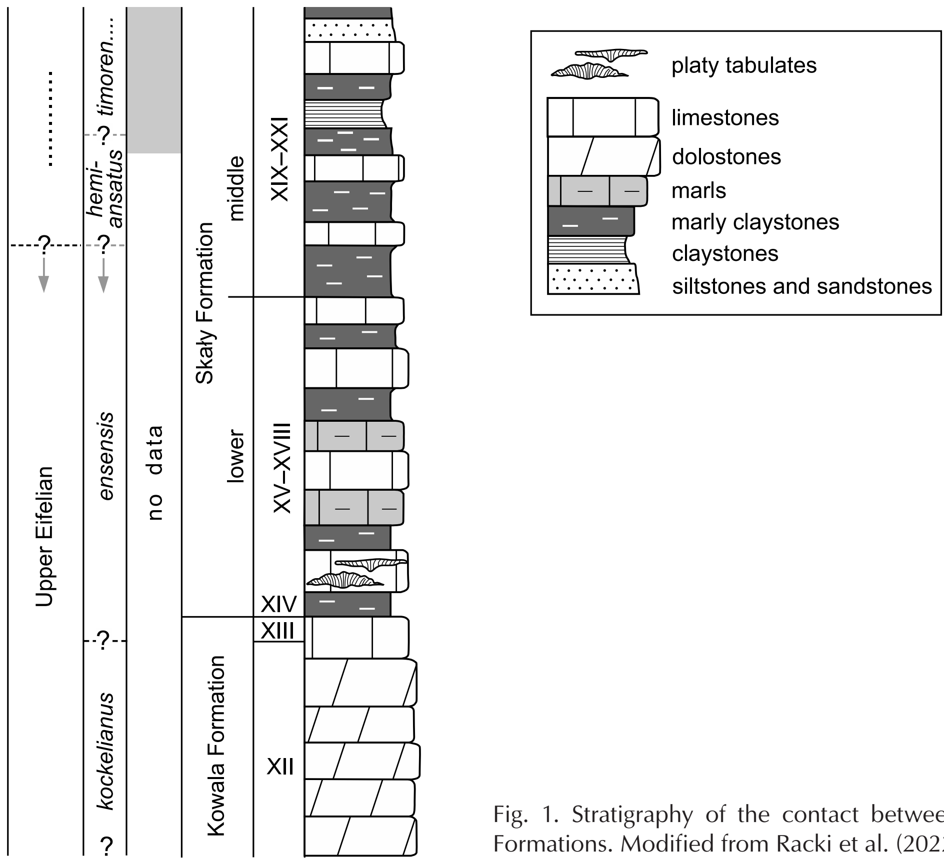

Fig. 1. Stratigraphy of the contact between the Kowala and Skały Formations. Modified from Racki et al. (2022).

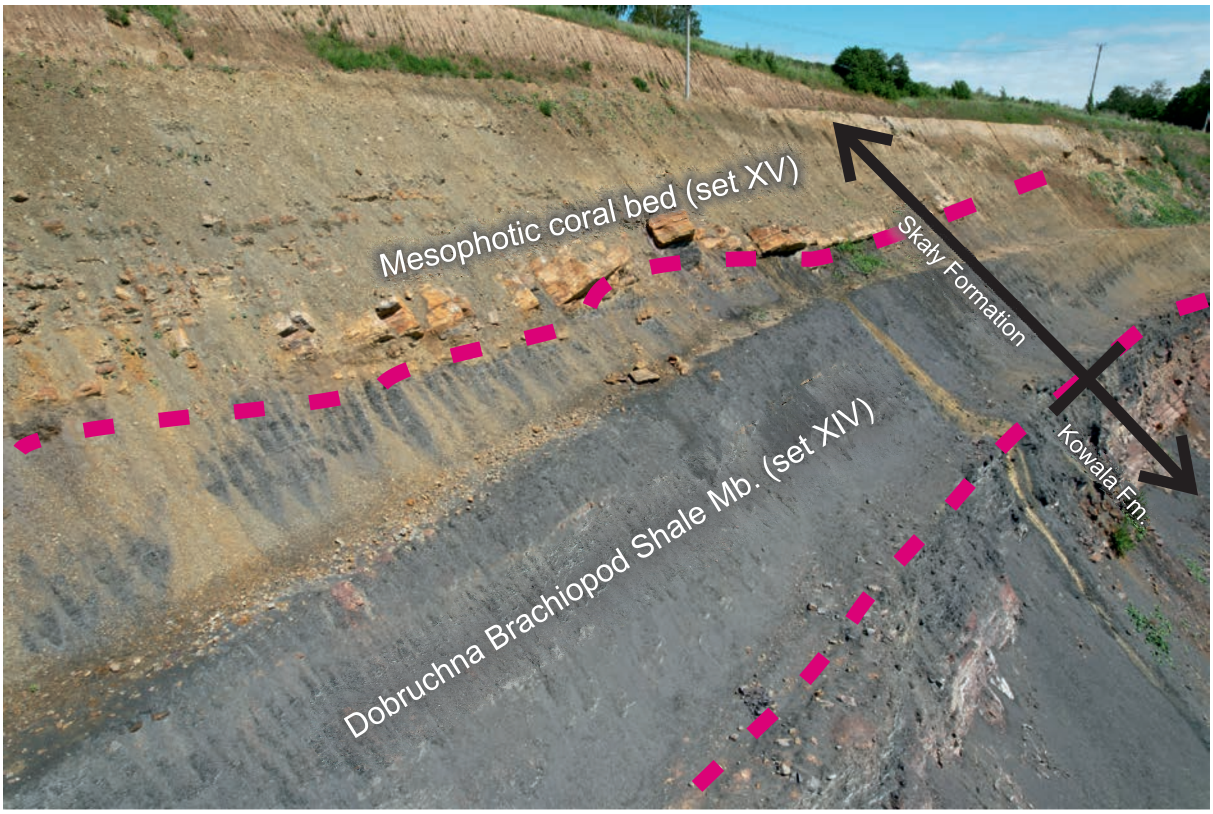

Fig. 2. Northern wall of the Skała Quarry, with contact of the Kowala Fm. (bottom) and Dobruchna Brachiopod Shale Member – the lowermost unit of the Skały Formation. Drone photo by M. Zapalski.

al. 2022). The limit between the Kowala and Skały Formations (Fig. 1) crops out on the northern wall of the quarry. We will see it from a distance (Fig. 2).

The limestones of the Kowala Fm. cropping out in the quarry represent very shallow environments (intertidal/supratidal, see Skompski and Szulczewski 1994; sets complexes XI and XII *sensu* Pajchlowa 1957). Set XIII of Pajchlowa (1957) is represented by so-called *Calceola* beds, with abundant *Calceola sandalina*. This is the last bed of the Kowala Fm, visible as prominent, bedded limestones, and it is overlain by so-called "brachiopod shales" (now formally described as the Dobruchna Brachiopod Shale Member, Racki et al. 2022) – the lowermost unit of the Skały Formation. The Shaly-Calcareous Skały Formation (late Eifelian to middle Givetian, *ensensis* to *varcus* conodont zones) is a 250–280 m thick sequence of variable lithology, representing the outer shelf of the gently sloping carbonate platform (Woźniak et al. 2022). Tabulate corals from the Skały Formation were described by Stasińska (1958, 1974) and Nowiński (1992); a case study on interactions between brachiopods and encrusting auloporid tabulates was published by Zapalski (2005). Rugose corals have been described by Różkowska (1956), Fedorowski (1965, 1967) and Stolarski (1993). The Dobruchna Brachiopod Shale Member (lithological set XIV of Pajchlowa, 1957) consists of grey and brownish marly shales with a diversified brachiopod assemblage (e.g., Biernat 1966, Halamski 2009) and sporadically occurring rugose corals (Różkowska 1956), such as *Macgeea bathycalyx*, *Ceratophyllum eifeliensis* and *Thamnophyllum* sp. Tabulate corals are not common, and are represented by *Platyaxum* sp.

The next, XVth lithological set of Pajchlowa (1957) consists of micritic marly limestones with abundant coral fauna (Fig. 3). These corals are dominated by platy and foliose tabulates *Platyaxum escharoides*, *P. clathratum minus*, *Roseoporella* sp., *Alveolites* cf. *taenioformis*, *A.* cf. *fornicatus*, *Favosites* sp., *Heliolites* cf. *porosus*, and with relatively diversified rugose corals such as *Calceola sandalina*, *Microcyclus praecox*, *Metriophyllum skalense*, *Metrionaxon schlueteri*, *M. accipiter*, *Syringaxon bohemica*, *Stewartophyllum polonicum*, *Amplexocarinia tortuosa*, *Guerichiphyllum skalense*, *Thamnophyllum trigemme* and *Macgea bathycalyx*, and rare cystiphyllids. These corals formed a mesophotic coral ecosystem, the oldest in the Holy Cross Mountains (Zapalski et al. 2017). A recent paper by Majchrzyk et al. (2023) partly based on the material from Skały, demonstrated that platy and branching coenitids (*Roseoporella, Coenites*) may be different morphotypes of the same taxa. Other fauna of this ecosystem also included large-eyed phacopid trilobites, gastropods, tentaculoids, crinoids and bryozoans. While these beds cannot be observed *in situ* during our trip (they crop out in the active quarry), we will visit the heap, where the debris of this bed is stored, and large amounts of the material can be collected.

Younger beds represent undivided strata of the Skały Formation, locally containing platy corals of the mesophotic ecosystems (Zapalski et al. 2017).

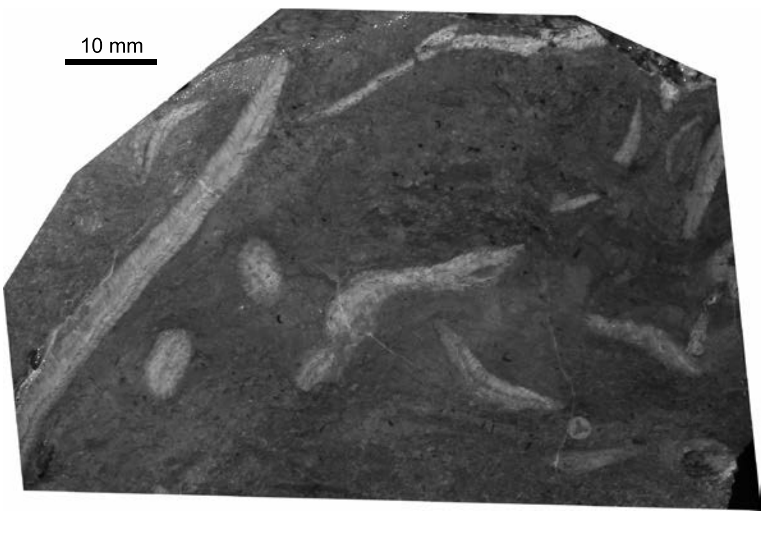

Fig. 3. A thin section with mesophotic coral fauna from the Skały Formation. Photo M.K. Zapalski.

STOP 2. Ostrówka Quarry, Gałęzice Syncline, Kielce Region

Visean gravity flows from a shallow-water carbonate platform into a deep, basinal facies; ecologically mixed fauna

The description is based upon Szulczewski and Skompski (1995)

In the southern part (Kielce Region) of the Holy Cross Mountains, a carbonate platform developed continuously starting in the Eifelian. Its central, shallowest part, however, emerged during the late Frasnian, leaving a stratigraphical gap (Szulczewski et al. 1996). Local tectonic movements and sea level rise contributed to a strongly condensed Famennian deposition that continued into the Tournaisian in deep basinal facies, with progressive deepening. Continued tectonic unrest in the Visean caused gravity flows from the shallow-water, carbonate platform south of present-day Ostrówka. These limestones contain very diversified fauna, including corals, from various ecological niches (Fedorowski 1971). The detailed depositional history of this sequence has been provided by Szulczewski et al. (1996). We will be mainly observing the Carboniferous strata cropping out along the northern edge of the active quarry (Figs. 4, 5).

The sequence starts with peritidal Amphiporoid Limestones (unspecified Frasnian). They crop out in an inaccessible part of the quarry. These micritic limestones contain microbial laminites, solution levels, and locally abundant amphiporoids and massive stromatoporoids. They are arranged in deepening-upward cycles (Skompski and Szulczewski 2000). They are penacordantly covered by condensed Famennian (upper *marginifera* to middle *expansa*) limestones, 20 to 200 cm thick. The penacordance (<10°) is a result of local block tectonic movement. Famennian limestones exhibit graded bedding with crinoid debris, abundant cephalopods (*Cheiloceras* spp. *Sporadoceras* spp.), rugose corals (*Cyathaxonia* fauna), *Oligophylloides* and *Mariaephyllia* octocorals (see: Różkowska 1969) and trilobites (Osmólska 1962). These condensed beds locally reach the Tournaisian *sandbergi* Zone (Szulczewski et al. 1996). The sedimentation of the next unit, i.e. siliceous shales of the Zaręby Formation continued until the late Visean.

The Upper Visean bioclastic limestone complex is laterally discontinuous, and developed as several lenticular bodies, tens of meters long and up to 35 m thick (Fig. 6). The fauna contains very abundant, large crinoids, productid brachiopods and corals (Fig. 7). Tabulates in-

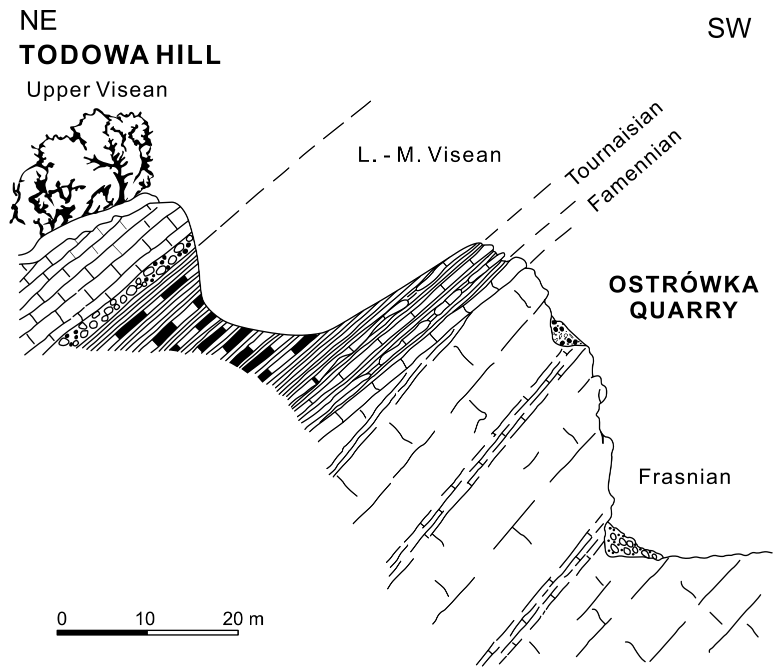

Fig. 4. A schematic cross-section through the northern edge of the Ostrówka Quarry. Modified from Szulczewski and Skompski (1995).

Fig. 5. A drone view over the Ostrówka Quarry towards West. Dark-grey rocks visible on the northern edge (right) of the quarry represent Zaręby Formation (Tournaisian to middle Visean), overlain by upper Visean detrital limestones. Photo M.K. Zapalski.

Fig. 6. Northern wall of the trench parallel to the northern edge of the Ostrówka quarry, with upper Visean detrital limestones cropping out in situ. Note their lens-shape, tapering eastwards (left part of the picture). Photo M.K. Zapalski.

clude *Squameofavosites megasquamatus*, *Emmonsia czarnieckii*, *Michelinia aseptata*, *M. tenuisepta*, *Syringopora ramulosa*, *S. reticulata*, *S. pachysifonata*, *Multithecopora polonica*, *M. spinosa*, *Syringoporella longituba*, *Paleacis* sp., and hydrozoans *Cladochonus* sp. (Nowiński 1976 and MKZ data). These beds also contain several species of chaetetids (Nowiński 1976). Rugose corals are mostly represented by phaceloid lithostrotionids and solitary taxa belonging to *Caninia–Clisophyllum* assemblage (Fedorowski 1971), several new taxa of columellate rugosans have been also described (Fedorowski 1970) e.g., *Carruthersella longiseptata*, *Amygdalophyllum axophyl-*

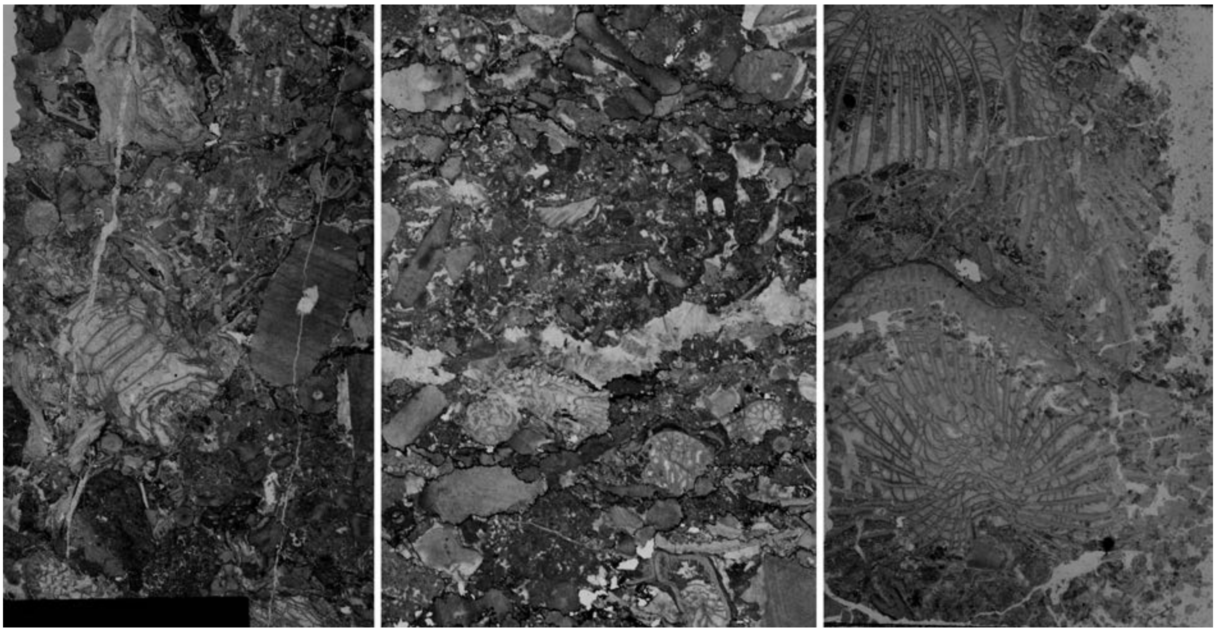

Fig. 7. Examples of fauna and microfacies of the Visean bioclastic limestone. Lower edge of each photo is about 2 cm. Photos S. Skompski.

loides, *Spirophyllum nexilis*, *S. multilamellatum*, *S. clisium*, *S. sanctaecrucense*, and *Rozkowskia parva*. Apart from large solitary and colonial dissepimented corals, small corals of *Cyathaxonia* fauna and heterocorals are relatively abundant.

The bioclastic limestone complex is composed of three lithological types: calcareous breccias at the bottom of the sequence, bioclastic limestones with abundant crinoids, brachiopods and corals (their fragments sometimes reach over 30 cm in diameter), and locally thin biomicritic limestone layers at the top, with juvenile cephalopods, abundant conodonts and *Globochaete* algae (Belka et al. 1996). The first two units are clearly allochthonous while the last represents autochthonous pelagic limestones (Belka et al. 1996). The hypothetical source area of these limestones was located south of Gałęzice, but due to post-Variscan erosion the Carboniferous strata are absent. The Visean sequence ends with the Lechówek Formation – basinal shales with siliceous intercalations.

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ABSTRACTS

Regular talk

THE THROMBOLITE-DOMINATED ARCHAEOCYATH REEFS OF THE CAMBRIAN SERIES 2 FROM THE ZUUNE ARTS AREA OF WESTERN MONGOLIA: CONSTRUCTION AND PALAEOENVIRONMENTS

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During the Cambrian Period, the first reef-forming skeletal organisms (archaeocyaths) of the Phanerozoic widely established archaeocyath reefs in low-latitude shallow-water settings. However, archaeocyath reefs disappeared entirely during the middle of the Cambrian Stage 4 (end-Toyonian). The reefs of the Cambrian Series 2 (Atdabanian) Salaany Gol Formation in the Gobi-Altai, western Mongolia, are well-developed reefs that formed during the peak of archaeocyaths. The palaeoecology and depositional environments of these reefs have been documented previously (e.g., Wood et al. 1993; Kruse et al. 1996); here, we examine the construction of the archaeocyath reefs, including the dominant thrombolitic textures, in terms of their relation to the background palaeoenvironment.

A ≥130 m thick succession of the Salaany Gol Formation is exposed in the Zuune Arts area of Gobi-Altai, western Mongolia. The studied reefs occur in the reef complex in the upper part of the succession. The reefs include varied archaeocyaths such as dish-shaped, laminar *Okulitchicyathus*; delicate, branching *Cambrocyathellus*; and cup-shaped *Robustocyathellus*. Small, solitary archaeocyaths in some cases are attached to the undersurfaces of *Okulitchicyathus*, representing pendent growth. These archaeocyaths occupy 10–20% of the reef volume. Calcimicrobes such as *Epiphyton* are rare. Thrombolitic textures composed of micritic clots encrust the surfaces of and the areas around the archaeocyaths and occupy up to 50% of reef volume. The thrombolitic textures include dominant cribricyaths (0.2–0.3 mm in transverse section, ~200 mm long) characterised by conical or horn-shaped cups with spirally ribbed walls and sporadic cup-shaped hydroconozoans. The spaces among the reef frameworks were filled first by lime mud including bioclasts (e.g., sponge spicules and chancelloriid sclerites) and peloids. Acicular crystal cements and botryoidal cements developed locally within the sediments. The remaining spaces were further filled with fibrous and blocky cements.

Archaeocyath reefs are commonly inferred to have been constructed with the aid of pronounced calcimicrobial encrusting and binding activities. However, calcimicrobes are not necessarily abundant in the studied reefs; instead, thrombolitic textures including dominant cribricyaths and a variety of cements are much more common. The large amount of cement within the reefs indicates that the reefs were formed in high-energy, subtidal settings, in which thrombolitic textures and cements rather than calcimicrobes acted to consolidate the archaeocyath-built frameworks. Acicular and botryoidal cements within the sediments originated from primarily aragonitic precipitates, reflecting the relatively high Mg/Ca molar ratio of seawater chemistry (i.e., an 'aragonite sea') at that time.

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Regular talk

HOLDFASTS AND GROWING TIPS OF HETEROCORAL COLONIES: A CASE STUDY OF TWO FAMENNIAN GENERA *OLIGOPHYLLOIDES* AND *MARIAEPHNYLLIA*

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Heterocorals represent an enigmatic group of Palaeozoic corals, known from relatively short time intervals in the Devonian and Carboniferous periods. The major differences between Heterocorallia and other Palaeozoic corals are the lack of an external theca (epitheca), lack of calices and the presence of dichotomously dividing septa-like structures in the central part of the skeleton. Heterocoral skeletons were most likely externally covered by soft tissue and each branch of their skeleton has, until recently, been regarded as a corallite – a skeleton of a single polyp. We investigated two upper Famennian genera: *Oligophylloides* and *Mariaephyllia* from Morocco, focussing on wall structure, previously poorly known initial growth stages, holdfasts and especially on the growing tips. We demonstrate that both genera show a unique colony development unknown in any other group of anthozoans, possessing a septate-like architecture. We suggest that the previously postulated homology between true septa in hexa- and rugose corals on one hand, and both studied genera on the other, must be rejected. Comparing the external morphology of their skeleton and also the internal structure and branching patterns to some groups of recent octocorals, we postulate, contrary to former ideas, that the stem and branches of heterocorals represent the skeleton of a multi-polyp colonial coral. In conclusion we propose to include the order Heterocorallia within the subclass Octocorallia.

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Regular talk

ANISIAN CORAL FAUNA FROM GUIZHOU, SOUTHWESTERN CHINA

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The Anisian coral fauna found in Guizhou, situated at the junction of the eastern Tethys and the Paleo-Pacific Ocean in the middle-low latitude region during the Triassic, hold significant implications for understanding coral evolutionary diversity during this period. While prior studies have documented approximately 13 species of scleractinian corals from the Qingyan Formation in Guizhou, this investigation emphasizes the coral assemblage of the Poduan Formation within the same region. The Poduan Formation fauna reveals the highest abundance and diversity of Anisian corals identified to date. Noteworthy features of the skeletal architecture include the near absence of vesicular dissepiments and axial structures, well-developed tabular endotheca, thin septa tapering towards the axis, challenging differentiation of costal septa, the common occurrence of non-trabecular septa, and the nearly ubiquitous presence of external epithecal segments of corallites in unintegrated colonial forms. Furthermore, certain specimens can be readily classified as scleractiniamorph corals identified in the Permian strata, based on macroscopic examination of the skeletal structure, growth mode, and intraspecific variation features. Additionally, the conodonts present in both the upper and lower strata of the coral-bearing bed in the Poduan Formation of Guanling can be attributed to two conodont zones: the *Paragondolella bulgarica* Zone and the *Paragondolella bifurcata* Zone, providing evidence that the coral fauna in the Poduan Formation of Guanling may have existed no later than the well-known Cracow-Silesia coral fauna of Poland.

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Regular talk

THE ROLLING STONES: AN EXTREME EVOLUTIONARY ADAPTATION OF COLONIAL SCLERACTINIAN CORALS TO COLONIZE SOFT BOTTOMS

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Scleractinian corals are primarily known for their ability to build reefs on hard substrates such as rock or dead coral skeletons. However, soft sediments, such as sand or mud, are frequently the only available substrates on the seafloor. Solitary and colonial corals developed various adaptations that allow them to settle and colonize these environments. Coral larvae are capable of settling on some tiny, hard objects on the soft bottom, such as sand grains or shell debris but the main challenge is further development of larger skeletal structures on the unstable, soft seafloor. Some corals (e.g., *Heterocyathus*, *Heteropsammia*) have developed symbiotic relationships with sipunculid worms dwelling in empty mollusc shells and keeping them constantly on the sediment surface; this allows coral larvae to settle on those shells and grow over them together with the living worm. Another adaptation is to actively move over/within the soft sediment (automobility) thanks to embedment of the skeleton by the soft tissue (e.g., some fungiids and turbinoliids). Other strategies include the development of fast growing, branching/phaceloid growth forms that allow corals to extend above the sediment (‘mudsticker’ analogy in bivalves), or the development of coralla with flat surfaces to mimic the snow-shoe effect (‘recliners’ analogy in bivalves).

In this work we focus on an exceptional strategy for dwelling on the soft bottom by some colonial corals that form spherical colonies entirely covered by living tissues. Such colonies are described under different names i.e., rotatory, circumrotatory, coralliths, informally known also as “rolling stones”. To date, various authors provided different, sometimes controversial interpretations about their growth mechanism and strategy. Their fossil record is poorly explored and only few studies focused on comparison of present-day rotatory corals to Pleistocene (scleractinians) and Silurian (tabulates) corals. Here, we provide the first comprehensive analysis of the “rotatory” strategy of the extinct, Cenozoic colonial scleractinian *Stylocoenia*, based on macro- and micromorphology as well as microstructural skeletal features in 60+ specimens of Eocene *Stylocoenia* sp. from the Veneto region (N. Italy) and Bavaria (Germany). Representatives of *Stylocoenia* form perfectly spherical cerioid colonies with unique pillars developed between the corallites. Intercorallite pillars, of variable length and thickness, show multi-layered structure and longitudinal ridges. Similar but much smaller pillar-structures (or styles) are developed only in some modern pocilloporiids (*Pocillopora*, *Stylocoeniella*). Although some tissue-protective functions were suggested for styles in modern pocilloporiids, in *Stylocoenia* these structures seem to play the role of “stilts”, to avoid sinking in mobile and fine-grained sediments. This interpretation, together with taphonomic signatures, allows reconstruction of the original habitat of these corals otherwise only known from collections.

Regular talk

TROPICAL REEF CORALS UNDERWENT CHRONIC HEAT STRESS BUT NO BLEACHING EVENTS DURING THE LATE MIOCENE: EVIDENCE FROM STABLE ISOTOPE DATA AND CALCIFICATION RECORDS

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The scleractinian coral reef ecosystem originated ~250 million years ago and since then was subject to regional and global crises because of changes in oceanic circulation and climatic warmings. Here we present calcification records and sub-seasonally resolved stable isotope time-series from reef corals on a paleo-tropical Caribbean reef dating from the globally warm, Late Miocene (6.3 million years). A low annual calcification rate and preferential skeletal growth in winter document the breakdown of nutrient cycling between the coral hosts and their photosynthetic endosymbionts due to chronic heat stress during summer. Nonetheless, our records display no evidence for bleaching events, although inter-annual climatic variability resulting in hot spells similar to the recent are known from Late Miocene coral records. Our methodology has the potential to identify heat stress in the ongoing coral reef crisis even before bleaching events have occurred and thus make an important contribution to assessing future reef health.

Regular talk

THE DEVONIAN CORAL FAUNA OF THE BRUCHE VALLEY (NORTHERN VOSGES MASSIF, FRANCE)

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The Saxo-Thuringian zone of Western Europe displays rare Devonian sediments such as deep-water siliciclastics which are commonly metamorphosed. In some parts, however, carbonate sediments are preserved or only slightly affected by variscan metamorphism. In addition to Ossa Morena in Spain, the Northern Vosges in Eastern France is one of these rare points. In the Bruche river valley, west of Strasbourg, fossiliferous sediments are known to crop out. Fossil invertebrates from this location were described firstly by Jaekel (1888) who recognised *Calceola sandalina* and some stromatoporoids. The carbonates, quarried in the locality of Russ as an ornamental stone, form large lenses embedded in a coarse-grained siliciclastic matrix. Firtion (1957) described tabulate and rugose corals from the area and established a Givetian (Middle Devonian) age for the assemblage based on the occurrence of a single specimen of the brachiopod *Stringocephalus burtini* in a polished slab of the 'Marbre de Russ' in the church from this locality. After the updating of Firtion's (1957) taxonomic attributions the following genera are recognised from this area: *Calceola*, *Lekanophyllum*, *Mesophyllum*, *Cystiphylloides*, *Acanthophyllum*, and *Xystriphyllum*.

Re-investigation of the Devonian carbonate of the Bruche river valley yielded a larger collection of rugose and tabulate corals among which include *Acanthophyllum* spp., *Mesophyllum* spp., *Cystiphylloides* spp., *Dohmophyllum* sp., a putative *Siphonophrentis*, *Tryplasma* sp., *Synaptophyllum* sp. and *Zelophyllum* sp. However, the most abundant taxon is a small-sized fasciculate rugosa probably belonging to the genus *Fasciphyllum* but requiring a new specific name. The tabulate corals are represented by ramose *Coenites* sp., *Hillaepora* sp. and *Heliolites* spp. Stromatoporoids and chaetetid sponges are the other reef-building organisms. The coral fauna has is different from Givetian assemblages from other parts of Western Europe (Cantabria, Ardenne, Rhenish Schiefergebirge), and Eastern Europe (Carnic Alps, Pomerania, Bohemia) – lacking the typical disphyllids, sociophyllids and themnophyllids. The depauperate fauna, however, is more suggestive of an age older than the Givetian. Attempts to date with spores and conodonts have, so far, yielded inconclusive results.

The 'lenses' are not sedimentary bodies contemporaneous with the surrounding siliciclastic but form olistoliths in a flysch context, the size of the limestone blocks varying from a few millimetres up to 200 m-long and 40 m-thick. Some of the 'lenses' display boundstone facies that suggest a reefal origin, however the matrix and cement are usually recrystallized, precluding a correct sedimentological approach.

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Poster

SKELETAL PROPERTIES OF THE CORAL *DESMOPHYLLUM DIANTHUS* ARE RELATED TO THE ARAGONITE SATURATION STATE ALONG A DEPTH GRADIENT IN THE MEDITERRANEAN SEA

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Ocean biogeochemistry is now being strongly influenced by the oceanic uptake of anthropogenic carbon dioxide from the atmosphere, leading to an increase in hydrogen ion concentration (i.e., decreases pH) and to a decrease in the carbonate ion concentration, in a process commonly referred to as ocean acidification. Ocean acidification is likely to exhibit its most immediate effects on cold-water corals in deep waters with the shoaling of the aragonite saturation horizon, leading to dramatic declines in rates of calcification. It is now clear that the Mediterranean area will be a hotspot for climate change effects, making it a miniature model of global patterns to occur in the world's marine biota, and a natural focus of interest for research. This study aimed to investigate the effects of decreasing aragonite saturation state (Ωarag) on the biometric and skeletal parameters of *Desmophyllum dianthus* along a depth gradient (400–1200 m) in the Mediterranean Sea. The results indicate that as Ωarag decreases, bulk density decreased while skeletal porosity and micro-density increased (Fig. 1). This trend could be explained through the inhibition of calcification as Ωarag decreases, leading to a more porous and likely fragile skeletal phenotype. This is one of the few in situ studies conducted on a cold-water coral species in the Mediterranean Sea, providing evidence of their susceptibility to increased ocean acidity.

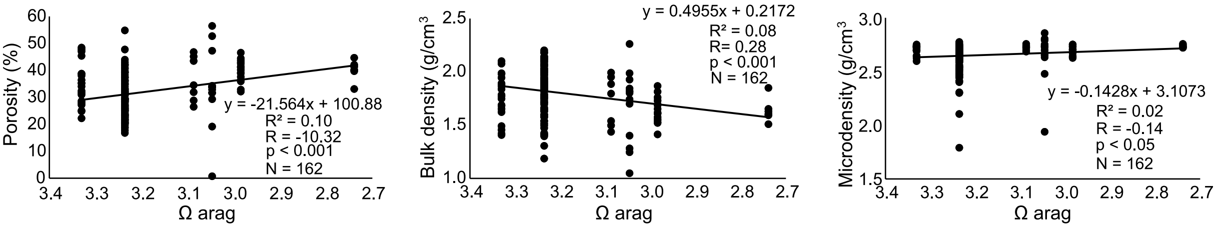

Fig. 1. Correlation analysis between Ω_{arag} and skeletal parameters (skeletal bulk density, porosity and micro-density). R^2 = Pearson's coefficient of determination, R = Pearson's correlation coefficient.

Regular talk

REEF REFUGIA IN THE AFTERMATH OF HYPERTHERMAL EVENTS

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In the face of rising global temperatures, coral reefs undergo significant stress, leading to mass bleaching events and mortality. While some corals possess adaptive mechanisms to cope with thermal stress, others may succumb to extinction. A considerable number of reef corals exhibit range shifts towards higher latitudes. Subtropical and mesophotic environments may represent refugia for reef corals under climate change, where they can survive and recolonize degraded areas. However, the significance of such refugia has been questioned because photosynthetically available radiation may be limiting in these environments. We provide an empirical assessment of the efficacy of subtropical and mesophotic environments under past hyperthermal events over the last 300 million years. We focus on tropical reefs using the PaleoReefs Database (PARED). Several global rapid climate warming events in the geological past coincided with reef crises (i.e., a significant reduction in reefal calcium carbonate production per unit of time) in the fossil record. Hyperthermal events occurred at the end of the Triassic, during the Toarcian anoxic event, the Cenomanian–Turonian anoxic event, and the Palaeocene Eocene Thermal Maximum (PETM). We observed an increase in the presence of reefs in deeper mesophotic environments following these events. Additionally, we found a notable trend of reef migration towards higher latitudes in response to these events. Even though the sample size is limited, this suggests that mesophotic environments may indeed have served as immediate sanctuaries for shallow water species escaping excessively warm seawater. Understanding the patterns of reef migration and the establishment of mesophotic refugia following hyperthermal events provide insights into the future of reefs in the current era of climate change.

Poster

NOVEL REEF COMMUNITIES EMERGING AFTER MASS EXTINCTION EVENTS

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Modern coral reefs are among the most vulnerable ecosystems to climate change. Accordingly, we hypothesize that past hyperthermal events had lasting impacts on reef coral communities. Specifically, novel reef communities are expected to emerge after ancient warming events, where novel communities are those that document a rapid and irreversible shift into a new state that differs in composition and/or function from past systems. To test our hypothesis, we used a global compilation of reef occurrences from the Ordovician period to modern times (past 486.9 million years) and applied a rigorous novel community detection framework at stage-level time bins. Novelty is quantified based on two components – cumulative novelty (i.e., the deviation from historical baselines and instantaneous novelty (i.e., the magnitude of change relative to the previous state). A novel community state is identified when both cumulative and instantaneous novelty match in a time series of ecological change.

Surprisingly, there were four novelty events at global scales, and they all occurred in the aftermath of the mass extinction events: the end-Devonian, the end-Permian, the Triassic–Jurassic, and the Cretaceous–Paleogene mass extinctions. These novel reef communities emerge due to origination and immigration to reefs rather than due to extinction and emigration from reefs.

Regular talk

PALEOECOLOGICAL CHARACTERIZATION OF MIDDLE AND LATE PLEISTOCENE REEFS OF THE DANAKIL DEPRESSION (NORTHERN AFAR, ETHIOPIA)

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The Danakil Depression is a tectonically controlled rift, located in the northern Afar at 126 m below the current sea level. Middle and Late Pleistocene reefs are outcropping at the margins of the depression which host diverse communities of reef coral species. These Pleistocene reef units developed during several flooding episodes that connected the southern Red Sea regions with northern Afar. During the Middle Pleistocene (240 ka), most reefs were fringing reefs that completed at least one reef growth cycle consisting of a *start-up* phase mainly characterized by sediment-matrix facies with sparse coral colonies, a *catch-up* phase represented by pillarstones–mixstones–rudstones, and a *keep-up* phase comprised domestones and branching coralline algae biostrome. On the other hand, Late Pleistocene reefs (120 ka) mostly developed as patch reefs and coral carpets. The main goal of this study was to (1) characterize the species composition, coral cover, species richness and diversity of these Middle and Late Pleistocene reefs, in order to (2) evaluate spatial variations of the coral taxa composition across the Danakil Depression, and (3) infer Paleoecological successions in these reef terraces. Surveys were performed using Line Intercept Transect (LIT) sampling method with transects ranging from 35 to 50 m parallel to the paleo-coast line. The main coral reef component categories recorded along the LIT include corals, crustose coralline algae and sediment. Corals were identified to the lowest possible taxonomic level. The forereef of the Middle Pleistocene fringing reefs were primarily dominated by the coral genera *Porites, Astraeosmilia* and *Diploastrea with* secondary *Lobophyllia*, *Goniopora*, *Echinopora and* crustose coralline algae (mainly branching *Lithophyllum* sp. and *Porolithon* sp.). The reef crest/reef flat were characterized by primarily *Porites* and *Favites* with secondary genera *Astraeosmilia* and *Platygyra*. The patch reefs and coral carpets of Late Pleistocene reefs were primarily dominated by *Porites*, *Dipsastraea*, *Echinopora* and *Pachyseris* with secondary *Platygyra* and *Favites*. Additionally, monospecific stands of genus *Galaxea* and *Goniopora* occur in the Late Pleistocene reefs. This study indicates that the Middle and Late Pleistocene reefs of the Danakil Depression hosted diverse coral communities. There is significant variation in species composition of the Late Pleistocene reefs related to a reconfiguration and partial disappearance of some genera from the community. Additionally, differences are observed in the dominance of different colony growth forms between and within the Middle and Late Pleistocene reef terraces across the Danakil Basin. This novel data contributes to a better understanding of the history and dynamics of the reef ecosystems in the southern Red Sea.

Regular talk

REVIEWING FAGERSTROM'S REEF-GUILDS WITH GEOMETRIC MORPHOMETRICS: A CASE STUDY OF PERMIAN REEF FROM MEXICO

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John A. Fagerstrom (1930–2022) made a model of reefs focusing on spatial resources like marine substrate, including five reef-guilds: Builders, Bafflers, Binders, Dwellers and Destroyers (Fagerstrom 1988, 1991). The main criticism of this model is that some authors consider it just a mere extension of geological terminology of Embry and Klovan (1971) regarding the terms *Framestone*, *Bafflestone* and *Bindstone* (Precht 1994). However, the Fagerstrom model has a strong conceptual component highlighting the external shape as a result of environmental factors and guild-overlapping, like phenotypic plasticity (e.g., Pigliucci et al. 2006). In this sense, a novel approach of Geometric Morphometrics (GM) has been rapidly developed in recent years that improved many areas and analyses in biology and paleontology, especially with samples limited to external shape.

In northern Mexico, Coahuila state harbors, the only Permian Reef of Mexico (Guadalupian), is composed by abundant sponge-like organisms ('sphinctozoans', 'inozoans' and 'chaetetids') as well as by 'richtofenid' brachiopods, crinoids, molluscs, and corals (*Lophophyllidium*). This reef belongs to the Las Delicias Formation, which is closely related to those of Texas and New Mexico (Girty 1909). Considering the abundance of well-preserved reef organisms, both previously mentioned groups ('reef sponges' and 'richtofenid brachiopods') were used in morphometric and paleoecology analysis, with the aim at building a morphometric model based on Fagerstrom's proposal.

Our results suggest that genera *Amblysiphonella*, *Lemonea* (Porifera) and *Sestropoma* (Brachiopoda) are dominant in the reef, while other North American localities have more diversity in Guadalupian and other genera of 'richthofenids' (Finks 2010). GM analysis shows that even with *Guadalupia* distributed in both Coahuila and Texas-New Mexico, the shapes are not the same. In Coahuila, reef organisms grow in erect position, differing with sheet-like morphologies in northern localities. Furthermore, many organisms also have epibionts like 'serpulids' (Annelida) and bryozoans (i.e., *Fistulipora*). PCA shows that the main clusters are concordant with the description of three main guilds: Builders, Bafflers, and Binders. GM is a powerful tool that allows to understand phenotypical information and therefore make a better reef model.

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Regular talk

PROLIFIC DEVELOPMENT OF AMPHIASTREIDS AND OTHER PACHYTHECAL CORALS (HEXANTHINIARIA?, SCLERACTINIA?) IN REEFS ON THE ŠTRAMBERK CARBONATE PLATFORM (TITHONIAN–BERRIASIAN)

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The Štramberk Limestone (Moravia, Czech Republic) and the Štramberk-type limestones (Poland) occur in flysch of the Outer Carpathians as olistoliths, blocks and pebbles. They contain the world's most diversified coral assemblages (c. 115 species of 50 genera) in the reefs developed at the Jurassic/Cretaceous transition. Coral-microbial reefs have been developed primarily in the late Tithonian. In particular, numerous corals occur in the Štramberk Limestone which were studied in the 19th century by Maria Ogilvie and, since the 1960s, extensively studied by Helena Eliášová (see: Eliáš and Eliášová 1984; Kołodziej et al. 2023). Most characteristic are corals classified to the Pachythecaliina Eliášová, 1976 (accepted in this presentation), or alternatively to Amphiastreina Alloiteau, 1952, the suborder distinguished earlier. From samples from the Czech Republic and Poland, about 30 genera of pachythecaliine corals were distinguished (mostly with phaceloid growth form). Most of the species and some genera are endemic or rarely described from other countries (coeval coral assemblages typically contain no more than several genera of this suborder). We classify Pachythecaliina to the following families: Amphiastreidae (most common), Carolastraeidae (including some taxa alternatively classified to Heterocoeniidae), Intersmiliidae and Donacosmiliidae. A distinctive feature of these corals is a wall interpreted by most recent authors as a pachytheca (type of epithecal wall), which is developed prior to septa. The bilateral symmetry of the septal arrangement is another distinctive feature. Some discussed corals have poorly developed septa. In the extreme case of wall-based corals – *Pachythecophyllia eliasovae* (Štramberk-type limestones) – only one strong septum occurs, while others are hardly visible and developed as short septal spines. "Taschenknospung" (pocket budding) occurring in the Amphiastreidae is not known in other fossil and modern corals.

The discussed corals are perhaps the most controversial post-Palaeozoic coral group with contrasting opinions on a wall type and a high rank taxonomy. Some recent authors interpret the wall as a trabecular, not a pachythecal wall. Another controversy is the issue of whether this suborder together with amphiastreids and related families should be classified as the corals from the family Heterocoenioidea. This superfamily by some authors is classified to the Pachythecaliina (Amphiastreina), or alternatively (and originally) to the suborder Heterocoeniina Beauvais, 1974 (or if the concept of suborders is not accepted – to the superfamily Heterocoenioidea). A great controversy is the taxonomic position of discussed corals on the order level. They are classified to the Scleractinia or the Hexanthiniaria Montanaro-Gallitelli, 1975. This second order is the systematic position of the Upper Triassic (rarely Lower Jurassic) corals of the family Zardinophyllidae (= Pachythecaliidae) which were by some authors considered as descendants of Rugosa. Discussion on the Hexanthiniaria and its taxonomic composition will benefit from the contribution of specialists on Paleozoic and modern corals. Samples from the Štramberk Limestone are excellent sources for obtaining new data on supposed post-Triassic hexanthiniarians. Comparable but weaker taxonomic diversification of phaceloid pachythecaliines (including Heterocoenioidea) were recognized only in the Barremian of Bulgaria.

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Keynote lecture

CORALS IN CHANGING SEAS: A GEOCHEMICAL JOURNEY THROUGH GEOLOGICAL EPOCHS

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Since their evolution in the Middle Triassic, despite dramatic changes in Mesozoic and Cenozoic geochemistry of seawater and global temperatures, scleractinian corals have inhabited the warm shallow tropics, subtropics, mesophotic depths and the deep sea (Drake et al. 2020; Campoy et al. 2020). Their near-global coverage and ability to geochemically record environmental parameters in their skeletons make these corals powerful archives of past ocean change. However, the physical and chemical properties of the seawater in which these corals live is also known to impact coral physiology. It is important to elucidate the relationship between coral physiology, skeletal composition, and the environment corals inhabit. Such knowledge will enable better reconstructions of past climate, improved understanding of how corals were able to be successful over the last ~250 My despite different ocean boundary conditions, and better predictions of how corals will fare under modern climate change.

In this talk, I will share observations of how corals respond to and record changes in ocean geochemistry through the lens of geochemical measurements made on well-preserved fossil and lab-cultured corals. For example, well-preserved Cenozoic fossil coral skeletons have trace element ratios that vary in concert with secular changes in Cenozoic climate and seawater chemistry reconstructed from other, independent paleoclimate archives (e.g., Gothmann et al. 2015). Additionally skeletal elemental and isotopic compositions measured in lab-grown corals display a dependence on the composition of external seawater carbonate chemistry (Gothmann and Gagnon 2021). While these sensitivities to the external environment reinforce the utility of corals as climate archives, skeletal geochemistry in lab-grown and fossil samples also appears to be sensitive to changes in coral physiology. For example, in lab-cultured corals, trace element ratios show variability, and are correlated, even at constant external seawater composition (Gothmann and Gagnon 2021). Physiological effects on coral geochemistry can complicate reconstructions of past ocean conditions from coral skeletons, but may also may offer an opportunity to learn about how the coral calcification process has evolved over geologic time. I will conclude the talk by sharing suggestions for how to leverage apparent physiological impacts on coral geochemistry to learn more about coral calcification in changing seas.

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Poster

NANOSCALE IMAGING OF ORGANIC MATRIX AND ARAGONITE FORMATION IN A SKELETON OF A COLD-WATER CORAL *BALANOPHYLLIA ELEGANS*

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Organic matter in scleractinian coral skeletons is thought to largely derive from the skeletal organic matrix (OM). This OM provides a template for skeletal growth and has become a target for paleoclimate reconstruction. While the bulk molecular and isotopic composition of skeletal OM is well studied (e.g., Muscatine et al. 2005), there are fewer studies that have mapped OM in corals at the micro- to nano-scale (e.g., Mass et al. 2014). The distribution of OM in coral skeletons must be fully characterized to unravel its role in coral calcification and identify implications for coral paleoclimatology.

We designed experiments to visualize the presence and formation of skeletal OM relative to the precipitation of mineral aragonite in a cold-water coral (CWC), *Balanophyllia elegans*. Coral individuals were incubated under controlled temperature and pH for 16 days in a medium alternating between seawater spiked with trace amounts of Mn (6 hrs), ^{6}Li and Sr (42 hrs), and natural seawater (48 hrs). Additionally, corals were fed with ^{15}N-labelled *Artemia salina* (56 atom % ^{15}N, sacrificed by freezing and thawing) during short pulses (<1 hr) every 2 days at the beginning and end of the incubation intervals using natural seawater. Coral samples were then sacrificed, embedded in epoxy, polished, coated with 30 nm gold, and measured by Nanoscale Secondary Ion Mass Spectrometry (NanoSIMS) at the Environmental Molecular Sciences Laboratory at PNNL. Using both O^- and Cs^+ beams, we reconstructed maps of elemental and isotope ratios that helped us trace the newly formed aragonite (Mn/Ca,^{6}Li/Ca, Sr/Ca) and organic matrix (CN/C, C_2/C, S/C, and $^{15}N/^{14}N$).

Tracer elements Mn, Sr, and ^{6}Li were concentrated in bands which had patterns indicative of preferential growth directions and variable rates of skeleton extension at fine spatial scales. The spacing between the bands translates to a mean skeleton extension rate of 1.5 ± 0.5 µm/day, which is similar to extension rates measured in other scleractinian CWCs (e.g., Robinson et al. 2014). Organic matrix tracers CN, C_2, and S were concentrated in bands parallel to those formed by the inorganic tracers and appeared to be more abundant in faster growing regions of the coral skeleton. However, OM-specific N, C, and S were not always co-located at fine spatial scales, suggesting different incorporation mechanisms and roles of these elements in coral biomineralization. ^{15}N enrichment appeared in the newly formed coral skeleton soon after feeding and disappeared within a few hours of the end of a feeding pulse, suggesting that the deposition of OM may be triggered by feeding. Furthermore, the level of ^{15}N enrichment (up to 3 atom %) indicates that the skeletal OM may primarily be composed of amino acids synthesized by the animal with a small fraction (possibly essential amino acids) added directly from the diet. Together, our results improve our understanding of the role of OM during skeleton growth in cold-water corals.

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Poster

CNIDARIA: A PROXY FOR CAMBRIAN TIDES?

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The ocean tides influence a variety of Earth system processes, including evolution and extinctions. Hence, constrained tidal properties for Earth's past are imperative when investigating other Earth system processes. Results now exist from numerical tidal model simulations covering 1500 million years and they require more detailed validation. Here, we present a novel way to constrain both Cambrian tidal model results and reconstructions: paleobiology in the form of fossilised Cnidaria. The presence of marine fossils allows us to obtain detailed information about the environmental setting, e.g., sediment grain sizes and bedforms, which informs us about the tidal currents at the time. The results overall show good agreement between the modelled tides and the proxy data. The medusae stranding in the Mialongian Blackberry Hill Formation, USA (Braddy et al. 2022; Fig. 1: Proxy 1) occurred in a coarse sand, giving peak current speeds above 0.4 m s^{-1}; this is matched by the tidal model results. At the Furongian medusa stranding in present day New York (Hagadorn and Belt 2008; Fig. 1: Proxy 2), the fine-medium sand implies currents between 0.2–0.5 m s^{-1}, a range matched by the model. Where there was poor agreement, e.g., the Utah locality in Fig. 1, Proxy 3 from Cartwright et al. (2007), we adjusted the bathymetry so that the model and proxy information matched. We argue that paleobiology is a useful marker for paleo-environments which can provide proxies for tides, and we ask to be pointed towards any published information that may be of use to us.

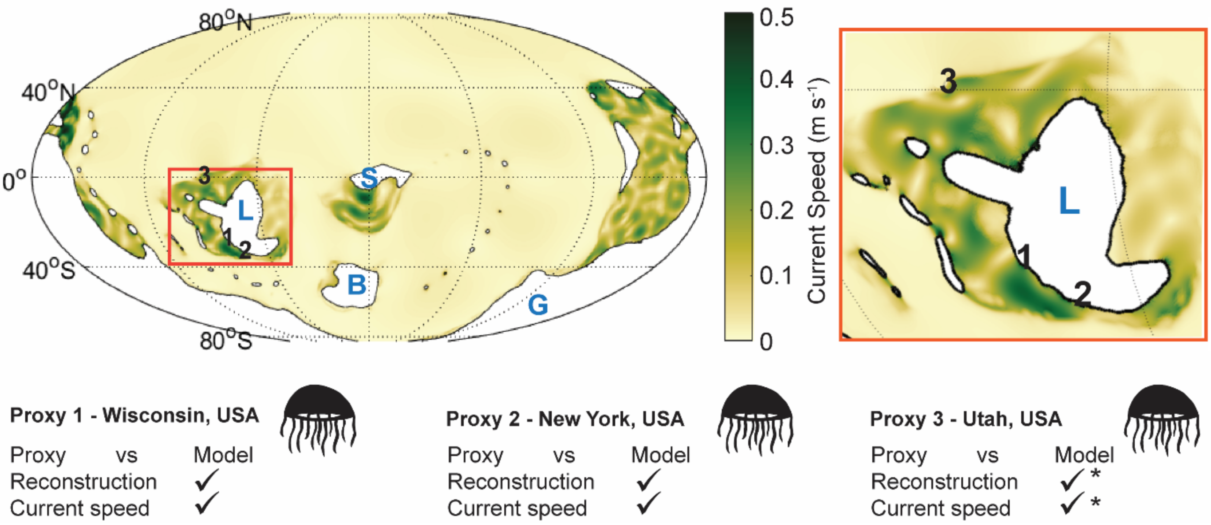

Fig. 1. Current speed simulation for the Early Upper Cambrian (500 Ma), with major continents highlighted in blue lettering: L for Laurentia, S for Siberia, B for Baltica and G for Gondwana. Zoom-In of Laurentia is highlighted in orange, with three fossil medusae proxy locations (1–3) marked.

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Regular talk

A COMPARISON OF THREE SAMPLING TECHNIQUES IN EGYPTIAN PLEISTOCENE CORAL REEFS

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Transect and quadrat methods are two types of techniques used for quantitative sampling of alpha diversity, reef cover and community composition on fossil and modern coral reefs. Transect methods are plotless and two variations of this technique are particularly widespread: the Line Intercept Transect (LIT) and the Point Intercept Transect (PIT). In contrast, quadrat methods always record an area, which is either photographed (photo quadrat: PQ) or recorded by video for later analysis. To date all of the above-mentioned methods have been applied in coral reefs of different ages and localities. Often data surveyed with one method are directly compared to data analyzed with a different method. In particular, fossil reefs that grew in warmer oceans than today are commonly compared to modern reefs because they are used as analogues for the future. However, fossil reefs are different from modern reefs because they are diagenetically altered and time averaged. While studies on the comparability of methods in modern coral reefs are common, only few studies compared methods in fossil reefs and between fossil and modern reefs.

Therefore, we compare data gathered by LIT, PIT, and PQ on Pleistocene coral reefs of the Red Sea using five replicate transects at two Egyptian localities. We find that transect and quadrat methods cannot be directly compared to each other with respect to reef cover and community composition. In contrast, the two transect methods LIT and PIT result in similar coral cover and community composition. For PITs, however, alpha diversity decreases with increasing intervals (i.e., with decreasing resolution).

We argue against the use of quadrat methods on fossil coral reefs because they do not allow comparisons with data obtained by the transect methods. In addition, quadrat methods capture a larger amount of time averaging and have a poor time efficiency. We conclude that large numbers of transects using the PIT with 20 cm intervals are the most appropriate method to survey fossil coral reefs.

Regular talk

INVERSE LATITUDINAL DIVERSITY GRADIENTS IN LAST INTERGLACIAL CORAL REEF COMMUNITIES

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Marine organisms are currently expanding their ranges poleward in response to global climatic change. Some studies have also provided support for equatorial range retractions within several marine groups. However, such observations are frequently based on short-term monitoring data with natural ecosystem baselines largely unknown due to anthropogenic impacts. The fossil record offers the unique opportunity to study the long-term response of organisms to global climatic change with empirical evidence and establish ecological baselines under various climate states. The Last Interglacial (~125,000 years ago) is commonly recognised as an interval with a climate as warm, or warmer than today, offering the potential to evaluate the structure and diversity within coral reef communities. Previous work has shown that reef corals experienced poleward range shifts and an equatorial decline in diversity during the Last Interglacial. However, more recent work has suggested that this observed pattern might be the result of data absence at low latitudes. Here, we present preliminary work from a concentrated effort to map Last Interglacial coral reef communities along a latitudinal gradient in the Red Sea. The long-term aridity within the Red Sea has resulted in excellent preservation of reef ecosystems and easy access due to the absence of vegetation. Together, these conditions enable Red Sea Pleistocene reefs to be studied using approaches from modern-day ecology (e.g. line intercept transects) to enable robust comparisons with coral reefs today. We present data from ten Last Interglacial coral reef sites from the Egyptian coast, sampled using the line intercept transect method. Using this data, we test for a latitudinal gradient in the diversity of reef ecosystems within two depth environments (reef edge and shallow reef slope). We show that reef communities are distinct between the reef slope and reef edge, yet diversity and community evenness moderately increase with latitude within both environments. Moreover, dissimilarity in community composition decreases with latitude. Our findings lend support for previous work in suggesting a decline in diversity towards the equator during the Last Interglacial. Future work will expand this dataset across the Red Sea basin with data from Sudan and Eritrea, providing a broader latitudinal coverage.

Regular talk

MATCHES AND MISMATCHES BETWEEN REEF PROLIFERATION AND REEF BUILDER DIVERSITY ON GEOLOGICAL TIME SCALES

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Coral reefs are under increasing pressure from human-driven climate change with projections of near total elimination before the end of this century under high levels of global warming. Reef corals are also thought to be at elevated extinction risk but estimates vary profoundly among studies. Works that use lost reef area as a proxy of coral population reduction tend to estimate high extinction risk (Carpenter et al. 2008), whereas approaches which estimate coral population sizes more directly estimate low extinction risk for reef corals (Dietzel et al. 2021).

The geological record of reefs and reef builders may provide important information on the correspondence between reef proliferation and the fate of its constructors. However, previous approaches achieved somewhat contradictory results suggesting on the one hand a positive correlation between mean reef builder diversity and reef volume (Kiessling 2005) and on the other hand that reef development and coral diversity were independent (Johnson et al. 2008).

Here we apply multiple approaches to estimate the correspondence between reef builder diversity and reef proliferation. We use the Paleoreefs Database (https://www.paleo-reefs.pal.uni-erlangen.de/) for global estimates of reef volume and within-reef (alpha) diversity and the Paleobiology Database (https://paleobiodb.org/#/) for global estimates of reef builder (gamma) diversity over time. A new compilation of Cenozoic reef corals in the Mediterranean area allowed us to also assess the correspondence between reef building capacity and coral diversity at regional scales.

Although there are exceptions, our results suggest that diversity and productivity were decoupled in fossil reef systems. Neither the within-reef nor the global diversity of reef builders was cross-correlated with reefal carbonate production as estimated from the Paleoreefs Database. Our results suggest that while coral reefs may vanish in near future, corals will survive and eventually restart building reefs when environmental parameters permit.

The main pitfall in our approach remains the estimate of reef carbonate production, which is entirely based on the preserved reef volume. Census-based approaches (Perry et al. 2012) may be better suited to estimate reefal carbonate production and a pioneer study in Oligocene and Miocene reef systems in Apulia (Italy) revealed that high-diversity reef systems in the Oligocene (Bosellini et al. 2021) were indeed much more productive than low-diversity Miocene reef systems in the same area. While sampling issues are increasingly being recognized in the assessment of fossil biodiversity, there is a research gap in the estimate of ancient reef proliferation.

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Regular talk

THREE TYPES OF REEFS IN THE ŠTRAMBERK LIMESTONE DEVELOPED AT THE JURASSIC/CRETACEOUS TRANSITION (CARPATHIANS, CZECH REPUBLIC)

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The locality Štramberk near Ostrava in Moravia (Czech Republic) is one of the most renowned paleontological sites. The Štramberk Limestone is known for its reefal facies with numerous corals and other fossils, but in fact, these limestones include various facies deposited at the Jurassic/Cretaceous transition on the Štramberk Carbonate Platform and its slope (Eliáš and Eliášová 1984; Kołodziej et al. 2023). These limestones occur as olistoliths and large blocks embedded in the Cretaceous flysch of the Outer Carpathians.

The Štramberk Limestone contains the world's most diversified coral assemblages (c. 115 species of 50 genera) in the reefs developed at the Jurassic/Cretaceous transition (Tithonian–Berriasian). They were described in 1897 by Maria Ogilvie and later in numerous papers by Helena Eliášová (see Eliáš and Eliášová 1984; Kołodziej et al. 2023). Corals occur in the coral-microbial boundstones. Besides microbialites, photophile microencrusters (e.g., "*Lithocodium–Bacinella*") are common. During our studies, we found that in addition to the coral microbial boundstones, there are also boundstones which can be attributed to the microencruster-microbial-cement reefs and sponge-microbial reefs (Kołodziej et al. 2023).

Late Jurassic–earliest Cretaceous reefs with a microencruster–microbial–cement framework and with rare (microsolenids) or without corals and without photophile microencrusters were distinguished for the first time by Schlagintweit and Gawlick in 2008 in the Alps. In the Štramberk Limestone, they were recognized by Hoffmann et al. (2017). Such reefs are known only from the Tethyan domain where they were developed in a deeper environment, in a high-energy, upper fore-reef slope setting.

Sponge-microbial reefs were common in the Late Jurassic on the northern margin of the Tethys, but are poorly known from the Tethyan domain and never described before from the Štramberk Limestone. Recent studies in the new, lowest level of the huge Kotouč quarry in Štramberk revealed olistoliths of sponge-microbial boundstones with rare corals (Kołodziej et al. 2023). Further studies will aim to determine the age of these boundstones to reveal whether they were formed before the development of a shallow-water carbonate platform or are coeval with coral reefs but developed in a deeper environment. In contrast to the northern Tethyan margin (European epicontinental seas; e.g., Wierzbowski and Stolarski 2023) mesophotic coral reefs dominated by platy microsolenids were not recognized in the Štramberk Limestone.

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Regular talk

PHOTOSYMBIOSIS IN HELIOLITID CORALS

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The matter of photosymbiosis in Paleozoic corals remains contentious. Without preservation of soft tissue that can be tested for the presence of algal symbionts, and with no direct living descendants, it is virtually impossible to prove or disprove this concept in absolute terms. However, present-day photosymbiotic corals are characterised by a number of other features that differentiate them from aposymbiotic ones. Those features are: compound growth, large colonies, small polyps, highly integrated colonies, seasonal cyclic growth patterns, and skeletal plasticity, especially resulting in platy growth forms in low-light environments. Heliolitid corals, very common in Middle Paleozoic reefal assemblages, developed plocoid colonies, making them some of the most highly integrated corals of that time. Additionally, while they have no living descendants, heliolitids exhibit a remarkable similarity in skeletal structure to the modern photosymbiotic, aragonitic octocoral genus – *Heliopora*. In the presented study, the following hypothesis was tested: if heliolitid corals were also photosymbiotic, their skeletons should exhibit the abovementioned features typical for modern zooxanthellate taxa.

A total of 266 heliolitid specimens were collected from three Silurian outcrops in Gotland: Ireviken (Lower Visby Beds), Ygne (Lower and Upper Visby Beds), and Lau Käldu (Eke beds). An additional 5 Devonian specimens from Poland and Belgium, exhibiting cyclic growth patterns, were also analysed. At Ireviken, which is considered a deep-water, mesophotic assemblage, 64% of the specimens exhibited tabular and platy growth forms. At Ygne, where specimens from the mesophotic Lower Visby Beds are mixed with the from the shallower Upper Visby Beds, only 25% of the coralla exhibit such growth forms, while 34% of the heliolitids were branching. In Lau Käldu, where the conditions were most likely shallow but very turbid, 81% of the specimens were platy or tabular. A total of 9% of all heliolitid specimens had irregular growth forms, most commonly shaped in the form of a plate, with vertical protrusions on top. Such growth forms were described for present-day *Porites sillimaniani* as an adaptation to low-light conditions. Of all Silurian specimens, 61% belong to the species *Steliporella parvistella*, known for very high skeletal plasticity and a wide range of growth forms. Cyclic growth patterns were observed in four sectioned specimens of *Propora tubulata* from Ireviken, and in five specimens of *Heliolites porosus* from the Upper Emsian–lower Eifelian deposits of Olloy-sur-Viroin and the Eifelian reef of Wancennes in Belgium, as well as the Givetian carbonate facies of Dziewki and Skały in Poland.

Most known heliolitid species exhibit small corallites below 2 mm in diameters. Heliolitids often formed large colonies exceeding 1 m in diameter. Such features never occur in present-day aposymbiotic corals. Additionally, unlike some other tabulate groups such as favositids, pachyporids or alveolitids, heliolitids usually do not occur in very deep water, basinal facies, or in cryptic environments. Together with the observed skeletal plasticity in low light environments in the Silurian of Gotland and the regular cyclic growth patterns in well preserved specimens, this suggests that most likely heliolitid corals were photosymbiotic.

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Poster

APPROXIMATION OF SKELETAL DENSITY IN TABULATE CORALS

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The density of coral skeletons is an important feature, often overlooked in coral paleontology. In the study of present-day scleractinians it is a metric useful in assessing the influence of such environmental stressors as bioerosion and ocean acidification. It can be measured e.g. on the basis of the weight and volume (Archimedes' Principle), or using x-ray densitometry. For the case of fossil corals, however, it is far more difficult to quantify skeletal density. Usually fossil skeletons are filled by cements which are composed of calcium carbonate, and therefore have the same density as skeletal elements, making measurements difficult. In addition, the coralla commonly occur embedded within a solid rock, and in an incomplete state of preservation. The presented study proposes an easily replicable method of quantification of skeletal density in tabulate corals despite these factors.

The approximated skeletal density is here understood as a proportion of skeletal elements to the volume of the corallum, given as an area percentage value. It is measured in oriented sections of coralla. For a longitudinal section, it offers a rough estimate of the skeletal density of the corallum. In transverse sections it allows for the approximation of skeletal density at a given stage of astogeny.

The oriented thin sections or acetate peels of the coral are photographed in darkfield. The digital photographs are then converted to black and white bitmaps, and basic graphic processing software is used to remove any artifacts and to change the background to a neutral colour. Subsequently the image is analysed using a pixel-counter tool. The result is the number of white (= skeleton) and black (= empty/cement) pixels. The percentage of white pixels is the approximated skeletal density.

In the presented study, a juvenile corallum of *Favosites goldfussi* was used as an example. It comes from the Eifelian of Ouihlane in the Anti-Atlas (Morocco), where a monospecific community of juvenile, short-lived *F. goldfussi* occurred in deep-water facies of the Mader basin. Ten serial transverse acetate peels were made from the lower parts of the studied corallum, presenting the earliest stages of astogeny. While the representatives of the genus *Favosites* are generally characterised by relatively thin corallite walls, the approximation of skeletal density yielded results in the range of 85–98%. This anomalously dense skeleton was most likely an adaptation to soft bottom conditions. The corals from the studied strata did not have long lifespans, probably dying via burial by gravitational mass movements. Thick, heavy skeletons could provide them with an anchor to the soft seafloor during early life.

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Regular talk

MIDDLE DEVONIAN (GIVETIAN) CORAL-STROMATOPOROID PATCH REEFS FROM THE LAZHULUNG FORMATION, XIZANG (TIBET) AND THEIR IMPLICATIONS

Liang KUN

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This study reports detailed investigations on the coral-stromatoporoid patch reefs from the Lazhulung Formation near Shouxinghu in the Lazhulung-Badangco area, Ngari prefecture of Southwest China's Xizang (Tibet) autonomous region. By as many as 1085 thin sections prepared from three patch reefs, the fossil components and reef structures are depicted. The patch reefs are found to encompass diverse fossil organisms, including tabulate and rugose corals, stromatoporoids, brachiopods, gastropods, ostracods, nautiloids, calcified cyanobacteria, and tubeworms. Tabulate corals and stromatoporoids are the predominant reef-builders, particularly *Alveolites obtortus* and *Gerronostromaria gromotuchense*. The patch reefs are judged to be Middle Devonian Givetian in age based on the tabulate coral and stromatoporoid assemblage. Extensive biotic interactions between the reef organisms are found in all three patch reefs, which are beneficial for the reef formation and development. The ecological features of the corals and stromatoporoids indicate a mesophotic ecosystem that is widespread in the Givetian. In addition, the common species and similar characteristics between the faunas in the Lazhulung Formation in the North Qiangtang Block and those in the South China suggest a close palaeobiogeographic relationship. This study improves our understanding on fossil components, reef structure and tectonic affiliation of the Palaeozoic strata in the Lazhulung-Badangcuo area.

Regular talk

TENTATIVE CLADOGRAMS FOR TRIASSIC AND JURASSIC CORAL FAMILIES

Bernard LATHUILIERE[1], Danwei HUANG[2], and the corallosphere group

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A major work in progress of the Corallosphere network of coral taxonomists involves producing a glossary of terms applied to the morphology of scleractinian corals. The definition of terms allowed the assembly of a dataset that includes more than one hundred characters with their associated character states. These morphological characters constitute the basis of a taxon/character matrix that was used to build a general cladogram of extinct and extant scleractinian families. The initial results comprise poorly-resolved trees which may be biased by the complexity of the multiple character states and the multiplicity of coders in the coding process. When the analysis was restricted to matrices consisting of families from the Triassic and Jurassic periods and coded by a single person, resolution increases, allowing for further exploration of various taxon inclusions and outgroups. The new results presented here come from: (1) Data matrix with all families represented by their type genus; (2) Data matrix with selected families represented by their solitary or phaceloid genera; (3) Data matrix with only Triassic corals; (4) Data matrix with only Jurassic corals; (5) Data matrix with Triassic and Jurassic corals; (6) Data matrices with several outgroups. Well-resolved trees are obtained in several cases (see Fig. 1). Phyletic relationships with basal, robust and complex groups established from the molecular approach are suggested.

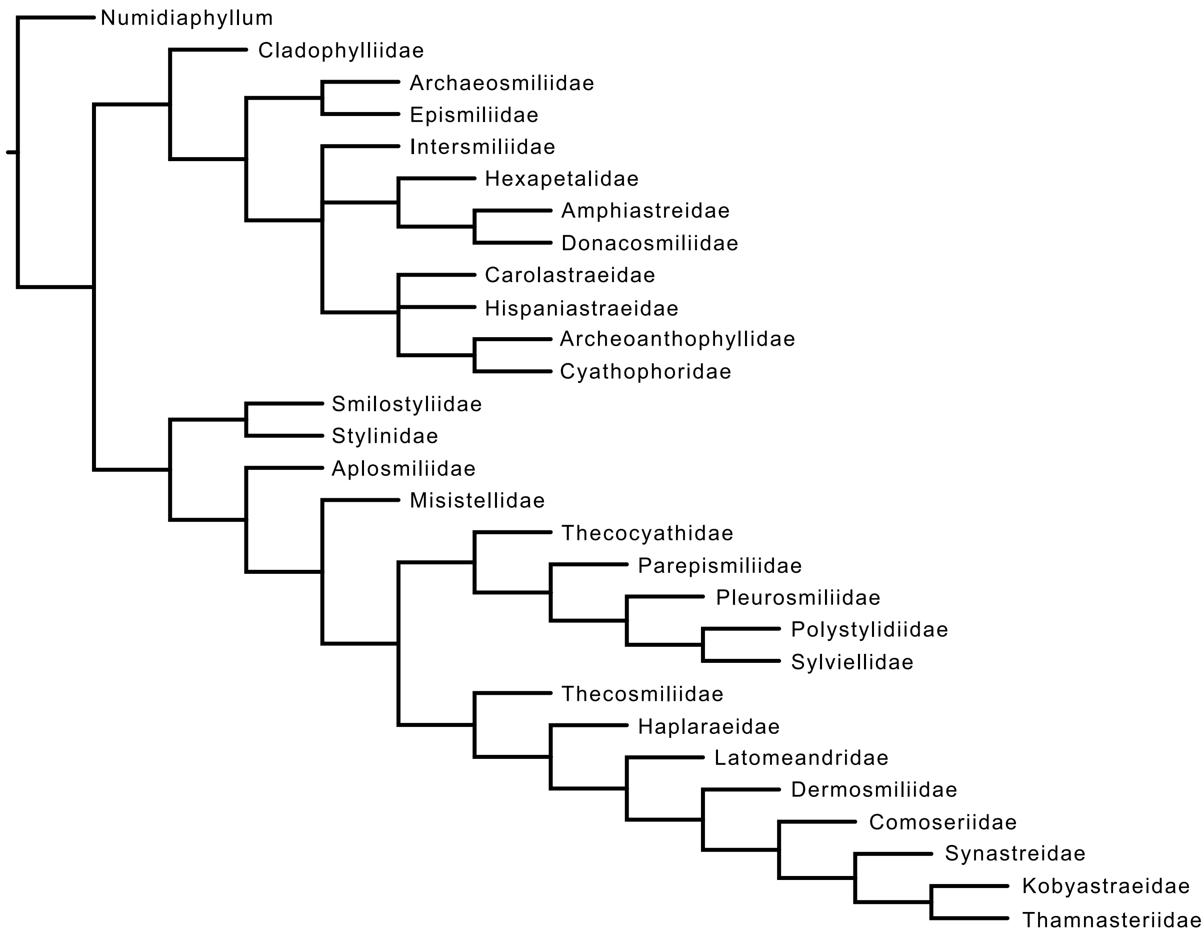

Fig. 1. Example of a preliminary cladogram with only Jurassic genera and *Numidiaphyllum* as an outgroup.

Regular talk

COLONIAL CORAL RESILIENCE BY DECREASING SIZE: REACTION TO INCREASED DETRITAL INFLUX DURING ONSET OF THE LATE PALAEOZOIC ICE AGE

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Modern coral reefs and associated biodiversity are severely threatened by increasing terrestrial runoff. Similar scenarios could be suspected for geological times, but reef coral resilience is still an enigma. In late Visean-Serpukhovian (Mississippian foraminiferal zones/MFZ14-16) times, a major glaciation phase of the late Palaeozoic Ice Age (LPIA) associated with enhanced terrestrial weathering and runoff coincides with a biodiversity crisis and coral reef decline. In this study, the impact of enhanced terrestrial runoff is tested on size variations of colonial corals *Aulina rotiformis* and *Lithostrotion decipiens* along a gradient of contemporaneous (Serpukhovian) open marine carbonate to near-shore siliciclastic facies in South China. Along this gradient, coral sizes decrease from carbonate, through intermediate carbonate-siliciclastic, to siliciclastic facies. This is consistent with increasing abundance of terrestrial materials of high silicon, aluminium and phosphorus values. On a larger million-year-long interval (MFZ14-16) and for several palaeocontinents, size data of *Lithostrotion decipiens* and *Siphonodendron pauciradiale* show a distinct decline in the late Visean, when enhanced terrestrial weathering occurred commonly with palaeosols developed during sea-level regression. This suggests that terrestrial sediment and nutrient input may have mainly controlled phenotypic plasticity in Mississippian reef corals, with a decrease in size as a component of resilience across the LPIA onset.

Poster

A NEW REEF CLASSIFICATION MODEL WITH INSIGHTS INTO PHANEROZOIC EVOLUTION OF REEF ECOSYSTEMS

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Organic reefs are largely calcareous build-ups of sessile organisms, commonly in shallow marine ecosystems, with a long Precambrian to Modern history. Despite a long history of study, reef classification is still open to development due to reefs encompassing diverse organic and inorganic components with various imprecise and synonymous terms. In this study, a new classification model for organic reefs is expressed in two hierarchical levels. Level 1: Reef outline geometry has two major forms: bioherms (prominent relief and laterally constrained) and biostromes (low relief and large lateral extension interbedded with non-reef sediments), within which constructional components highly vary. Level 2: Four reef constructor groups form end-members in a pyramid diagram: macroskeleton (S), microbia (Mi), matrix (Ma) and cement (C). Thus five reef types are recognized depending on the composition and structure of these constructors: (i) S-supported reef; (ii) Mi-supported reef (calcimicrobial and agglutinated microbial); (iii) Ma-supported reef (cluster and carbonate mud mound); (iv) C-supported reef; and (v) hybrid component-supported reef (comprising two or more major types of reef components). This arrangement makes a more streamlined and accessible reef classification than prior schemes. Two associated non-reef habitats that may grade into reefs are relevant: debris biostromes/banks and level-bottom communities containing taxa found in adjacent reefs. Based on this 'SMiMaC' model, the structural evolution of reef ecosystems is demonstrated for the Phanerozoic, characterized by S-supported and hybrid-supported, and Mi-supported and Ma-supported structures under cooling and intense warming climates, respectively.

Regular talk

CONVERGENT PATTERNS IN LIGHT-INDUCED PHENOTYPIC PLASTICITY IN DEVONIAN AND MODERN CORALS

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Life has an impressive potential to adjust to environmental conditions. One of the key adaptations that enable organisms to cope with environmental variations is phenotypic plasticity. Modern scleractinian corals can display high phenotypic plasticity, which reflects an interplay among various environmental controls, such as sediment input, water hydrodynamics or light intensity. Especially the latter can strongly influence the morphology of coral species living across broad depth gradients. Light intensity was also a factor shaping the colonies of extinct Palaeozoic tabulate corals. Based on gradual transitions in morphology observed in corals from the Middle Devonian (Givetian stage) mesophotic coral ecosystems (MCE) of the Aferdou el Mrakib reef (Anti-Atlas mountains, Morocco) and comparative material from the Holy Cross Mountains (Poland) and Ardennes (Belgium), originating from different palaeobathymetric and biogeographical settings, we show that Devonian tabulate corals, such as *Roseoporella* and *Alveolites*, were characterised by high phenotypic plasticity and the ability to dramatically change their morphology depending on the inferred light conditions (Fig. 1). That phenomenon was displayed as gradual changes of coral morphology from plate-like in the light depleted conditions to (semi) branching, when irradiance was higher. Some peculiar intermediate stages of platy colony bases with finger-like outgrowths oriented perpendicular to the rest of the corallum were also spotted. Such a mechanism is similar to that observed in modern scleractinians, e.g., *Porites sillimaniana*. This recurring morphological theme suggests that Palaeozoic tabulate corals shared many functional characteristics of modern scleractinians.

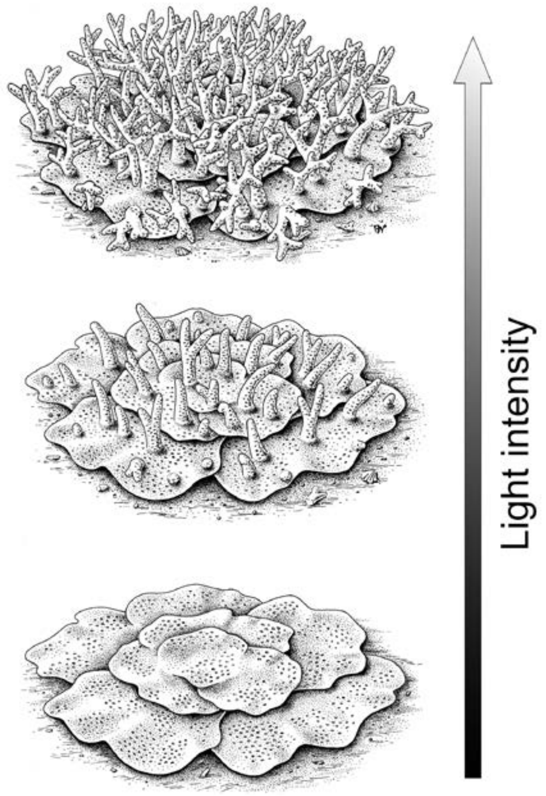

Fig. 1. Reconstructed morphological plasticity of *Roseoporella* colonies depending on different light conditions. Drawing by B. Waksmudzki.

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Keynote lecture

MECHANISMS THAT ENABLE CORALS TO PERSIST AND THRIVE IN EXTREME ENVIRONMENTS: WHAT CAN WE LEARN FROM MODERN CORALS

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Coral reefs have global ecological, structural, social, and economic importance, are a fundamental component of marine ecosystems, and are a major locus of global biodiversity. The recent devastating impacts of global climate change and local stressors on coral reef communities are expected to increase as oceans continue to warm, leading to more frequent and severe mortality events. However, many corals are able to persist in extreme environmental conditions, such as low light, high temperature, low pH, and high salinity. Survival under rapid environmental change relies, in part, on the ability of organisms to adapt to new conditions. Species that exist along broad environmental gradients and in extreme environments require a high capacity for adaptation and/or trait-based selection in response to different conditions. Understanding the reef coral physiological plasticity under a rapidly changing climate is of crucial importance for the protection of coral reef ecosystems. Most of the reef corals operate near their upper limit of heat tolerance. A possible rescue for some coral species is migration to deeper, cooler mesophotic depths. However, gradually changing environmental parameters (especially light) along the depth gradient pose new adaptative stress on corals with largely unknown influences on the various biological molecular pathways.

In this presentation I seek to provide a thorough overview of the mechanisms that allow zooxanthellate corals to continue forming mineral carbonates under extreme conditions, using a multidisciplinary experimental approach. By applying a variety of spectroscopy, molecular biological, and biochemical techniques applied to corals from diverse locations and/or after reciprocal translocation our aim is to characterize the nanocrystals (What are they?), the molecular and physical mechanism of their formation (How are they made?), the spatial and temporal production of the material (Where and when are they formed in vivo?), and how these characteristics respond to changes in the environments (How stable are they?). Answering these questions can provide insights into possible molecular mechanisms of calcification and skeletal adaptations that have repeatedly allowed this coral group to adapt to a range of environments in the geological past.

Regular talk

DEEP AND DIRTY CORAL BEARING BIOHERMS FROM THE LATE DEVONIAN OF SOUTH DEVON: EXPLORING THE LIMITS OF PALAEOZOIC CARBONATE BUILDUPS

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Modern scleractinian corals require a specific set of environmental conditions in order to thrive, namely clear, warm, and high energy waters. In contrast, Palaeozoic corals were often most comfortable in calm waters, settled on muddy substrates. Yet there must have been some limit to the depth and sedimentary environment that they could tolerate. To explore this, we examined the Devonian fossiliferous rocks of South Devon, UK. Despite historical palaeontological records dating from this, the type area of the Devonian System, these successions have been overlooked for many years, with little to no geochemical investigation undertaken until now. Here we report the results of fieldwork, optical and electron microscopy, and elemental and stable isotope geochemistry of Frasnian coral-bearing bioherms from Saltern Cove, Paignton, to deduce the palaeoenvironmental circumstances under which the corals grew, and those that may have resulted in their demise. The studied bioherms were up to 5 m across and 1.5 m thick. They are preserved as interbedded layers of cemented limestone (2–30 cm), draped in a red siliciclastic mudstone facies (1–15 cm) that is also the dominant lithology immediately above and below the bioherms. The muddy host-rock lithology (coupled with a lack of stromatoporoids) suggest a relatively deep water palaeoenvironment, associated with significant inputs of muddy, terrestrial siliciclastic sediment. Corals within the cemented limestone of the bioherms often appear to be in situ, with both branching and encrusting tabulate corals, while corals in red mudstone are often loose and may have been washed in from shallower platforms during storms. On some biohermal horizons, most of the corals have been partially or fully replaced by diagenetic silica, whereas other corals remain calcitic. While the growth of any individual bioherm was able to outcompete mud deposition for some time, significant smothering of mud (20+ cm) appears to have been terminal. This suggests that Palaeozoic corals may have been quite resilient though not immune to terrestrial inputs.

Regular talk

RECONSTRUCTING ULTRA-HIGH-RESOLUTION CLIMATE VARIABILITY AND SYMBIONT BLEACHING IN TROPICAL CORALS: INTRODUCING A MULTI-PROXY APPROACH

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Climate change poses a global challenge to many ecosystems. Coral reefs, the most diverse ecosystem in the marine realm, are one of the most affected by the increasingly rapid warming of the world's oceans. As sea surface temperature increases, coral bleaching events are becoming more frequent and severe. However, little is known about suspected multiple contributors to coral resilience. Furthermore, the hypothesis that there are chemical fingerprints of bleaching events recorded in the aragonitic skeleton of corals remains to be tested in present and past environments through the use of modern and fossil corals. The EPIBleach project aims to address these questions by developing and utilizing a multi-proxy, ultra-high-resolution approach in corals of the present and past warmer-than-present periods. Our target periods in which the Earth's climate was demonstrably warmer than today are the Pliocene (2–3ºC warmer than preindustrial), and the Eocene (7–14ºC warmer than preindustrial). Preliminary analyses of one modern coral colony (*Porites* sp.) from the western subtropical North Pacific (Ogasawara Islands, Japan) and two colonies of fossil *Goniopora* spp., one from Eocene deposits (34 Ma) of the English south coast and another from Pliocene deposits (3.2 Ma) of the Cibao Basin (Dominican Republic), show significant growth anomalies according to computer tomography (CT) and X-ray analysis. This strong deviation from the seasonal density banding pattern could potentially indicate bleaching, since the loss of symbionts during bleaching can cause calcification rates to vary anomalously and thus change the density of the affected growth layers. Additional CT analyses on the modern *Porites* sp. reveal density anomalies which coincide with published records of a pronounced shift in the Sr/Ca and U/Ca temperature proxy signals on the same coral specimen. The variation of independent proxies strengthens the assumption that we are dealing with a modern bleaching event. Ongoing study of such growth anomalies will be coupled with further multi-proxy geochemical analyses on both modern and fossil corals, to provide information on when and how coral bleaching occurred. Our results will allow us to obtain a suite of tracers for paleo-bleaching events over wider geological timescales in coral skeletons, which can be useful to fill in a gap in coral reconstructions of past climate and environment.

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Regular talk

FIRST RECORD OF CALCIFICATION PERFORMANCE OF SUBTROPICAL REEF CORALS FROM THE EOCENE

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Scleractinian reef corals are excellent climate archives, frequently used for paleoclimate and paleoenvironment reconstructions. High-precision measurements of geochemical proxy data derived from the aragonitic skeleton provide records of local sea surface temperature (SST) variation at the time of coral growth, with monthly to seasonal resolution. However, next to temperature there are additional environmental and biological factors that affect coral calcification performance and proxy signatures e.g., light and nutrient availability, water chemistry, diseases, or interspecific relations.

Here, we present timeseries of element concentrations and stable isotope ratios ($\delta^{18}O$, $\delta^{13}C$) of subtropical Eocene (~40 Ma) reef corals (*Astreopora* sp.) with an unusually unaltered state of preservation. The examined corals are from Northwestern (Paris Basin, France) and Eastern Europe (Dnipro, Ukraine). We investigate anomalies in coral calcification and proxy records, and aim to answer the following questions: 1) Is there a dependency between temperature-sensitive geochemical proxies and coral extension rate and if so, how does this relationship present? 2) How can we distinguish between (paleo-)environmental signals and effects of subtle diagenesis (cements, recrystallization, secondary aragonite) in the evaluation of geochemical proxy data? 3) What additional ecological factors might have influenced temperature-sensitive geochemical proxies during coral growth?

For examination, coral slabs of 6.0 ± 0.05 mm thickness were imaged with a SHR 50V digital x-ray cabinet to visualize the annual density bands. The coral bulk density was measured using Coral XDS (Helmle et al. 2011). Data on the distribution of oxygen and carbon stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and element/Ca ratios along the maximum growth axis of a coral transect were acquired by mass spectrometry and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), respectively.

Corals from both locations have extremely low extension rates with averages of 1.04 ± 0.01 mm/year (Ukraine) and 1.32 ± 0.55 mm/year (France). $\delta^{18}O$ data show cyclic patterns that largely coincide with the annual density bands. Maximum density is in accord with high $\delta^{18}O$ values and vice versa, allowing for a differentiation into a cold (high density, high $\delta^{18}O$) and a warm season (low density, low $\delta^{18}O$). $\delta^{13}C$ values are negatively correlated with $\delta^{18}O$ values. The $\delta^{13}C$ cycles also indicate that the corals studied were zooxanthellate and had maximum photosynthetic activity in the warm season. Temperature-sensitive geochemical proxies (e.g., Sr/Ca, U/Ca, Li/Mg) show ambiguous results that do not always coincide with the cyclic pattern of stable isotopes but are in accord with the density pattern.

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Poster

CORALS FROM THE MIDDLE VISEAN BLACK SHALES OF THE DONETS BASIN

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The Styla Suite forms the middle part of the Mississippian carbonate sequence of the Donets Basin. This 40 m-thick unit is composed of organic-rich dark-grey and black thin-bedded siliceous marls, argillaceous limestones, shales, spiculites and spiculite-bearing rocks. A bentonite from the lower Styla Suite, dated at 342.01 ± 0.10 Ma (Davydov et al. 2010), indicates that the suite corresponds to the lower part of the Tulian substage, correlated to the Holkerian and Livian substages (middle Visean) of Europe.

The lower part of the suite yields few fauna. The mudstone and crinoidal wackestone forming the upper part of the suite yield crinoids, brachiopods, bivalves, gastropods, bryozoans, and rare trilobites. The Styla Suite fossils are long-known but corals are only poorly documented.

Our collection includes exclusively tiny solitary rugose corals *Amplexus*, *Allotropiophyllum*, *Bradyphyllum*, *Sychnoelasma*, *Caninia*, and small colonies of tabulate corals *Cladochonus* and *Sutherlandia*. *Allotropiophyllum uralicum* (Vojnovsky-Krieger 1934) predominates among the corals. These corals belong to the ecological assemblage traditionally called '*Cyathaxonia*-fauna'.

The coral association is very similar to the one described on the western slope of the South Urals (Vojnovsky-Krieger 1934), which was considered as late Tournaisian in the original publication. However, a palynological revision of the coral-bearing rocks of the Ryauzak Member studied by Vojnovsky-Kriger indicates a correlation with the Tula Horizon of the East European Platform (Krauze and Chibrikova 1984). Hence, the age of the Styla Suite and the Ryauzak Member is considered similar.

No similar association of middle Visean corals have been described in other regions of the world. At the same time, black shales, including spicule-rich rocks, are widespread in the Dnipro-Donets Basin and other regions of Eastern Europe. Similar siliceous carbonates rich in sponge spicules and heterozoan remains have been documented in the Mississippian of Kansas (Franseen 2006). The origin of such rocks is debatable.

In our opinion, the sedimentation in the Middle Visean time was determined by the low relief of the East European craton after its peneplanation, largely covered by wetlands, under a warm and humid climate. Intense laterite weathering was the source of silica dissolved in organic-rich river waters flowing into shallow coastal bays. These silica-enriched waters were favourable for the development of siliceous sponges. Hyperpycnic flows (Zavala 2020) of fresh water during the rainy seasons led to anoxic conditions in the bottom waters of shallow seas, stagnation of benthos and other marine biota, movement and accumulation of sediments enriched in biogenic silica and organic substances of mixed terrestrial and marine origin in relatively deep areas of the seabed. These ecological conditions have precluded the development of a rich marine fauna but rather were suitable for the taxa of the '*Cyathaxonia*-fauna'.

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Regular talk

MICRO-MUDMOUNDS AT THE END OF THE LATE FRASNIAN, THE LAST GASP OF FRASNIAN BIOCONSTRUCTIONS BEFORE THEIR END

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In the Namur-Dinant Basin, the development and the evolution of successive distal middle Frasnien buildups ("Lion-type" buildups) and of proximal carbonate platforms are linked to the rise (LST-TST-HST) and then fall (FFST) in sea level of third-order sequences. Each emersion stopped carbonate production and the next transgression triggered new production. The last regression at the top of the middle Frasnian corresponds to the end of the Lion-type reefs and of the carbonate platform. During the transgression of the first late Frasnian eustatic sequence ("Aisemont sequence"), there was no renewal of these carbonate facies due to the first step of the late Frasnian extinctions, probably linked to a lowering of seawater oxygenation (Mottequin and Poty 2016). This first late Frasnian extinction was marked by a major crisis in rugosa, tabulate corals and stromatoporoids, during which, for example, disphylids and thamnoporids disappeared and were immediately replaced by other corals, not previously known in the Frasnian, including phillipsastreids and *Iowaphyllum*. Following this event, a new type of bioconstruction developed, corresponding to mudmounds. Two main types of mudmounds can be recognized: (1) small-sized, 5 to 10 m thick, slightly pink to light grey, microbialite-dominant buildups, with stromatactis but without any tabulate or rugose corals and almost completely devoid of other animal fossils, and (2) red to pink mudmounds rich in tabulate and rugose corals and other fossils such as brachiopods, receptaculites, and sponges ("Petit-Mont type mudmound"). The latter are the most common and the most developed, reaching over 50 m in height. The growth of the Petit-Mont type mudmounds followed the TST-HST of the Aisemont sequence, and their end is due to their emersion during the FFST, similar to the middle Frasnian buildups. During the late Frasnian, anoxic-dysoxic facies developed increasingly and became dominant during the next third-order sequence. They are marked by green to black shale deposits in the deep part of the basin, almost devoid of fossils (Matagne facies). However some fossiliferous horizons developed locally during the TST of the sequence, and were marked by coral levels ("fauna 3" of Coen et al. 1977). Mudmounds also developed, but in an unsuccessful manner and not exceeding one to a few metres in length and one to a few dozen centimetres in height. These micro-mudmounds have the same two types of facies as those previously described (i.e. dominated by microbialite or rich in corals) and they are remarkable because they are a small replica of the usual, larger mudmound, and they allow us to see the whole of this type of facies on a very small scale. These micro-mudmounds were the last attempt of Frasnian bioconstructions, and they disappeared a few metres below the level of the tsunamites recorded throughout the basin (*linguiformis* Zone), which lies at the base of the Upper Kellwasser black shale event marking the end of the Frasnian world. To date, no similar mudmound of greater size has been recorded elsewhere in the same stratigraphic interval.

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Regular talk

ORIGIN AND EVOLUTION OF THE GENERA *LONSDALEIA* AND *ACTINOCYATHUS*: INSIGHTS FOR MISSISSIPPIAN PALAEOGEOGRAPHY FROM THE WESTERN PALAEOTETHYS

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Representatives of the subfamily Lonsdaleiinae (Chapman, 1893) are common in the Mississippian of the Western, but also along the Central and Eastern Palaeotethys. *Lonsdaleia* and *Actinocyathus* are present in all continents except in Australia and South America during the Visean and Serpukhovian. Their distribution is quite irregular for several reasons: The knowledge of the Mississippian coral record shows strong variations in different geographical areas. In addition, the name *Lonsdaleia* has been used for Pennsylvanian corals that belong to other families such as Petalaxidae or Waagenophyllidae. Moreover, some citations may not be consistent, either because the identification is not clear, or because the age of the occurrence is doubtful. A global revision of the occurrences of the genera *Lonsdaleia* and *Actinocyathus* provides new data that are useful to present a general view of the origin, evolution and migrations of these two genera.

The taxonomic position of *Lonsdaleia* (McCoy, 1849) and *Actinocyathus* (d'Orbigny, 1849), has been a matter of discussion for a long time, but the most probable hypothesis for the origin of the colony-forming *Lonsdaleia* (McCoy, 1849) is evolution from solitary ancestors such as *Axophyllum (*Milne Edwards and Haime, 1851). *Actinocyathus* (d'Orbigny, 1849) would be a descendant of *Lonsdaleia* by increasing integration in the colonies.

The first occurrences of *Lonsdaleia* have been recorded in the lower Visean from northern Britain and the northern Tian-Shan Mountains, but both records show inconsistencies because of possible misidentifications and because the diversification and migration across the whole Palaeotethys only happened in the late Visean. Based on the data, three hypotheses are proposed. (1) Origin in Western Europe and first migration along the epicontinental seas bordering the Palaeotethys; (2) Origin in northern Tianshan Mountains and first migration using the equatorial current and later the epicontinental seas; (3) Simultaneous appearance in several domains of the Palaeotethys and migrations using the previously mentioned routes (polyphyletic hypothesis).

The Serpukhovian was also a period of migration and diversification for these genera. Both *Lonsdaleia* and *Actinocyathus* have been recorded in Bashkirian refuges, the Sverdrup Basin in northern Laurasia and the Tindouf Basin in northern Africa, respectively. The division of the western Palaeotethys into six subprovinces based on the distribution of corals is proposed here: (1) The Atlantic Subprovince (West European countries and Nova Scotia), (2) The Mediterranean Subprovince (Pyrenees, Montagne Noire, Betic Cordillera, Rif, Balearic Islands, Nötsch, and Carnic Alps), (3) The Saharan Subprovince (Béchar, Reggan, Ahnet-Mouydir, and Tindouf Basin), (4) The West peri-Gondwanan Subprovince (SW Spain and Moroccan Meseta) (5) The Eastern European Subprovince (Moscow Basin, Donetz Basin, and Voronezh), (6) Finally, the Central Europe Subprovince (Germany and Poland).

Poster

GLIMPSE OF A BRIGANTIAN (MISSISSIPPIAN) TROPICAL SEA FLOOR ON THE DERBYSHIRE CARBONATE PLATFORM, ENGLAND

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The floor of Furness Quarry near Eyam in the Derbyshire Peak District, exposes a horizontal bedding plane of the 'Lonsdaleia Bed' (or 'Black Bed') and gives a rare view of a well-preserved coral-dominated Mississippian tropical sea floor. The bed is a bituminous, bioturbated, peloidal wackestone-packstone in the upper part of the Monsal Dale Limestones Formation. We infer that this sea floor lay below wave and storm base or in otherwise very sheltered conditions in relatively shallow water. The bed is dominated macroscopically by corals which are mostly colonial and seemingly in place or nearly so, well preserved, and at least in part silicified. They are of similar diameter (30–50 cm), though they may be wider below the level of the floor. Aside from the bioturbating organism(s), other macrobiota are rare. Taking the corals to be a true life-assemblage, and assuming a radial linear extension rate of c. 4 mm/yr (Scrutton 1999), they seem to represent a short-lived larval recruitment and survivorship event, which lasted c. 125 yr before conditions became unfavourable for them.

To estimate colony frequency across the irregularly oval outcrop area (75x55 m: 0.32 ha), we paced out 14 transects in different directions, scoring 58 colonies in 553 m total length of exposed surface, i.e. 1 colony in 9.5 m. For an average colony size of 40 cm diameter (above), two methods of conversion give colony cover of c. 2.5%. From field identifications, the corals were dominantly phaceloid: mostly *Siphonodendron* and *Diphyphyllum* (c. 70%) and *Syringopora* (c. 30%), along with rare solitaries, and the infrequent eponymous cerioid *Actinocyathus* [*Lonsdaleia*] *floriformis*. Comparing with Aretz's (2010) classification of colonial rugose habitats, the assemblage clearly belongs with his B1 category ('regular coral meadow') in this case, of 'moderate' diversity. The assemblage is closest to Rugose Coral Association #4 ('*Siphonodendron–Diphyphyllum–Actinocyathus*') of Somerville and Rodríguez (2007).

Fig. 1. Partially silicified colony of *Actinocyathus [Lonsdaleia] floriformis* (Martin) on the sea-floor (bedding plane) of the 'Lonsdaleia Bed' in Furness Quarry, near Stoney Middleton, Derbyshire. (Corallites are 10–15 mm in diameter).

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Regular talk

BAJOCIAN CORAL REEFS: LIKELY A GLOBAL REEF GROWTH EVENT

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On a global scale, the Middle Jurassic (Bajocian, Bathonian, Callovian) is currently not considered to be favourable for coral reef growth. During this time, most reef builders were assumed to be recovering from the devastating climate-induced crisis of the Late Triassic and of the Early Jurassic, along with a global perturbation of the carbon cycle and increased continental weathering. We present here a recently discovered coral reef in the informal “Herrenwis Unit” in the northern part of Switzerland. Data are from the Bülach-1 and Stadel-3 boreholes in the Nördlich Lägern area, displaying well-preserved corals. These cores were drilled as part of the exploration program of Nagra, which is currently investigating three siting regions in northern Switzerland as potential repositories for radioactive waste in Switzerland. The results obtained show at least a dozen coral genera in both cores. Five coral genera account for more than ninety percent of the total number of identified coral specimen in these cores (*Isastrea*, *Periseris*, *Thamnasteria*, *Dendraraea* and *Thecosmilia*). Assessment of the growth features and orientation of the corals, the presence of surrounding microbialite crust around some corals and the scarcity of transport features indicates that most corals are upright and occur in growth position. Growth bands found on some specimens indicate a growing speed similar to other corals of the same time (around two mm per year). This reef is typical of the Bajocian time, based on quantitative data such as the coral diversity and abundance. It is probable that due to local current mechanics, a small paleohigh was formed out in the underlying formation. This paleohigh, maybe concurrently with a more favourable paleoclimate, made it possible for corals to start growing in patch reefs in this area. This new reef, dated from the Bajocian by using palynology, is the starting point to explore further coral reef growth at regional and global scale. The methodology of dating reef deposits by means of palynology was successfully applied to date coral reefs similar in size and composition in the Burgundy Platform over eastern France and Luxembourg. Results confirmed the coral reefs of the Burgundy Platform were coeval with their counterparts in Switzerland. By updating previous literature reviews and re-evaluating the coral assemblage of known and recently reported Middle Jurassic reefs, we hypothesise a global coral event in the early Bajocian. Most of these Bajocian reef sites are distributed along a hypothetical paleogeographic belt on the northern margin of the Tethys. The scarcity of reefs in low latitudes points is not yet fully elucidated but seems to confirm the assumption of elevated temperatures in low latitudes during the Middle Jurassic.

Regular talk

COLD-WATER CORAL MOUND BUILD-UP AT THE EAST MELILLA CORAL PROVINCE (SE ALBORAN SEA, WESTERN MEDITERRANEAN)

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The Alboran Sea hosts numerous cold-water coral ecosystems, including the East Melilla Coral Province. Based on a combined investigation of benthic foraminiferal assemblages, foraminiferal stable isotope compositions, grain size analysis, sediment geochemistry, and macrofaunal quantification, this study presents key events and processes having governed cold-water coral development at the East Melilla Coral Province.

Local variations in coral mound build-up along Brittlestar Ridge I over the last 300 kyr are identified by comparing different on-mound gravity cores along a longitudinal transect on the ridge crest. Mound build-up took place during both interglacial and glacial periods at average aggradation rates ranging between 1 and 10 centimeters per 1000 years (cm/kyr), indicating that corals never thrived like Norwegian coral reefs with aggradation rates of up to 1500 cm/kyr, but rather developed under more stressful environmental conditions. Aggradation rates of 18 cm/kyr are recorded during the last glacial period, evidencing coral mound development during this time period in the western Mediterranean. Planktonic and benthic stable oxygen isotope records show typical interglacial–glacial variations for this region which is in contrast with coral mounds from the NE Atlantic and highlights that the northern part of Brittlestar Ridge I experienced reduced albeit relatively continuous accretion.

Local differences in key environmental actors, such as bottom current velocities, fluvial supply to surface productivity and patchiness of substrate availability, drive the observed mound build-up. This demonstrates how local environmental variability may overprint global and regional climate variability over short time periods.

Regular talk

A NEW QUANTITATIVE APPROACH FOR PALAEOENVIRONMENTAL AND PALAEOECOLOGICAL STUDIES OF BIOSTROMES: THE CASE STUDY OF AN EMSIAN BIOSTROME IN THE FRENCH BASQUE COUNTRY

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According to Kershaw's (1994) classification, biostromes can include accumulation layers of reworked reef builders (parabiostromes and allobiostromes) as well as layers bioconstructed by in-situ preserved reef builders (autobiostromes). Of course, it is often a mix of the above (autoparabiostromes). This may result in very complex structures with sometimes tremendous heterogeneity in terms of taxa, spatial distribution of fauna, texture, etc. The assessment of how a biostrome is classified has a great impact on the interpretation in terms of palaeoecology and palaeoenvironment. We, therefore, need quantitative tools to characterize biostromes.

We present a new method to describe biostromes in a quantitative approach based on photomosaics and statistical analyses. Our case study is the never-in-detail studied Château-Pignon biostrome, a stromatoporoid-coral biostrome in the French Basque Country of Emsian age (Lower Devonian). We carefully photograph the bed surfaces to study the lateral variations at each time slice. Photomosaics have been digitized using the software QGIS© by applying a metric coordinate system. We add to each individual different attributes depending on outcrop conditions and photograph resolution, such as the morphology, the state of preservation and/or the taxonomy. Then, using QGIS© analytic tools, we calculate the area for each polygon and the coordinates of their centroid, the heatmap in order to delimit potential patches, and the distances between individuals to evaluate their proximity. Data are used to apply multivariate methods to characterize each patch. Preliminary results from the heatmaps show spatial heterogeneity with zones of high density and others with low density of reef builders. Thus, decimetres-size patches can be identified, and hence compared. In the case of Château-Pignon, patches are not significantly different from the surrounding areas in terms of taxa and morphologies. Only patches with a higher ratio of in situ reef builders are significantly different from the surroundings. Finally, distances between reef builders inside patches are significantly shorter than those in the surroundings. Those two features confirm the idea of a framework and thus bioconstructed independent patches. Hence, the Château-Pignon is a heterogeneous autoparabiostrome, wherein distinct patches, or small-sized bioherms, developed surrounded by coral debris-rich sediments. Our results show that this method has great potential to help with the description, classification and interpretation of biostromal reefs independently of their age, faunal content and location.

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Poster

SKELETON MICROBIOME OF FOSSIL SCLERACTINIAN CORALS DECIPHERED FROM MICROBORINGS

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Microborings are common in skeletons of modern and fossil corals. In addition to microborings produced post-mortem, there are ubiquitous microborings (mostly 2–10 μm in diameter) in modern corals made by microorganisms (boring algae, bacteria and fungi) during the coral's life (in vivo). These microendoliths are part of the skeletal microbiome, and together with tissue and mucus microbiome are important for coral health and reef conditions (Ricci et al. 2019).

The analysis of microborings is a key tool in deciphering the skeletal microbiome of fossil corals. Despite this, the first attempt to recognize the microbiome of the skeleton of fossil corals was performed only recently (Salamon and Kołodziej 2022; Salamon et al. 2022). Microborings produced during the coral's life have been recognized in SEM studies of resin replicas and naturally occurring internal moulds in skeletons of Jurassic, Cretaceous, Palaeogene, and Miocene colonial corals. A simple, but effective method is observation of etched thin-sections under a petrographic microscope, especially with application of fluorescence microscopy (Salamon et al. 2019). In contrast to microborings produced post-mortem, those made during the coral's life occur throughout the whole colony, are concentrated in the inner part of skeletal elements, and located commonly roughly along their longitudinal axis. Analyses of microborings imply that coral-associated microendoliths in fossil scleractinians were, like in modern corals, represented mainly by *Ostreobium quekettii* or similar green algae, and less commonly by red algae, cyanobacteria, and fungi.

Ostreobium is potentially beneficial for the survivorship of corals during bleaching. Blooms of these algae were observed in the skeleton when corals bleach. The coral-associated endolithic fungi are mostly parasitic (Ricci et al. 2019). Analysis of microborings of dead parts of modern living colonies is an unexplored, but interesting future topic for research by reef biologists. Obtained results will reveal the microbiome (banding linked with endolithic algal blooms) of modern corals during times when anthropogenic impacts on coral reefs were smaller than today.

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Regular talk

LONG-TERM RESILIENCE OF TURBID ECOSYSTEMS IN THE CORAL TRIANGLE

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The high diversity of the Coral Triangle region is at risk due to the climatic crisis. Therefore, the identification of potential ecological refugia has become a high priority. In the search for long-term resilient reef ecosystems in this dynamic biodiversity hotspot, we integrate the study of the fossil record with present-day reefs. Our palaeoecological studies have shown that pioneer coral assemblages developed under turbid conditions and hosted a high coral diversity from the Oligocene and throughout the Miocene. Low turnover suggests that once taxa appear, they may persist in turbid habitats over long periods of time. Our surveys on a mosaic of turbid and clear-water reefs in Darvel Bay (Sabah) have shown high coral cover (33% to 55%) and high representation of taxa with ~65% of coral genera from the entire region. Interestingly, during the 2020 bleaching event, corals in turbid reefs experienced less impact (12.5%) in comparison to corals in other localities across the Indo-Pacific, supporting the hypothesis that turbidity may act as a mitigation factor to thermal stress. Conversely, plastic pollution and increasing coastal development are the major threads of these long-standing habitats. Preliminary comparisons of ancient and modern turbid reefs show similarities in richness and fauna composition. The combination of fossil and modern data suggests that turbid reefs have played an important role as resilient ecosystems over the past 30 million years in the Coral Triangle.

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Regular talk

A BRIEF REVIEW OF THE STUDY OF 'CORALLINE SPONGES' FROM MEXICO

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'Coralline sponges' (formerly known as class Sclerospongiae) are an informal taxon which includes various poriferans with a primary spicule-based, as well as a secondary calcareous, basal skeleton. Fossil record of 'coralline sponges' has been studied in Mexico since the late 1980s, with the report of the taxa *Polytholosia cylindrica* and *Ascosymplegma expansum* from the Triassic of Sonora State, in northwestern Mexico (López-Alemán 1988). Subsequently, Sánchez-Beristain (2003) mentioned for the first time the presence of new 'chaetetids', with the report of *Blastochaetetes flabellum* from the Late Cretaceous of San Luis Potosí, as well as other unassigned specimens. Sánchez-Beristain et al. (2012) reanalysed the previously described material from SLP and along with new material, identified a new species of 'chaetetid' sponge: *Blastochaetetes reitneri*. These authors assigned the Cretaceous chaetetids from SLP to a platform environment based on the associated fauna and on its sedimentological features. Sánchez-Beristain et al. (2019) described also the 'chaetetid' *Acanthochaetetes huauclillensis* from the Early Cretaceous of Oaxaca, in southern Mexico. This species developed in shallow platforms dominated by rudist bioherms, showing a close relationship with randomly growing microbialites, thus suggesting that these sponges grew in cryptic areas within these reefs. *Acanthochaetetes huauclillensis* was subsequently described from the Late Cretaceous of Ladakh Himalaya, India (Barman et al. 2021). These and other findings of the genus (e.g., Schlagintweit et al. 2022; Sánchez-Beristain et al. 2023) have expanded the paleobiogeographic scope and fossil record of the genus worldwide. Recently, new findings of thalamid sponges from the middle Permian of northern Mexico were reported and further research are currently underway. Also some of these sponges are associated with epibionts like serpulids and bryozoans. These investigations make Mexico a promising place for the study of 'coralline sponges' as well as for their examination through different disciplines such as paleoecology, geochemistry and sedimentology.

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Poster

CRETACEOUS CORALS FROM SE INDIA: A RETURN TO FERDINAND STOLICZKA'S (1873) RESEARCH AREA

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Fossil scleractinian corals from India are poorly known. Detailed studies are concerned mainly with the Middle Jurassic, less is known about Cretaceous corals. The first detailed research was performed by Stoliczka (1873). Ferdinad Stoliczka (1838–1874) was a Moravian geologist and palaeontologist. His untimely death in Ladakh finished his extremely productive research lifecarried out in India since 1862 (Geological Survey of India, Kolkata). His palaeontological studies were focused on the Cretaceous fossils from SE India. Results were published in *Palaeontologia Indica* (1864–1873; four volumes, nearly 1500 pages, 178 plates) and concerned with various fossil groups: cephalopods, gastropods, bivalves, brachiopods, echinoderms, corals and other fossils.

Stoliczka (1873) described about 70 coral species, most of them were newly described species and one new genus. Coral samples were collected in 18 localities, between Pondicherry and Tiruchchirapalli (Tamil Nadu state), most of which are now identified (Alundalippur, Andhur, Karai, Karambiyam, Kulathur, Maravattur, Odiyum, Ootathur, Parali, Niniyur, Varagur, Valudavur) and some unidentified (Cooticaud, Koloture, Kullay, Penangoor, Velaghoor,). Albian–Cenomanian sediments in this area belong, according to recent lithostratigraphy, to the Uttatur Group, Trichinopoly Group and Ariyalur Group. Some corals were from Santonian–Maastrichtian deposits from Pondicherrry (Ariyalur Group).

Most of the new species distinguished by F. Stoliczka are still valid, but most of them are attributed to other genera. Some species are synonyms or still require revision. Based on recent taxonomic papers (e.g., Löser 2002) these corals can be preliminary attributed to the following genera of colonial scleractinians: *Actinastrea, Astraeofungia, Complexastrea, Cryptocoenia, Dimorphastraeopsis, Eocolumastrea, Eugyra, Heliastrea, Holocoenia* (including *H. indica* Stoliczka, 1873), *Isastrea, Latomeandra, Mesomorpha, Microphyllia, Placastrea, Placosmilia, Preverastraea, Turbinolia, Thamnasteria, Thecosmilia, Stelidioseris, Thecoseris,* solitary forms: *Balanophyllia, Caryophyllia, Cyclolites Eupsammia, Platycyathus, Plesiocunnolites, Rennensismilia, Trochocyathus,* and two octocorals: *Heliopora, Polytremacis.*

Löser and Mohanti (2004) described six coral species from the Cenomanian carbonate-siliciclastic sediments of the Karai Formation of the Uttatur Group. These authors did not recognize relationships with corals described by F. Stoliczka, which they attributed to differences in the facies. In 2023, the first author of this presentation collected samples of colonial and solitary corals and coral-bearing limestones in five localities in a similar area as the research area of F. Stoliczka. They were collected mainly in Kallakkudi and Kovandankurichchi quarries (Dalmiapuram), but also from Alundalippur, Maravattur and Kunnam. Coral-bearing limestones (not reefal boudstones), mostly bioclastic packstones with quartz, belong to the Albian–Cenomanian Dalmiapuram Formation of the Uttatur Group (Kallakkudi, Kovandankurichchi, Maravattur) and to the upper Turonian–lower Coniacian Garudmangalam Formation of the Trichinopoly Group (Alundalippur, Kunnam). These limestones were described in the literature as the coral-algal or coralline limestones, but in the studied samples coralline red algae are very rare. Field research will continue.

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Regular talk

A MESOPHOTIC CORAL FAUNA FROM THE MIDDLE RUPELIAN OF CENTRAL JAMAICA

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Little is known about coral faunas in the Early Oligocene of the Caribbean. Late Eocene corals are recorded in several areas and they differ significantly from the well-described common reef-building corals of the Late Oligocene. The Early Oligocene gap in the record, then, occurs during an apparent Eocene/Oligocene faunal turnover event. A new road cut in central Jamaica, however, has exposed a thick coral rich succession from the Early Oligocene that appears to represent the oldest mesophotic coral fauna in the Caribbean and an important bridge between the Eocene and the Late Oligocene coral communities in the region.

This new road cut in Faith's Pen, Jamaica exposes an approximately 40 m thick succession in the White Limestone Group. The large benthic foraminferal fauna collected here includes *Eulepidina undosa* in the absence of *Heterostegina antillea* and indicates that the unit is Middle Rupelian in age and represents an outer shelf fauna.

At the base of the section, draped over a carbonate mound is a 2 m thick, densely packed bed of platy corals. The coral plates are all <1 cm thick and separated by a cm or less of micritic sediment. The fauna in this unit have a low diversity, dominated by *Fungophyllia* spp. Upsection, there are fewer platy corals. The fauna upsection include isolated massive corals (chiefly *Antiguastrea cellulosa*), in-place thickets of phaceloid branching forms (*Caulastraea* sp.) and scattered thin, ramose branching forms.

On the whole, the fauna collected here are considerably less diverse than those found in shallower water sediments from the Late Oligocene. The platy coral fauna are dominated by a single species, suggesting that diversification occurs later in order to produce the rich deep-water coral fauna that is seen in the Neogene and Modern Caribbean. Overall, the coral species that dominate this Early Oligocene fauna are the same corals that are most common in the Late Oligocene of Jamaica, Antigua and Puerto Rico. This suggests that the Late Eocene/Late Oligocene coral turnover occurred before the formation of the Middle Rupelian mesophotic coral fauna.

Regular talk

EVOLUTIONARY POTENTIAL OF SCLERACTINIAN CORALS TO BUFFER OCEAN ACIDIFICATION: CENOZOIC FOSSIL RECORD PERSPECTIVE

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Modern coral reefs are under extreme threat due to a number of stressors, but those related to rising sea surface temperatures (resulting in coral bleaching) and diffusion of increasing amounts of carbon dioxide (pCO_2) into seawater (resulting in acidification of those environments) are the most severe. However, there is also compelling evidence that species-dependent physiological adaptations such as pH-buffering capacity, which raises the saturation state at the coral calcification site, will result in much more complex responses and at least higher resilience of some taxa to ocean acidification. While there is general agreement that the pace of today's environmental changes are unprecedentedly rapid, the reconstructed absolute values of CO_2 concentration levels and sea surface temperatures tens of millions of years ago far exceed those predicted for the end of this century. The astonishing observation is that despite such large changes in environmental parameters, several taxa that make up reefs today, such as *Acropora* and *Porites*, have an uninterrupted fossil record dating back often to the Eocene (c. 40 Ma). This suggests that modern descendants of those corals could inherit the evolutionary potential to adapt to future environmental stressors. To test the CO_2 buffering capacity of fossil corals that lived in conditions of significantly elevated CO_2 levels, we used exceptionally preserved skeletons of coeval Oligocene/Miocene (c. 23–24 Ma) scleractinian corals from the Aquitaine Basin (France). All skeletons retained their original aragonite mineralogy and finest-scale structural details, which allowed us to confidently use boron isotopes ($\delta^{11}B$) and B/Ca skeletal proxies to interpret aragonite saturation state (Ω) at fossil coral calcification sites. The calculations that included several assumptions e.g., temperature, salinity, $\delta^{11}B_{sw}$, Ca concentration values of ancient seawater, suggest a taxon-dependent capacity to up-regulate pH at calcification sites. Similar to their modern counterparts, the fossil *Porites* (but also *Goniopora*) showed a higher capacity to up-regulate pH at the calcification site in comparison to fossil *Acropora* (but also *Favites*). Other examined fossil corals *Turbinaria*, *Astreopora*, *Pavona* (with living representatives) and extinct *Tarbellastraea* showed similar, rather lower capacities to up-regulate the pH. On the other hand, the fossil *Siderastrea* strongly up-regulated DIC, which compensated for the low-pH value, resulting in a high saturation state of aragonite. Considering the Western Tethys and Paratethys distributions of *Tarbellastraea* in contrast to the global distribution of all other genera, the factor triggering extinction of *Tarbellastraea* in the Miocene was likely linked to the restricted distribution of the latter taxon. The evolutionary ability acquired by scleractinians to physiologically counteract the consequences of changes of carbonate chemistry allowed them to thrive in a variety of environments from the shallow to greatest oceanic depths and may also allow them to adapt to future ocean acidification events.

Regular talk

BIOLOGICAL CONTROL OVER $CACO_3$ POLYMORPHISM AND THE EVOLUTION OF BIOMINERALIZATION: INSIGHTS FROM THE BI-MINERALIC SKELETON OF *PARACONOTROCHUS ANTARCTICUS* SCLERACTINIAN CORAL

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For several decades, coral calcification was interpreted as a predominantly physico-chemical process with only limited physiological influence by the living organism. Such interpretations had profound implications for phylogenetic reconstructions and for the taxonomic interpretation of fossil corals for which only a few skeletal characteristics, such as the distribution pattern of calcification centers, were considered reliable. The unaltered coral skeleton, most commonly composed of aragonite, was considered a simple, largely passive recorder of past ocean conditions. However, the last few years have seen tremendous progress in understanding the genetic processes driving biomineralization, which call into question these physico-chemical interpretations. In corals, as in many other biomineralizing organisms, there are various organic macromolecules associated with biomineralization physiology (notably some coral-specific proteins and polysaccharides) that play a critical role in the formation of specific skeleton ultrastructure components. It was recently discovered that the scleractinian coral *Paraconotrochus antarcticus* has a skeleton composed of simultaneously formed aragonite and high magnesium calcite, which suggests that its bi-mineralic composition is controlled by mineral-specific sets of biomineralizing macromolecules. Here, we use Photo-induced Force Microscopy (PiFM), a novel imaging technique mapping both surface and molecular chemical information to detect structural and compositional differences between aragonitic and calcitic skeletal regions of *P. antarcticus* with nano- to micrometer spatial resolution. At micrometer resolution range, aragonite and calcite fibers can be differentiated by systematically varying proportions of carbohydrates (1055 cm^{-1}) and amides I (1663 cm^{-1}), both of which dominate in the aragonite skeleton. At the nanoscale, the phase PiFM topography images show more compact nanogranular texture of calcite vs. aragonite and a highly heterogeneous distribution of organic-rich phases in aragonite, with boundaries between carbohydrate- enriched and depleted nanograins often extremely sharp. Compositional differences between aragonite/calcite skeletal regions in *P. antarcticus* thus suggest that the biomineralization process is modulated by mineral-specific organic macromolecules, analogous to the specific organic macromolecules controlling the calcitic prismatic layer and aragonitic nacre shell layers in mollusks. The prospect of physiological, macromolecular modulation of calcium carbonate polymorphs in corals provides an entirely different perspective to a purely geochemically-driven (e.g., seawater Mg/Ca ratio) interpretation of shifts in coral skeletal mineralogy throughout the fossil record.

Regular talk

EXTINCTION-INDUCED CHANGES TO MOROCCAN REEF ECOLOGY IN THE EARLY JURASSIC

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Mass extinctions in the early Mesozoic were foundational to the development of modern marine communities, such as coral reefs. Two Early Jurassic extinctions, the Pliensbachian/Toarcian (Pl/To) boundary event and the Toarcian Oceanic Anoxic event (T-OAE), caused one of the most severe reef collapses of the Phanerozoic. Current research on the effects of shallow-water reef ecosystems during these extinctions lacks the resolution necessary to either quantify the ecological changes caused by the extinctions or determine how specific extinction drivers (e.g., nutrient influx, ocean acidification, sea-level change) influenced ecological shifts. Evidence suggests that the two extinctions were not caused by identical drivers; so, this study uses fossil data to reconstruct the ecology of reefs from intervals before, between, and after the events to identify variability in how taxa responded to each extinction and determine if those differences could be explained by extinction drivers unique to each event.

This study focuses on reefs that grew in the shallow waters of the Atlas Rift Basin. Within the Central High Atlas Mountains of Morocco, this interval is uniquely expanded, and we have been able to thoroughly sample reefal units from multiple locations, chronostratigraphic units, and facies across the upper Lower Jurassic. The Moroccan shallow water environments experienced two severe carbonate factory collapses during the Pl/To and the T-OAE. During these events, differing factors led to a pause in reef growth and after each extinction, the biotic structural components of the reefs changed, providing insight about how extinction drivers impacted reef taxa.

The Pl/To caused a severe extinction in corals, and following that event, lithiotid bivalves recovered more rapidly than corals, which lead to a shift from a mix of coral-dominant and lithiotid bivalve-dominant reefs to predominantly lithiotid bivalve reefs immediately following the recovery of the carbonate factory. The T-OAE, however, had a much more severe impact on the lithiotids, which went extinct; in contrast, corals recovered quickly and coral-dominated reefs returned to the platform. An ongoing quantitative point count analysis of more than 250 thin sections provides data for a quantitative assessment of the specific structural and ecological changes that occurred within reefs, as well as assess how the roles of certain taxa changed during this time. Occurrence and volumetric composition data are used to quantify the differences in reef facies between time intervals. Detailed analyses of reefal compositional and structural change across these two extinctions will allow for determination of the causes for the differential effects of the two extinctions on reef systems. Together, these data may also shed light on the specific drivers of each biotic crisis, as well as their effects on the faunal community and structure of the reefs.

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Poster

THE KLUTERT BIOSTROME: A MODEL FOR REEFS IN SEDIMENT-STRESSED ENVIRONMENTS?

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The Devonian period is remarkable as it witnessed an acme of reef development. Classic reefs are known from Belgium, Germany, Morocco and Australia. The biostrome presented here from Germany represents a short-lived autoparabiostrome that developed during a regional transition from a siliciclastic-dominated environment to a carbonate-dominated environment ('Massenkalk'). Detailed studies were possible because the biostrome is accessible in three dimensions through a cave system (Klutert Cave) of 5.8 km path length. Acid digestion analysis revealed a high siliciclastic content of the matrix (up to 98 wt.-% siliciclastics) and underlined the sediment-stressed environment during reef development. Conventionally, these mixed carbonate-siliciclastic environments were considered unfavourable to reef organisms. Such 'challenging' conditions are reported from several reefs in mixed-carbonate siliciclastic environments throughout Earth's history (e.g., Lower Devonian of France; Upper Cretaceous of Jamaica; Miocene of Indonesia; Recent Amazon River). It would be valuable to test whether the compiled model for the Klutert biostrome can serve as an analogue for other reefs that developed in sediment-stressed environments.

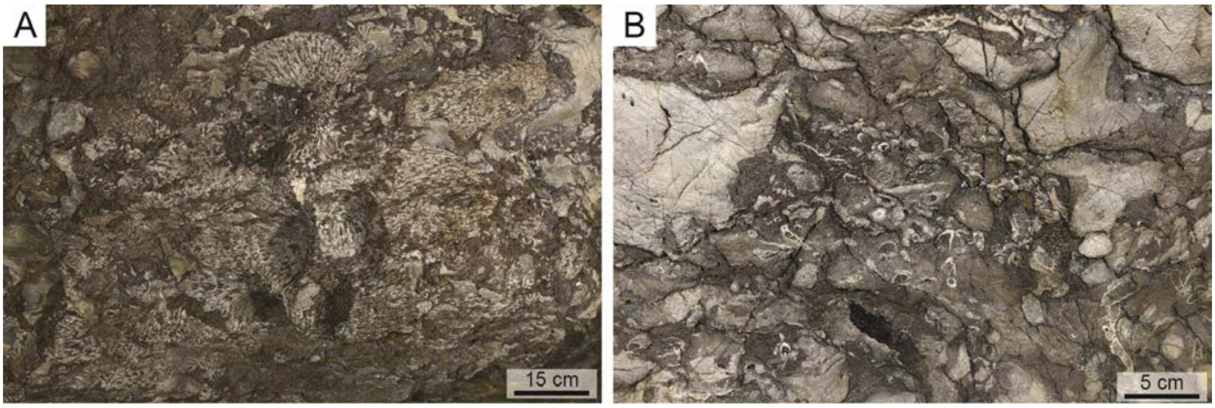

Fig. 1. **A**. Example of the Klutert biostrome that formed in a sediment-stressed environment. Here the reef-building organisms are preserved in a matrix comprising 95 wt.-% of siliciclastics. The delicate branching coral growth forms are preserved articulated, while in other areas the same coral species is preserved in fragments. Surprisingly, the highest coral species diversity is observed in the areas with the highest silicilastic values. **B**. Example of the Massenkalk accessible at the Dechen Cave, Germany. Here the reef-building organisms flourished in a clear water environment. The matrix consists of 1 wt.-% of siliciclastics.

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Poster

OUTCROP3D: A DIGITAL PATHWAY TO THE DEEP-TIME REEFS

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The facies heterogeneity of the reefal build-ups requires multi-profiled, even multi-dimensional studies to comprehensively reveal the process of reef growth and the construction of reef complexes. However, the size and accessibility of the outcrops usually restricted the data acquisition based on traditional field works. Nowadays, unmanned aerial vehicles (UAVs), especially commercial drones, provide low-cost and highly efficient ways for outcrop investigation. Close-range photogrammetry using UAV images can build three-dimensional models for outcrops with accuracy at the centimeter level. DDE-Outcrop3D platform (outcrop3D.deep-time.org) is a Web platform based on the Cesium open-source 3D earth engine for presenting and sharing real-scene three-dimensional digital outcrops. 111 digital outcrop models are being uploaded to the DDE-Outcrop3D platform and are open to the public. Here, we present the two 3D models of the Upper Permian Jiantianba Section from China and Middle Miocene lacustrine reefal build-ups from Nördlinger Ries impact crater in Germany, and their application for measurement and making virtual field trips. Both models are accessible on the Outcrop3D platform.

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Regular talk

AN EARLY DEVONIAN MESOPHOTIC CORAL ECOSYSTEM FROM THE EAST GONDWANA

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Mesophotic coral ecosystems (MCEs) are one of the most widespread coral ecosystems in the modern seas. Ecologically similar ecosystems, built by platy tabulate corals (Anthozoa: Tabulata, an extinct group), can be extended back to the Silurian (430 Ma; Zapalski and Berkowski 2019). Corals with their calcium carbonate skeletons have high fossilization potential, and together with other benthic calcareous organisms are common fossils. As a result, MCEs described from the Palaeozoic so far focused on benthic fauna, typically with data lacking on nekton.

Here we report on an Early Devonian (Emsian, c. 400 ma) fossil locality at Wee Jasper, New South Wales, Australia, also famous for a rich fossil fish assemblage (Young 2011). In the Early Devonian this area was located on the eastern shelf of Gondwana, at higher tropical latitudes, near the tropic of Capricorn. The studied sequence belongs to the Taemas Fm. of the Murrumbidgee Group.

In a 2-m thick biostrome we have identified a coral community dominated by platy tabulate corals, with contribution from branching forms. Platy colonies are mostly represented by genera *Alveolites* and *Roseoporella*, with rare occurrence of *Platyaxum.* Branching forms are represented by *Thamnopora*. Rugose corals are virtually absent, represented only by very rare, small, solitary, dissepimented *Embolophyllum* sp. Besides corals, these and adjacent beds have yielded other benthic invertebrate groups (brachiopods, nautiloids, ostracods and others) and a very diversified fish fauna (Burrinjuck fish fauna), for example *Dipnorhynchus* and *Ligulalepis* (osteichthyans), and the placoderms *Errolosteus*, *Taemasosteus* and *Cathlesichthys* (arthrodires) and *Brindabellaspis* and *Weejasperaspis* (acanthothoracids). Our microfacies analysis, as well as previous studies (Reynolds 1978) suggest a deeper part of the shelf. We interpret this community as a mesophotic coral ecosystem that developed on the offshore shelf.

In the Palaeozoic, tabulate corals played ecological roles very similar to their modern scleractinian analogues. Similarly, the Burrinjuck fish fauna, the oldest known coral reef fish assemblage, is the most diverse known from the Devonian, and thus comparable to the diversity peak in tropical reef environments for the modern fish fauna. Hence, the studied site seems to represent the most complete record of MCE fossil assemblages known from the Palaeozoic.

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Poster

NEW U-TH AGE DATA FOR MIDDLE AND LATE PLEISTOCENE CORAL TERRACES AT FIVE LOCALITIES OF THE NORTHERN RED SEA OF EGYPT AND THEIR PALAEOECOLOGICAL COMPOSITION

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Coral reef terraces from interglacial periods of the Middle and Late Pleistocene occur alongside modern day fringing reefs along the Red Sea coast. Although a number of radiometric ages are available, most of these Pleistocene reefs remain undated. Precise age assessment is crucial to confidently assign individual outcrops to a specific marine isotope stage (MIS) and disentangle the temporal changes in community composition between fossil coral reefs. Such fossil reefs can then be compared to modern coral reef communities, for example to evaluate climatic and anthropogenic impacts. We age-dated reef terraces with the U-Th method using well-preserved specimens (>97% aragonite) of massive coral colonies of the genera *Dipsastraea*, *Echinopora*, *Favites*, *Goniastrea*, *Leptastrea*, *Leptoria*, and *Platigyra* at five localities that we studied for their palaeoecological composition in the regions around Hurghada (localities Wadi Gawasis, Sharm El Arab, Sahl Hasheesh), El Quseir (locality Flamenco Beach), and Marsa Alam (locality Wadi Igla). Results document that they belong to three marine isotope stages (MIS5e, MIS9, and MIS11). The four localities from Late Pleistocene MIS5e (Flamenco Beach, Sahl Hasheesh, Wadi Gawasis, and Sharm El Arab) are situated about 1–3 m above current sea level. They all have a coral composition strongly dominated by *Porites* and indicative of a either a reef edge (Sharm El Arab, Wadi Gawasis) or a shallow reef slope community (Flamenco Beach, Sahl Hashees) and therefore most probably reflect a palaeowater depth of maximum 3–5 m. At the locality Wadi Igla, two terraces are situated 9–10 m and 5 m above current sea level and belong to the Middle Pleistocene MIS9 and MIS11, respectively. The MIS9 terrace at 9–10 m above current sea level is dominated by *Acropora*, while the MIS11 terrace at 5 m above current sea level is again dominated by *Porites* and both terraces are interpreted to represent a shallow reef slope community.

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